Environmental Assessment of Food Losses and Reduction Potential in Food Value Chains

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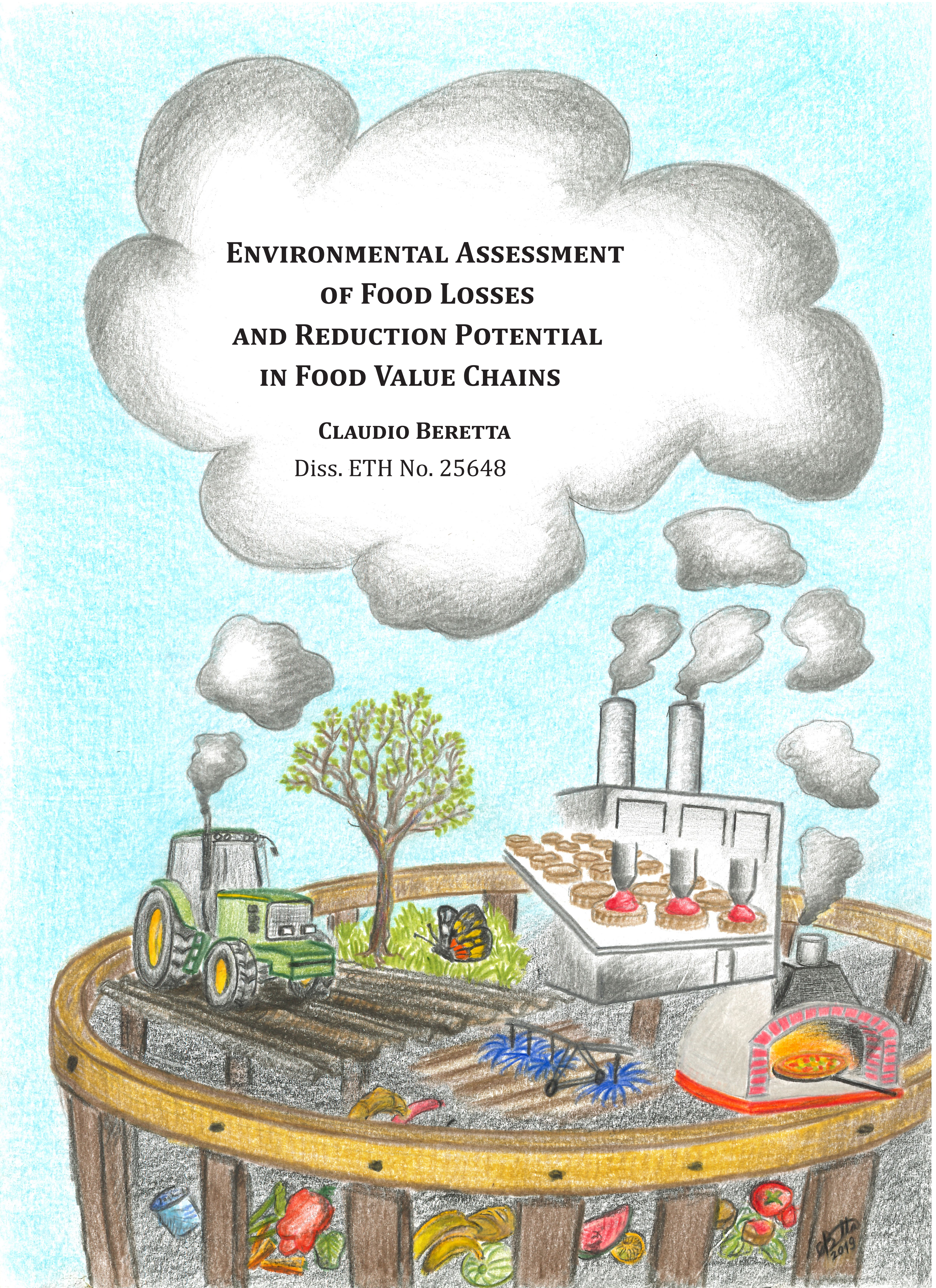

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ENVIRONMENTAL ASSESSMENT OF FOOD LOSSES AND REDUCTION POTENTIAL IN FOOD VALUE CHAINS

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There is a sufficiency in the world for man’s need, but not for man’s greed.

Mahatma Gandhi

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Sometimes the most unspectacular moments in life are the ones shaping life the most. Eight years ago, while walking past a bakery shortly before closure, I saw plenty of delicious breads and pastries about to be discarded. I was far away from realising that this moment was the beginning of a new chapter of my life --- a chapter that would define my main activities for many years and strongly influence the way of my life. It was the first moment that I considered food waste as an interesting topic for my master thesis, despite the eight other available topics, for which I felt interest and passion. Independently from my 'bakery moment', a few days later my mother asked me "Oh by the way, did you ever think of investigating the topic of food waste? I thought it might be interesting to know more about it…" Suddenly the image of the bakery staff throwing away delicious sourdough breads and cheesecakes resurfaced. I felt strong emotions towards the delicious food that was wasted for nothing. Delving deeper into my feelings, I found a surprisingly strong identification with the food, a feeling that was much more valuable than the price of the food. I felt compassion with the people working hard to produce the food, with the animals dedicating their entire life to produce discarded ingredients, and with the roughly one billion people suffering from hunger at the same time in the same world. I felt the injustice and was motivated to speak with people that were causing unnecessary food waste. I felt increasing curiosity to know if people were aware of the wastage they are causing every day. Surprisingly, I found myself in the same boat, also sometimes wasting food.

From my study of environmental sciences, I knew that food production can cause large environmental impacts. Nevertheless, I wasn't aware of any scientific results or estimates about the amounts and environmental impacts of food waste. Wasn't a master thesis an ideal opportunity to investigate these topics?

So I contacted my future supervisor, *Stefanie Hellweg, a*sking for her support in writing my master thesis about food waste in Switzerland. Her positive answer was the perfect door opener into the new chapter of my life --- thank you a lot! When I contacted *Urs Baier* as the author of the only food waste study in Switzerland available at that time, his reaction was like a wind through the door, which blew away my last doubts of choosing this topic. Much thanks for your enthusiastic reaction to this topic and your offer to act as a thesis co-supervisor! I would also like to express my gratitude to my supervisor, *Franziska Stoessel*. Your detailed feedback during my master thesis and while preparing my first scientific publication, your empowering encouragement, and your patience deserve a big thank you!

After completing my master thesis and estimating the amount of food waste in Switzerland, *Stefanie* opened the second door in my career: a PhD position for analysing the environmental impacts of food waste and the potential for reduction. Now in the last phase of my PhD, I do not know how to adequately express my gratitude for the last years to *Stefanie*: you are the best supervisor I can imagine. Since I have strong personal interests and a clear desire to contribute to a more sustainable society by abstaining from activities that are at the cost of future generations, it is hard for me to follow a perfectly predefined pathway. You supported me by allowing me to follow my own research questions, and your openness let me follow my interests, while also providing me very clear and constructive guidance how to optimally reach the goals of my PhD. You always provided extensive, valuable feedback, you regularly fed my motivation, and you shared many inspiring experiences with me. You contributed to fruitful collaborations using your extensive personal network and offered the most desirable working conditions I can imagine to optimally unfold my productive phases and to find a healthy work-life balance.

Furthermore, I would like to thank to all my colleagues sharing some time with me at ESD. Without your empowerment "in the back" I would have resisted spending so many hours in front of my laptop. A special thank you goes to *Mélanie Haupt*. Your recommendations, inspirational inputs, and shared experiences were an important support throughout my PhD and especially in the last phase. A special thank you also goes to *Laura Scherer* who supported us with her extensive expertise on the land use and biodiversity impacts from crops and animal products. *Carl Vadenbo* gave me important inspiration and insights into variable methodologies, *Christie* and *Catherine* invested numerable hours of proof-reading into this book, *Stephan* gave me valuable feedback about my publications, and *Christopher, Franziska, Dörte, Andi, Thomas, Dominik, Tobias, Florian, Niko, Abdi, Farzin, Émile, Jonas, Bernhard, Maja, Magdalena, Danielle, Francesca, Ronnie, Mike, Helen, Ingrid*, *Zhanyun* and all other current and previous group members made ESD a perfectly welcoming and friendly place to work – a thousand thanks! And *Barbara*, you solved administrative problems before I realized that they existed and enabled several conference attendances and group retreats, which are the trees of the most important fruit of my PhD --- the growing network. Many thanks!

A big thank you also goes to all organizations and contact people for delivering valuable information. I met innumerable experts, stakeholders, and actors of the food supply chain during my PhD, who dedicated their precious time to answering my questions and giving me insights into their work -- sometimes even during their own birthdays and vacations.

A special thank you goes to the *Federal Offices for the Environment (FOEN)* and *for Agriculture (FOAG)* for providing the financial support for chapters 3 and 4, and to all members of *food services* and the *food industry*, to *Moritz Müllener* from the association United Against Waste, *Markus Hurschler* and *Joao Almeida* from Foodways Consulting, *Naomi MacKenzie* from Kitro, and *Alfredo Lehmann* from SV Group. They supported us with data and interviews and allowed food waste measurements in their companies. The great support by *student assistants* carrying out many of the food waste measurements was indispensable, including the contribution by *Manuel Klarmann* from Eaternity who organised the financial support for the student assistance. Many students supported this project with their bachelor, master, and project theses, including *Beatrice Keller, Chasper Gmünder, Nicolas Hirzel, Cordelia Kreft, Andrea Wehrli, Guillaume Wurlod, Christian Maurer, Fabia Zermin, Francesco Paganini, Martin Ulrich, Sam Lanners, Isabelle Kohler, Laura German, Selina Ott, Eliane Waser, Alessa Perotti, Carolina Städeli, Katja Henz, Clara Streule, Rahel Fischer, Florian Schmid,* and *Martin Probst*. *Mirko Buri* from "Mein Küchenchef" offered a lot of his precious time in sharing professional knowledge as a pioneering chef specialised on FW reduction in high quality cuisine --- thanks a lot. I also express a big thank you to *Antonia Blumenthal* and *Frank Waskow* for sharing primary data from food waste assessments in German school canteens. *Matthias Stucki* and *Claudia Müller* from ZHAW provided valuable support for Chapter 3 of the thesis; *Thijs Defraeye* and *Wentao Wu* enabled the cold chain project --- thank you for the fruitful collaboration. For the final part of my PhD I would like to thank to my co-examiners *Nina Langen* and *Urs Baier* for your interest into my work.

All this would not have been possible without an ocean of friends and family surrounding me on the island of my PhD. It is the greatest gift in my life, not only to have a place in my family and a place in my WG where I always feel welcome, but also innumerable places at my friends' homes and in my friends' hearts, where I feel warm and safe and can regenerate all my energies. The love in my ocean of friends and family was the nutrient who made this work grow --- thanks a million.

ABSTRACT

In order to enable future generations to lead a decent life, human consumption of natural resources and impacts on the environment must urgently be reduced. A cornerstone among all human activities is food consumption, which is responsible for roughly one third of all environmental impacts of consumption. The food supply chain is inefficient, as present studies estimate roughly one third of the edible food to be wasted globally. There are numerable political commitments to dramatically reduce FW, notably the UN's recently released Sustainable Development Goals (SDG) calling to halve per-capita retail and consumer food waste (FW) by 2030. In order to identify promising interventions for FW reduction and to involve the key stakeholders able to successfully implement such interventions, detailed quantitative information on the amount, origin, and environmental impact of FW is needed.

There has been an increasing body of literature related to FW in the past years. Nevertheless, due to data inconsistency and a narrow temporal, geographical, and food supply chain coverage in present literature, FW quantification is still associated with large uncertainties and based on many assumptions. Due to insufficient data about the composition and the treatment methods of FW, existing environmental assessments are rough estimations. Thus, the present state of knowledge is insufficient to understand the current situation and to quantify the future reduction potential.

The goal of this dissertation was to provide methods and data to identify FW hotspots in terms of amounts and environment and assess reduction measures. We therefore developed a new approach that can be applied to food systems of any region or country and that would provide a solid information base to support the identification, prioritization, and implementation of effective strategies for FW reduction.

To reach this goal, we defined three subgoals: 1) The creation of a simplified model of the food value chain in form of a mass flow analysis (MFA) in order to understand the system and to quantify FW by origin and type of food. 2) The extension of the model with life cycle assessment (LCA) in order to quantify environmental impacts of FW and to identify hotspots of environmental relevance. 3) For a selection of hotspots identified in subgoal 2, the assessment of case studies, in which measures for FW reduction are exemplarily implemented and their effect measured in terms of mass and environmental impacts.

The thesis starts with a bottom-up quantification of FW across the entire food system related to Swiss food consumption. We chose this life-cycle consumption based perspective, which includes domestic production and net imports, in order to capture the FW-related resource use and emissions induced by Swiss consumers. The result is an MFA of the entire food value chain including the stages 'agricultural production', 'trade', 'processing', 'retail', 'food services', and 'households' and encompassing relevant methods of FW treatment ('animal feeding', 'anaerobic digestion', 'composting', 'incineration', 'disposal in the sewer'). We thereby differentiated 33 food categories as well as edible and inedible parts of food (avoidable and unavoidable FW). Since the unit "wet weight" of FW, which was used in the MFA, is not an appropriate indicator for the nutritional value of food, we converted the MFA into an energy flow analysis (EFA) based on the nutritional value of food and FW. The results identify wasted 'fresh vegetables' and 'cereals' to be the main quantitative hotspots in terms of mass and 'cereals' and 'oils and fats' in terms of nutritional energy. The stage of the food value chain contributing most to total FW amounts were 'households' (~40% in terms of energy). However, these results do not necessarily reflect the environmental relevance of FW.

In the next step we therefore coupled the MFA with life cycle inventory data. We adopted and extended the system boundary of the MFA in order to take the entire life cycle of all inputs into account (agricultural production, transport, cooling, processing, cooking, and partly packaging). In addition, we modelled the environmental impacts of FW treatment. In order to consider useful outputs from FW treatment (e.g. energy and fertilizer from anaerobic digestion), we adopted the method of 'system expansion' and substituted heat from natural gas, electricity from the Swiss grid, nutrients by inorganic fertilizer, and organic matter by peat. Since the nutritional values of the products within some of the 33 modelled food categories varied considerably, we allocated environmental impacts to consumed and wasted food based on their nutritional value. This is important since allocation by mass would imply that, for instance, 1kg of whey can substitute 1kg of cheese, which is unrealistic. The life cycle impact assessment was carried out for the impact categories 'climate change', 'biodiversity loss due to land and water use', and the aggregated method 'ReCiPe'. The results showed that the total climate change impacts of food consumption could be reduced by 25% if all

edible FW was avoided. Furthermore ‘fresh vegetables’, ‘whey’, and ‘beef’ were identified as hotspots for climate change and ‘cocoa’, ‘beef’, and ‘wheat’ as hotspots for ‘global biodiversity loss’. The impact assessment confirmed the results of the MFA that ‘Households’ are key actors for FW, contributing 51% to the climate change impacts and 41% to biodiversity loss caused by total FW.

Since it is unrealistic to avoid all FW, in a next step we analyzed the effect of measures for FW reduction in real case studies. We therefore selected the food service sector, since the rate of FW has been identified to be largest in households and food services and since the Swiss Federal Office for the Environment chose the food service sector as a starting point to develop its strategy to reduce FW. We analyzed 13 case studies, in which food services implemented measures for FW reduction and measured their FW before and after implementation. We then extrapolated the achieved reduction to the entire food service sector, by weighing the subsectors ‘restaurants’, ‘school and university canteens’, ‘hospitals and care centers’, ‘business canteens’, and ‘hotels’ proportionally to the number of meals consumed in each subsector. In order to increase the reliability of the status quo FW amounts in individual subsectors, we included additional publications from Germany, Austria, Finland, and the UK and thus based our results on 1’042 measurements of status quo FW amounts. Considering the FW composition in the status quo and the reduction scenario, we calculated the environmental benefits of potential future FW reduction. In addition to this base scenario, which assumes that all food services achieve the same reduction as our case studies in the corresponding subsector on average, we calculated an extended scenario, in which food services additionally buy 50% of their vegetables from non-marketable origin and thus prevent them from being wasted in the supply chain. The results show that in-house FW is reduced by 38% and related climate impacts by 41% in the base scenario. In the extended scenario an additional 32% of FW and 17% of climate impacts can be saved by using products which otherwise would have been wasted in the supply chain. Thus, the SDG of halving per-capita FW was not reached in the food service sector by the base scenario, but by the extended scenario it was. This shows the importance of considering all stages of the food value chain in order to develop effective reduction strategies. Additionally, we quantified FW per meal in the entire supply chain of a progressive restaurant specialized on FW minimization. With 26 g/meal FW over the entire food value chain, this restaurant only causes 10% of the 252 g/meal estimated for average food services, suggesting that FW reduction on the long-term is larger than the achievements in our case studies, if innovative approaches are implemented.

Another way of reducing FW is to improve supply chains logistically, e.g. due to improved cooling systems or packaging for enhanced food preservation. In addition to the environmental benefits from reducing FW, in such cases also the additional environmental impacts of the improved cooling or packaging system need to be considered. We therefore coupled the LCA with a quality evolution model based on the thermophysical cooling history of the product. With the new methodology we exemplarily analyzed different supply chain options for oranges imported from South Africa and Spain to Switzerland, differentiating 3 cold chains (‘forced-air precooling’, ‘cold storage’, ‘ambient loading’) and three types of packaging (‘standard box’, ‘supervent box’, ‘opentop box’). The results identify a trade-off between direct environmental impacts of the cold chain and indirect environmental impacts from potential FW reduction due to better quality, which can only be evaluated by coupling the product’s quality evolution empirically to the FW amounts. While this was not yet done in the current study, in some cases the optimal solution could be identified without further analyses, e.g. in the case of precooling with solar energy, which saves environmental impacts compared to diesel-driven cooling in the container and provides better quality of the products.

We conclude that the method applied in the thesis of coupling MFA and EFA with LCA turned out to be an appropriate methodology to calculate environmental impacts of FW. The methodology represents a solid basis for further development and extensions into a model to evaluate scenarios and to support stakeholders in the food industry and policymakers to develop successful strategies to reduce FW and related environmental effects. By combining LCA with quality evolution modelling (and its implications on FW), such a model could be used to logistically improve supply chains. Digitalization and monitoring of parameters influencing the products’ quality (such as temperature, quality, degrees brix, etc.) can give new insights about the products’ storage life and help to improve food management. A further breakdown of food categories and the integration of a dynamic transport and seasonality model, which calculate environmental impacts depending on the season and the origin of the food, would further improve the quality of the results.

ZUSAMMENFASSUNG

Der Konsum natürlicher Ressourcen und die Belastung der Umwelt müssen dringend verringert werden, um die Lebensgrundlagen zukünftiger Generationen nicht aufs Spiel zu setzen. Ein Grundpfeiler aller menschlichen Aktivitäten ist der Lebensmittelkonsum, welcher für rund einen Drittel aller konsumbedingten Umwelteffekte verantwortlich ist. Die Lebensmittelkette ist besonders ineffizient, indem Nahrungsmittelabfälle weltweit gemäss aktuellem Wissensstand rund einen Drittel aller essbaren Lebensmittel ausmachen. Es gibt zahlreiche politische Bekenntnisse, um die Lebensmittelverschwendung deutlich zu verringern, insbesondere die kürzlich von der UNO verabschiedeten „Sustainable Development Goals" (SGD), welche eine Halbierung der pro Kopf-Lebensmittelverluste auf Konsum- und Detailhandelsstufe bis 2030 vorsehen. Für eine wirksame Umsetzung dieser Ziele ist es nötig, effektive Massnahmen zur Verringerung der Lebensmittelverluste zu identifizieren und die wichtigsten Stakeholder zu involvieren. Dazu braucht es detaillierte, quantitative Informationen über die Mengen, Ursachen sowie Umwelteffekte der verschwendeten Lebensmittel.

In den letzten Jahren ist die Zahl der Studien rund um Lebensmittelverluste stark gewachsen. Trotzdem ist die Quantifizierung der Lebensmittelverluste mit grossen Unsicherheiten verbunden und beruht auf zahlreichen Annahmen, denn die angewendeten Methoden in den verschiedenen Studien variieren und sind in vielen Fällen nicht konsistent. Zudem ist die Datenverfügbarkeit begrenzt auf relativ kleine Stichproben, kurze Zeitfenster und einzelne Stufen der Lebensmittelkette. Wegen mangelhafter Angaben über die Zusammensetzung und die Verwertungswege der Lebensmittelverluste liefern die bisherigen Untersuchungen nur grobe Schätzungen über die entstehenden Umwelteffekte. Der aktuelle Wissensstand ist somit ungenügend, um die heutige Situation zu beurteilen und das zukünftige Vermeidungspotenzial zu quantifizieren.

Das Ziel dieser Dissertation umfasst die Erarbeitung von Methoden und Daten zur Identifikation von mengen- und umweltmässig besonders wichtigen Lebensmittelverlusten und zur Beurteilung von Vermeidungsmassnahmen. Wir haben dazu eine neuartige Vorgehensweise entwickelt, welche auf Lebensmittelsysteme in andern Regionen und Ländern anwendbar ist und eine solide Grundlage liefert, um wirksame Strategien zur Verringerung von Lebensmittelverlusten zu identifizieren, zu priorisieren und zu implementieren.

Um dieses Ziel zu erreichen, haben wir drei Unterziele definiert, die sich wie folgt formulieren lassen: 1) Die Entwicklung eines vereinfachten Modells der Lebensmittelkette in Form einer Massenflussanalyse (MFA), um ein Verständnis des zugrundeliegenden Systems zu erlangen und Lebensmittelverluste je nach Herkunft und Zusammensetzung zu quantifizieren. 2) Die Erweiterung des Modells mit einer Ökobilanzanalyse (LCA), um die Umwelteffekte der Lebensmittelverluste zu quantifizieren und umweltrelevante Verluste zu identifizieren. 3) Die Untersuchung von exemplarischen Fallstudien, in denen umweltrelevante Lebensmittelverluste durch gezielte Massnahmen verringert und die Effekte bezüglich Verlustmengen und Umweltwirkungen gemessen werden.

Die Dissertation beginnt mit der Quantifizierung aller Lebensmittelverluste, welche in der Versorgungskette des Schweizer Lebensmittelkonsums anfallen. Diese konsumbasierte Perspektive schliesst die inländische Produktionskette sowie die Versorgungsketten von Netto-Importen ein, damit alle mit dem Schweizer Konsum verbundenen Lebensmittelverluste erfasst werden. Das Ergebnis ist eine Massenflussanalyse der gesamten Lebensmittelkette einschliesslich der Stufen „landwirtschaftliche Produktion", „Handel", „Verarbeitung", „Detailhandel", „Gastronomie" und „Haushalte" und einschliesslich der Verwertung der Lebensmittelverluste durch „Verfütterung an Nutztiere", „Vergärung in Biogasanlagen", „Kompostierung", „Verbrennung in einer Kehrichtverbrennungsanlage" und „Entsorgung im Abwasser". Die Analyse unterscheidet 33 Lebensmittelkategorien sowie essbare und nicht essbare Teile von Lebensmitteln (vermeidbare und unvermeidbare Lebensmittelverluste). Die Einheit der Massenflussanalyse ist «Masse Feuchtsubstanz». Weil dieses Mass ein schlechter Indikator für den Nährwert von Lebensmitteln und Lebensmittelverlusten ist, wurden alle Massenflüsse auch in Energieflüsse umgerechnet, wobei der mittlere Energiegehalt der jeweiligen Lebensmittel und Lebensmittelverluste verwendet wurde. Die Resultate identifizieren die Verluste von „Frischgemü-

se“ und „Getreideprodukten“ als Spitzenreiter bezüglich Masse und die Verluste von „Getreideprodukten“ und „Ölen und Fetten“ bezüglich Energiegehalt. Die Stufe der Lebensmittelkette, auf welcher am meisten Lebensmittel verschwendet werden, sind die Haushalte (ca. 40% auf die Energie bezogen). Diese Ergebnisse wiederspiegeln aber nicht unbedingt die Umweltrelevanz der Lebensmittelverluste.

Deshalb wurde in einem nächsten Schritt die Massenflussanalyse mit Lebensmittelinventardaten verknüpft. Die Systemgrenzen der MFA wurden übernommen und erweitert, um den gesamten Lebenszyklus aller Inputs adäquat zu berücksichtigen (landwirtschaftliche Produktion, Transport, Kühlung, Verarbeitung, Kochen, und teilweise Verpackung). Ausserdem wurden die Umwelteffekte der Verwertung von Lebensmittelverlusten untersucht. Bei der Verwertung von Lebensmittelabfällen entstehen Produkte (z.B. werden bei der Vergärung Dünger und Energie produziert), deren Nutzen mit der Methodik der Systemerweiterung gutgeschrieben wurden. Es wurde angenommen, dass Wärme durch eine äquivalente Energiemenge Erdgas, Strom durch den Schweizer Strommix, Nährstoffe durch Kunstdünger und organisches Substrat durch Torf substituiert wird. Da die Qualität der Produkte bei Mehrproduktsystemen auch innerhalb der 33 angewendeten Lebensmittelkategorien zum Teil beträchtlich hinsichtlich ihres Nährwerts variiert, wurden die Umwelteffekte proportional zum Energiegehalt auf die konsumierten und verschwendeten Lebensmittel aufgeteilt. Dies ist wichtig, weil eine Massen-basierte Allokation implizieren würde, dass 1kg Molke beispielsweise 1kg Käse substituieren kann, was nicht realistisch ist. Die Analyse der Umwelteffekte (Life Cycle Impact Assessment) wurde für die Umweltkategorien „Klimawandel“, „Land- und Wassernutzungsbedingte Biodiversitätsverluste“ und für aggregierte Umwelteffekte mit der Methode „ReCiPe“ durchgeführt. Die Ergebnisse zeigen, dass ein Viertel der Klimawandel-Effekte des gesamten Lebensmittelkonsums auf Lebensmittelverluste zurückzuführen ist. Hierbei stellten sich die Verluste von „Frischgemüse“, „Molke“, und „Rindfleisch“ als Spitzenreiter bezüglich des Klimawandels heraus und „Kakao“, „Rindfleisch“ und „Weizen“ bezüglich des globalen Biodiversitätsverlusts. Die Analyse der Umwelteffekte bestätigte die Resultate der Massenflussanalyse, dass Haushalte eine Schlüsselrolle einnehmen. Die auf dieser Stufe anfallenden Lebensmittelverluste verursachen 51% der Klimawandel-Effekte und 41% der Biodiversitätseffekte aller Lebensmittelverluste.

Weil es unrealistisch wäre, alle Lebensmittelverluste zu vermeiden, haben wir in einem nächsten Schritt den Effekt von Massnahmen zur Vermeidung von Lebensmittelverlusten in realen Fallbeispielen untersucht. Für die Fallstudien wurde der Gastronomiesektor gewählt, weil die Lebensmittelverlustraten in Gastronomie und Haushalten gemäss Massenflussanalyse am höchsten sind und weil das Bundesamt für Umwelt (BAFU) diesen Sektor als Startpunkt gewählt hat, um FW zu reduzieren. In 13 Fallbeispielen wurden die Lebensmittelverluste in Gastronomiebetrieben jeweils vor und nach der Umsetzung von Massnahmen zur Vermeidung der Verluste gemessen. Darauf basierend wurde eine Hochrechnung für den ganzen Gastronomiesektor vorgenommen, wobei die Gastronomiesegmente „Restaurants“, „Schul- und Universitätskantinen“, „Spitäler und Heime“, „Betriebskantinen“ sowie „Hotellerie“ proportional zur Anzahl konsumierter Mahlzeiten gewichtet wurden. Um die Status quo Lebensmittelabfälle in den einzelnen Gastronomiesegmenten zuverlässiger quantifizieren zu können, wurden zusätzliche Publikationen aus Deutschland, Österreich, Finnland und Grossbritannien berücksichtigt. Somit beruhen die aktuellen Mengenangaben auf insgesamt 1‘042 Messungen von Lebensmittelverlusten. Es wurde die Annahme getroffen, dass alle Gastronomiebetriebe ihre internen Lebensmittelverluste im Mittel gleich stark reduzieren können wie die Fallbeispiele in ihrem entsprechenden Gastronomiesegment. Dabei wird die Zusammensetzung der Lebensmittelverluste jeweils sowohl im Status quo wie auch im Reduktions-Szenario berücksichtigt. Ausserdem wurde ein erweitertes Szenario betrachtet, in welchem alle Gastronomiebetriebe zusätzlich 50% ihres Gemüseverbrauchs mit nicht-verkäuflichem Gemüse decken und somit verhindern, dass dieses Gemüse in der Versorgungskette als Verlust anfällt. Die Resultate zeigen, dass die Lebensmittelverluste um 38% und die damit verbundenen Klimawandel-Effekte um 41% verringert werden können. Im erweiterten Szenario können zusätzlich 32% der Lebensmittelverluste und 17% der Klimawandel-Effekte eingespart werden, indem Produkte verwertet werden, welche ansonsten in der vorangehenden Versorgungskette entsorgt worden wären. Das „Sustainable Development Goal“ einer Halbierung der Lebensmittelverluste pro Kopf konnte somit im Gastronomiesektor mit einer Reduktion der internen Verluste allein nicht erreicht werden, aber mit der zusätzlichen Verwertung von nicht-verkäuflichem Gemüse schon. Dies zeigt die Notwendigkeit, alle Stufen der Lebensmittelkette zu berücksichtigen, um wirksame Vermeidungsstrategien zu entwickeln. Ausserdem wurden die Lebensmittelverluste über die gesamte Versorgungskette eines innovativen Restaurants quantifiziert, welches sich auf die Minimierung von Lebensmittelverlusten spezialisiert hat. Mit 26 g verursacht eine Mahlzeit in diesem Restaurant nur 10% der Lebensmittelverluste in einem Durchschnittsrestaurant (252 g/Mahlzeit). Dies deutet darauf hin, dass die Lebensmittelverluste langfristig mehr verringert werden können als in unseren Fallbeispielen, sofern innovative Massnahmen umgesetzt werden.

Eine weitere Möglichkeit für die Vermeidung von Lebensmittelverlusten ist die logistische Verbesserung von Versorgungsketten, beispielsweise durch bessere Kühlsysteme und haltbarkeitsverlängernde Verpackungen. In solchen Fällen müssen zusätzlich zur Reduktion der Umwelteffekte durch eingesparte Lebensmittelverluste auch die zusätzlichen Umwelteffekte der verbesserten Kühl- und Verpackungssysteme berücksichtigt werden. Hierfür wurde die Ökobilanzierung mit einem Modell verknüpft, welches die Lebensmittelqualität in Abhängigkeit der thermophysikalischen Kühleigenschaften über die gesamte Kühlkette modelliert. Mit der neuen Methodik konnten verschiedene Optionen von Versorgungsketten beispielhaft für Orangenimporte aus Südafrika und Spanien in die Schweiz untersucht werden. Die berücksichtigten Optionen umfassen drei Kühlketten (Vorkühlung mit Druckluft, Lagerung im Kühlraum, Direkt-Befüllung der Container) sowie drei Verpackungsvarianten („Standard-Box", „Supervent-Box" mit zusätzlichen Luftöffnungen, „Opentop Box" mit offener Oberseite). Bei der Analyse stellte sich ein Zielkonflikt zwischen den direkten Umwelteffekten der Kühlkette und den indirekten Umwelteffekten der potenziellen Verringerung von Lebensmittelverlusten dank besserer Qualität und Haltbarkeit heraus, der erst dann abschliessend beurteilt werden kann, wenn die anfallenden Lebensmittelverluste empirisch mit den modellierten Produktequalitätsindikatoren gekoppelt werden. Dieser Analyseschritt fehlt noch in der vorliegenden Arbeit. Jedoch konnte gezeigt werden, dass in gewissen Fällen die optimale Lösung bereits jetzt ohne weitere Analysen bestimmt werden kann, wie im Beispiel der Druckluft-Vorkühlung mit Solarenergie, welche das Klima weniger belastet als die Kühlung im dieselbetriebenen Container und zugleich die Produktequalität positiv beeinflusst.

Im Rückblick hat sich der in dieser Dissertation entwickelte methodische Ansatz der Kombination von Massen- und Energieflussanalyse mit einer Ökobilanzanalyse gut bewährt, um die Umwelteffekte von Lebensmittelverlusten zu berechnen. Methodisch gesehen haben wir eine solide Grundlage für die Weiterentwicklung zu einem Modell geschaffen, welches Szenarien berechnen und Entscheidungsträger aus Lebensmittelindustrie und Politik bei der Entwicklung erfolgreicher Strategien unterstützen kann, um Lebensmittelverluste und ihre Umwelteffekte zu vermindern. Durch die Kombination von Ökobilanz und Modellierung der Produktequalität (und deren Implikationen auf die Reduktion von Lebensmittelverlusten) könnte ein solches Modell ausserdem zur logistischen Verbesserung von Versorgungsketten genutzt werden. Eine Digitalisierung bzw. ein Monitoring der Parameter, welche die Produktqualität beeinflussen (z.B. Temperatur, Brix-Grad usw.), kann neue Erkenntnisse über die Haltbarkeit von Produkten bereitstellen und so ein besseres Management von Lebensmitteln ermöglichen. Die weitere Aufschlüsselung von Lebensmittelkategorien sowie die Integration eines dynamischen Transport- und Saisonalitätsmodells, um Produkteökobilanzen in Abhängigkeit von Herkunft und Jahreszeit zu berechnen, würde die Verlässlichkeit der Resultate zusätzlich verbessern.

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GLOSSARY

Abbreviations	
AD	**A**naerobic **d**igestion
CH_4	Methane (a greenhouse gas, emitted e.g. in processes of agricultural production and food decomposition)
DM	**D**ry **m**atter
EFA	**E**nergy **F**low **A**nalysis
FAO	**F**ood and **A**griculture **O**rganization
FM	**F**resh **m**atter
FOAG / BLW	**F**ederal **O**ffice for **Ag**riculture / **B**undesamt für **L**and**w**irtschaft
FOEN / BAFU	**F**ederal **O**ffice for the **En**vironment / **B**undes**a**mt **f**ür **U**mwelt
FS	**F**ood **s**ervice
FVC	**F**ood **v**alue **c**hain (food supply chain)
FW	avoidable **f**ood losses and **w**aste, including *possibly avoidable* (Quested et al., 2013)
gPDF-eq	**g**lobal **P**otentially **D**isappeared **F**raction of Species equivalents (Chaudhary et al., 2016)
GHG	**G**reen**h**ouse **G**as
GTP	**G**lobal **T**emperature Change **P**otential (Frischknecht et al., 2016)
GWP	**G**lobal **W**arming **P**otential (IPCC, 2013)
ILCD	The **I**nternational Reference **L**ife **C**ycle **D**ata System
IPCC	**I**ntergovernmental **P**anel on **C**limate **C**hange
kcal	**k**ilo-**cal**ory, an unit of energy (1 kcal = 4.1868 kJ)
LCA	**L**ife **C**ycle **A**ssessment
LCI	**L**ife **C**ycle **I**nventory
LCIA	**L**ife **C**ycle **I**mpact **A**ssessment
MFA	**M**aterial **F**low **A**nalysis
N_2O	Nitrogen dioxide (a greenhouse gas)
PDF	**P**ortable **D**ocument **F**ormat
SFOE / BFE	**S**wiss **F**ederal **O**ffice of **E**nergy / **B**undesamt **f**ür **E**nergie
UBP	ecopoints ("**U**mwelt**b**elastungs**p**unkte", unit of the impact assessment method „ecological scarcity")
UNEP	**U**nited **N**ations **E**nvironment **P**rogramme (web.unep.org)
VBA	**V**isual **B**asic for **A**pplications
WFLDB	**W**orld **F**ood **LCA** **D**ata**b**ase (Bengoa et al., 2015)
ZHAW	**Z**ürcher **H**ochschule für **A**ngewandte **W**issenschaften

Terms

Acidification	A process, which happens when compounds like ammonia, nitrogen oxides and sulphur dioxides are converted in a chemical reaction into acidic substances. Most of the compounds are a direct result of air pollution (http://www.chemistry-dictionary.com). The main types of acidification are: ➢ **Ocean acidification** is the ongoing decrease in the pH of the Earth's oceans, caused by the uptake of carbon dioxide (CO_2) from the atmosphere (Caldeira and Wickett, 2003). ➢ **Freshwater acidification** is a decrease in the pH of freshwater, for example due to acid rain. ➢ **Soil acidification** is the buildup of hydrogen cations, also called protons, reducing the soil pH. Chemically, this happens when a proton donor gets added to the soil. The donor can be an acid, such as nitric acid and sulfuric acid (these acids are common components of acid rain). It can also be a compound such as aluminium sulfate, which reacts in the soil to release protons. Many nitrogen compounds, which are added as fertilizer, also acidify soil over the long term because they produce nitrous and nitric acid when oxidized in the process of nitrification (https://en.wikipedia.org/wiki/Soil_acidification).
Agribalyse	***LCA* database**, mainly containing agricultural products and services from France (Colomb et al., 2015).
Agri-footprint	***LCA* database**, mainly containing agricultural products and services from the Netherlands (Agri-Footprint, 2014).
Ecoinvent	***LCA* database**, initiated by various research institutions (ETH Zurich, EPFL, Agroscope, PSI, EMPA…) (ecoinvent, 2016).
Ecological scarcity 2013	Swiss **impact assessment method of *LCA***, results expressed as ecopoints (Umweltbelastungs-punkte, *UBP*) (Frischknecht et al., 2013).
eSankey!	Software to visualize material and energy flow analyses (e!Sankey, 2015).
Eutrophication	*Eutrophication* (from Greek eutrophos, "well-nourished") is when a body of water becomes **overly enriched with minerals and nutrients** that induce **excessive growth of plants and algae** (Chislock et al., 2013). This process may result in oxygen depletion of the water body (Schindler and Vallentyne, 2004).
Food service (FS) institution	With *food service institutions* we refer to **companies offering out-of-home food consumption**, including the subsectors ‘restaurants’, ‘school and university canteens’, ‘business caterings’, ‘care institutions and hospitals’, and ‘hotels’. Cafés and take-aways are excluded.
Food service (FS) (location)	*Food services* and *food service locations* refer to **individual units or places** of a *food service institution* (e.g. hotels of a hotel chain, restaurants and canteens of a catering company).
Foodsharing	Organisation of volunteers for the **distribution of food donated by *food services* and retailer**s (Foodsharing, 2018).
Life cycle assessment (LCA)	A **methodology** for the “compilation and evaluation of the inputs, outputs and the potential **environmental impacts** of a product system **throughout its life cycle**” (ISO, 2006).
Material / mass flow analysis (MFA)	According to Brunner and Rechberger (2004), MFA is a “systematic **assessment** of the **flows** and **stocks** of materials within a system defined in space and time”. In this context, the term ‘material’ includes food, by-products of the *food value chain*, and *FW*.
Resource	**“**A **stock** or **supply** of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively” (Oxford Dictionary, 2013).
SimaPro	*LCA* Software (Pre, 2017).
Sous-vide cooking	Method of cooking in which food is filled in a plastic bag or glass jar, vacuumed, and cooked in a water bath or in steam **for longer than normal cooking times** at an **accurately regulated temperature**, which is usually lower than conventional cooking techniques.
World Food LCA Database (WFLDB)	***LCA* database**, mainly containing agricultural products and services from main producing and exporting countries (Bengoa et al., 2015).

Definitions specific for this dissertation

Avoidable food losses and waste (FW)	*Food losses and waste* that **can be avoided by best practice methods** of efficient supply chains (even if an optimal food distribution system may imply less consumers' freedom of choice for some fresh products than at present), **by a reduction of cosmetic standards** for products such as fruits and vegetables (e.g. using all forms and sizes of potatoes for human consumption), and **by applying appropriate methods of preparation** to use all potentially edible parts of the products (e.g. stem of broccoli and skin of apples). This definition is consistent with Norwegian *food waste* studies (Hamilton et al., 2015). However, in some cases the exact boundary between what is considered edible or not differs between cultures, regions, and habits (e.g. potato skin, leaves of radish, inwards, etc.). A special case is whey, which is mainly fed to calves, shoats, and swine. In the case of swine it can be substituted by cereals; in the case of calves and shoats, however, the protein composition of whey is important (Kopf-Bolanz et al., 2015). Therefore, whey used as high quality fodder for calves and shoats may be more difficult to be substituted by plant based feed and is analysed separately in this thesis.
Biodiversity (impacts)	In the Millennium ecosystem assessment report *Biodiversity* is defined as "the **variability among living organisms** from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." *Biodiversity* includes managed and unmanaged ecosystems. Indicators are "scientific constructs that use quantitative data to measure aspects of biodiversity, ecosystem condition, services, or drivers of change" (Millennium-Ecosystem-Assessment, 2005). The *impacts on biodiversity* refer to the **influence of specific human activities** on *biodiversity*, e.g. land use changes and water withdrawal. They are measured by **comparing the managed ecosystems with the unmanaged ecosystems in the same region**. In this thesis we use an **indicator of global biodiversity loss** based on Chaudhary et al. (2016). **Species** translate into global species loss (extinction) if they are **endemic to the ecoregion** in which they are lost.
Climate change (impacts), global warming	*Climate change* in *IPCC* usage refers to a **change in the state of the climate** that can be identified (e.g. using statistical tests) **by changes in the mean and/or the variability of its properties (statistical distribution of weather patterns)** and that **persists for an extended period**, typically decades or longer. It includes changes due to natural variability and due to human activity. This usage differs from that in the United Nations Framework Convention on Climate Change, which only includes changes that are attributed directly or indirectly to human activity (IPCC, 2007, National_Research_Council, 2010). In this thesis *climate change impacts* or *global warming impacts* refer to the **influence of specific human activities** (e.g. the use of fossil fuels, deforestation) on *climate change*.
Food loss, food waste, food wastage	In this study *food losses and waste* (abbreviated FW) refer to food which is originally produced for human consumption but then **directed to a non-food use or waste disposal** (e.g. feed for animals, biomass input to a digestion plant, disposal in a municipal solid waste incinerator). We include food originally intended for human consumption but then **diverted to animal feed** in the definition of FW, since it represents an environmental loss of resources, even though this differs from the FUSIONS definitional framework by Östergren et al. (2014). With our definition we are consistent with the term *waste* as defined by Dijkema et al. (2000). However, the potential food that would be available if the methods of production were optimized (e.g. avoiding crop failures by pesticide application) as well as products with nutritional value that have not originally been produced as food (e.g. wild fungi, berries, game, pets, etc.) are not defined as *FW* even though they represent a potential of increasing food availability with given resources. In literature often *food losses* refer to food not used for human consumption in the early phases of the *food value chain* (agricultural production to trade and processing), whereas *food waste and food wastage* refer to food not used for human consumption in the consumption phase (retail, food service and households) (Gustavsson and Cederberg, 2011). However, since the distinction is not always clear, in this paper the terms are used as synonyms. In contrast to Smil (2004) **over-nutrition**, the gap between the energy value of consumed food per capita and the energy value of food needed per capita, is **not included**. Since the environmental credits of *food waste* prevention only refer to the prevention of *avoidable food waste* and this is the main focus of this paper, we often use the term *food waste (FW)* for *avoidable food waste (FW)*. *FW* only refers to *unavoidable* or *total FW* if explicitly mentioned.

Environmental impacts of food waste (FW)	The environmental impacts of *FW* are based on a comparison of the present situation with *FW* and the alternative situation, in which the corresponding **food** is not wasted, assuming that it **replaces food of the same type with the same amount of calories**. In the alternative situation, **useful co-products from *FW* treatment** have to be **produced in an alternative way** ("system expansion"). This includes the additional production and supply of **feed** (same nutritional value as the FW which is presently fed to the animals), **electricity** (present electricity mix), **heat** (natural gas), **inorganic fertilizer**, and **organic matter** (peat). Inorganic fertilizer is substituted based on the content and the utilization rates of N, P, and K for compost, liquid, and solid digestate. The improved soil effect is quantified with peat substitution in growth media based on typical compost densities. Peat and fertilizer substitution in private gardens is based on surveys reporting utilization and replacement rates (21% for peat, 18% for fertilizer) (more details in appendix B). Final **food intake** is assumed to be **constant** and possible **rebound effects** are **ignored**.
Food value chain (FVC), Food supply chain	Connected **series of activities to produce, process, distribute, and consume food**, including the stages 'agricultural production and fishery', 'trade', 'processing', 'retail, '*food services*', and 'households'*.* Also referred to as '*food supply chain*'*.* Food consumption in take aways and cafés is attributed to households in this thesis.
Unavoidable food losses and waste (unavoidable FW)	*Food losses and waste* that **cannot be avoided with realistic efforts and current technologies** (e.g. losses from cleaning production lines using best practice methods) and **inedible parts** of food (bones, shells, peels, residues).
Waste	According to the Basel Convention (UNEP 2011) the term *waste* is defined as "substances or objects which are **disposed of** or are **intended to be disposed of** or are **required to be disposed of** by the provisions of national law". An alternative definition is offered by Dijkema and colleagues (2000) who argues that *waste* is "an emerged **quality of a substance or an object**" that results "**when it is not used to its full potential**". (Haupt, 2018) In this thesis we use the term in a wide sense including both meanings.
Waste management, waste treatment	According to the waste directive of the European Commission *Waste management* refers to „the **collection, transport, recovery** and **disposal** of waste, including the supervision of such operations and the **after-care of disposal sites**, and including the actions taken as a dealer or broker" (EC, 2008). In this dissertation, *(food) waste management* includes the different options of *(food) waste treatment* (e.g. incineration, composting, anaerbic digestion, feeding).
Waste valorisation	According to Nzihou and Reid (2010) *waste valorisation* refers to *waste treatment* **for "beneficial use as raw material or as an energy carrier**, with **emphasis on processes and practices that reduce emissions and related environmental impacts**". According to our definition of *FW, FW valorisation* only includes non-food uses. If products are used as human food, we refer to as *FW* prevention or food valorisation.

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CHAPTER 1

INTRODUCTION

1.1 THE ROLE OF FOOD WASTE IN GLOBAL FOOD SYSTEMS

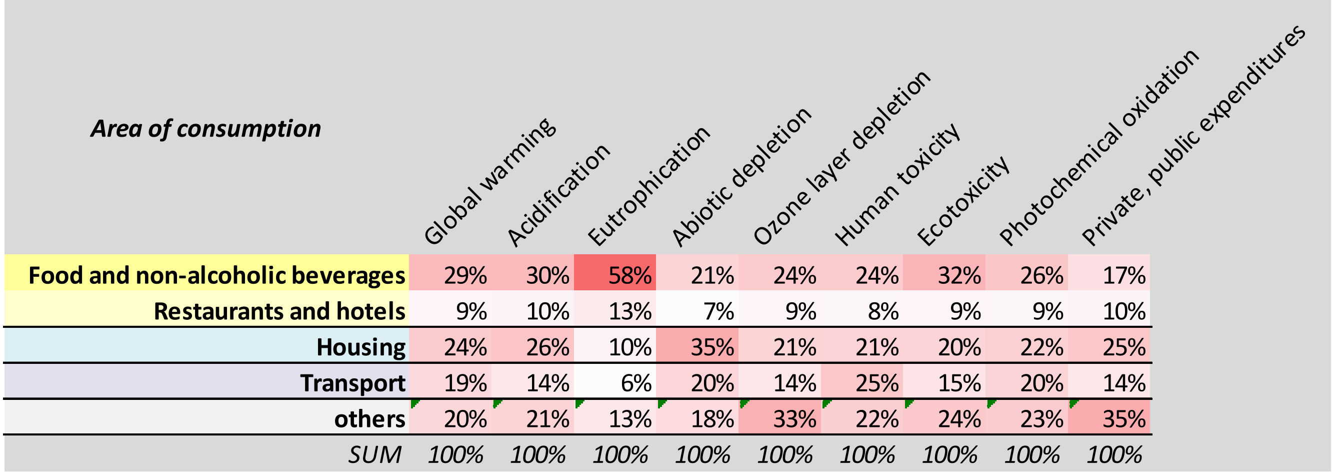
1.1.1 Ethical and environmental importance of food systems

In an *ethical perspective*, food systems are the basis to meet our **fundamental need of healthy nutrition**. Food systems ideally ensure a balanced and healthy diet for everyone at any point of time (HLPE, 2017), but this is still far away from being fulfilled. According to the 2015 report by the high level panel of experts (HLPE) on food security and nutrition, about **870 million people** were estimated to be **undernourished** in the period 2010–12 and undernutrition explains around **45 percent of deaths among children under five**. Malnutrition, which includes undernutrition (underweight, stunting and wasting), micronutrient deficiencies, and overweight and obesity, globally even affects one person in three (HLPE, 2017). Based on current trends the HLPE predicts that one in two could be affected by 2030, which is in complete contrast with the objective to end all forms of malnutrition by 2030 (FAO, 2015). In this context it is ethically unacceptable that roughly one third of the edible food is wasted globally (Gustavsson and Cederberg, 2011).

In an *environmental perspective*, food systems are heavily **based on natural resources**, notably fertile land, water, air, sufficient nutrients, biological diversity, which all provide the indispensable base for the production of essential goods and services upon which human survival depends (Mcintyre et al., 2009). If these natural resources are used in an unsustainable way, the functionality of food systems is endangered in future. We therefore need to use renewable resources at a rate not exceeding the natural regeneration capacity and to find alternatives to using unrenewable resources. However, this is presently not the case. According to a recent UNESCO report current agricultural **water demand is unsustainable** and will require greater emphasis on increasing water use efficiency and reducing water losses (WWAP, 2015). **Soil degradation** threatens the soil's ability to perform all of its functions, including food production (Hatfield et al., 2017). Soil degradation refers to adverse changes in soil properties and processes leading to a reduced capacity of the soil to provide ecosystem functions (Lal et al., 2003, Jones et al., 2012). Soil is responsible for 99% of the world's food production and declines in agricultural productivity are directly related to soil degradation. According to Rickson et al. (2015) the extent of **compacted soil**, which is one form of soil degradation, amounts to 33 million hectares in Europe, which corresponds to **18%** of Europe's agricultural land (EU28 in 2013, Eurostat Statistics Explained, 2015). Other estimations even report **32%** of European soils as being **"highly susceptible" to soil compaction** and an additional **18%** as being **"moderately affected"** (Jones et al., 2012). These impacts often persist on the long term and are sometimes even irreversible (Blume et al., 2015). **Soil erosion**, the major factor affecting soil degradation (Hatfield et al., 2017), is estimated to affect approximately **11.4% of the European Union (EU) territory by a moderate to high level** (Panagos et al., 2017). Another form of soil degradation is **salinity**, which represents a **pressing environmental problem** facing agricultural systems **worldwide** and which is associated with irrigation of soils in semi-arid areas (Feitz and Lundie, 2002).

Present food systems do not only depend on natural resources, but they also **cause substantial environmental impacts** and are one of the main origins of **greenhouse gases** responsible for **climate change**. According to Tukker et al. (2006), in the global average **21-32% of the environmental impacts of private consumption are caused by food systems**, depending on the impact category (Table 1.1). For **eutrophication** the food sector contributes **58%**. The numbers would be even higher, if they included food consumed in restaurants and hotels (category "restaurants and hotels" in Table 1.1, which however includes other services offered in restaurants and hotels, additionally to food consumption). **For all impact categories except abiotic depletion, food systems cause equal or higher environmental impacts than housing, transport, and other areas of consumption** (Tukker et al., 2006).

Table 1.1: Environmental impacts, differentiating 8 impact categories, and private and public expenditures of *food and beverages* and *restaurants and hotels* (including out-of-home food consumption and other services offered in restaurants and hotels) relative to the impacts of total private consumption. The category "others" includes i.a. health, recreation and culture, clothing and footwear, alcoholic beverages, tobacco, education. Modified from Tukker et al. (2006).



Area of consumption	Global warming	Acidification	Eutrophication	Abiotic depletion	Ozone layer depletion	Human toxicity	Ecotoxicity	Photochemical oxidation	Private, public expenditures
Food and non-alcoholic beverages	29%	30%	58%	21%	24%	24%	32%	26%	17%
Restaurants and hotels	9%	10%	13%	7%	9%	8%	9%	9%	10%
Housing	24%	26%	10%	35%	21%	21%	20%	22%	25%
Transport	19%	14%	6%	20%	14%	25%	15%	20%	14%
others	20%	21%	13%	18%	33%	22%	24%	23%	35%
SUM	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Agricultural processes are especially relevant emitters of greenhouse gases, notably livestock farming producing significant amounts of methane from enteric fermentation and the application of fertilizers creating direct emissions of nitrous oxides from soil processes (Scherhaufer et al., 2018). The growing reliance on fossil fuels additionally increased emissions of greenhouse gases in agriculture (Mcintyre et al., 2009). Furthermore, **fertilizer application** also causes ammonia and nitrogen oxides to be released, which **contribute to acidification** and **eutrophication** (Scherhaufer et al., 2018). Using **70% of all water withdrawals globally** (World_Water_Assessment_Programme, 2009), agriculture is the major water user worldwide and potentially deprives many ecosystems of water. This **affects biodiversity**, since wetland and terrestrial ecosystems depend on the availability of water. Many wetlands have a rich and specialized biodiversity (Lambert, 2003) and are important ecosystem service providers to humans. **Conversion to agricultural land and irrigation** are important **drivers of ecosystem degradation**, which is taking place at a higher rate in wetlands than in any other ecosystems (Millennium-Ecosystem-Assessment, 2005, Russi et al., 2013). The conversion of natural ecosystems to agricultural land, however, also directly leads to habitat loss. **Habitat loss** is the main reason for an **unprecedented extinction crisis of global biodiversity** (Ceballos et al., 2015).

According to Steffen et al. (2015), the **planetary boundaries most exceeded** (high or increasing risk) **are all affected by food systems**: ***Biosphere integrity***, including *genetic diversity*, is largely affected by habitat loss due to agricultural land and water use (Chaudhary et al., 2016); ~30% of the ***climate change*** impacts are affected by food consumption (Table 1.1); ***phosphorus*** and ***nitrogen*** are mainly used as fertilizers in agricultural production[1,2] (Smil, 1999, Vuuren et al., 2010); ***land-system changes*** are also largely caused by the production of food and feed[3] (Goldewijk, 2001) (Figure 1.1).

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[1] "Phosphorus is used by society mainly in fertilizers, detergents, animal feed and other chemicals. The first category 'fertilizers' is dominant in terms of volume (around 80% of global use of phosphate rock) and in terms of its importance to human society." (Vuuren et al., 2010)

[2] "Human activities have roughly doubled the amount of reactive N that enters the element's biosphere cycle. Crop production is by far the single largest cause of this anthropogenic alteration." (Smil, 1999)

[3] Goldewijk (2001)'s results suggest "a global increase of cropland area from 265 million ha in 1700 to 1471 million ha in 1990, while the area of pasture has increased more than six fold from 524 to 3451 million ha. In general, the increase of man-made agricultural land took place at the expense of natural grasslands and to a lesser extent of forests."

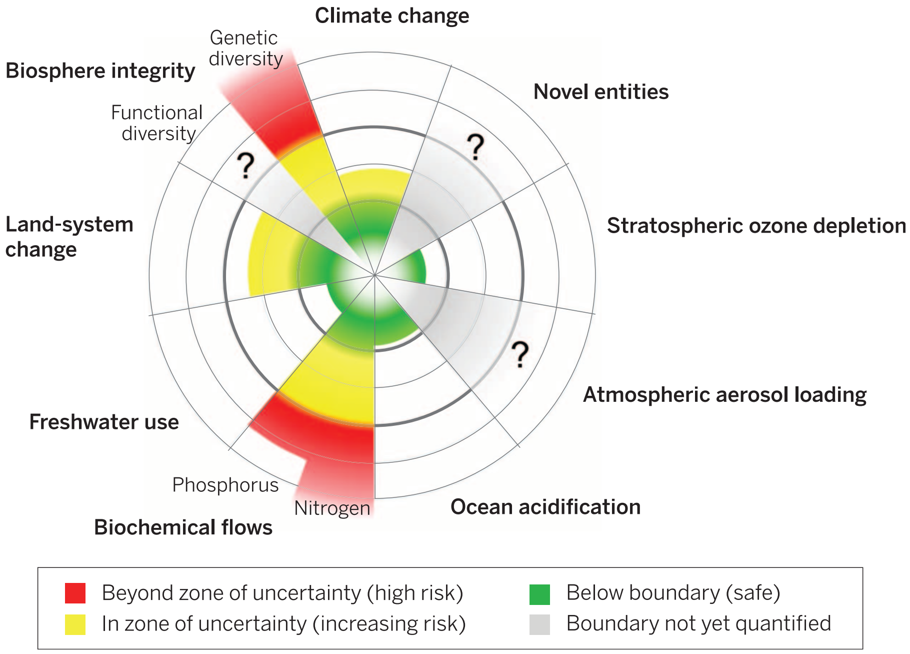

Figure 1.1: Current status of 9 control variables for 7 of the 9 planetary boundaries. The green zone is the safe operating space (below the boundary), yellow represents the zone of uncertainty (increasing risk), and red is the high-risk zone. The planetary boundary itself lies at the inner heavy circle. The control variables have been normalized for the zone of uncertainty (between the two heavy circles); the centre of the figure therefore does not represent values of 0 for the control variables. The control variable shown for climate change is atmospheric CO_2-concentration. Processes for which global-level boundaries cannot yet be quantified are represented by grey wedges. From Steffen et al. (2015).

Increased demand and degradation during the last 50 years caused the physical and functional availability of natural resources to shrink faster than at any other time in history. The use of natural resources in agriculture, in some cases, caused significant and widespread degradation of land, freshwater, ocean and atmospheric resources. Estimates suggest that **2.6 billion people are negatively influenced by resource impairment** (Mcintyre et al., 2009). At the same time, the FAO forecasts a **70% increase in global food demand from 2000 to 2050** (Alexandratos and Bruinsma, 2012). A high efficiency of the food value chain as the connector between agricultural producers and final consumers is therefore crucial.

However, the present food system is far away from being efficient. **One third of food produced across the globe is thrown away uneaten** and thus associated with large environmental burdens (Gustavsson and Cederberg, 2011, IMechE, 2013). The climate impact of global food waste (FW) is estimated at 3.3 Bt-CO_2-eq, which is equivalent to the world's third largest emitter of carbon after the economies of China and USA (FAO, 2013, Salemdeeb et al., 2016). According to Scherhaufer et al. (2018), **FW in the European Union** causes impacts of **186 Mt CO_2-eq on climate, 1.7 Mt SO_2-eq. on acidification**, and **0.7 Mt PO_4-eq on eutrophication**.

1.1.2 Relevance of food waste reduction

Figure 1.2 illustrates the key role of food systems to humans. As we discussed in the previous section, they have an ethical function of providing healthy nutrition and they depend on natural resources. In order to fulfil their ethical function of providing healthy nutrition on the long term, food system management needs to ensure enough productivity while avoiding to use natural resources unsustainably. However, we conclude from the previous section that there is a growing conflict between resource degradation due to unsustainable practices and production intensities on one hand and a growing food demand on the other hand, which needs to be solved urgently. In order to reduce resource degradation due to environmental impacts of food systems, we identified the following complementary approaches, which are also illustrated in the red box of Figure 1.2:

- Sustainable use of natural resources in agriculture, which implies to optimize **agricultural practices** without exceeding their natural rate of regeneration (Pretty, 2007)
- Avoiding any **food losses** throughout the food value chain, since they increase the gap between availability and demand (Gustavsson and Cederberg, 2011)
- Moving towards more resource efficient, healthy **diets**, which cause less environmental impacts (Tilman and Clark, 2014, Nemecek et al., 2016)

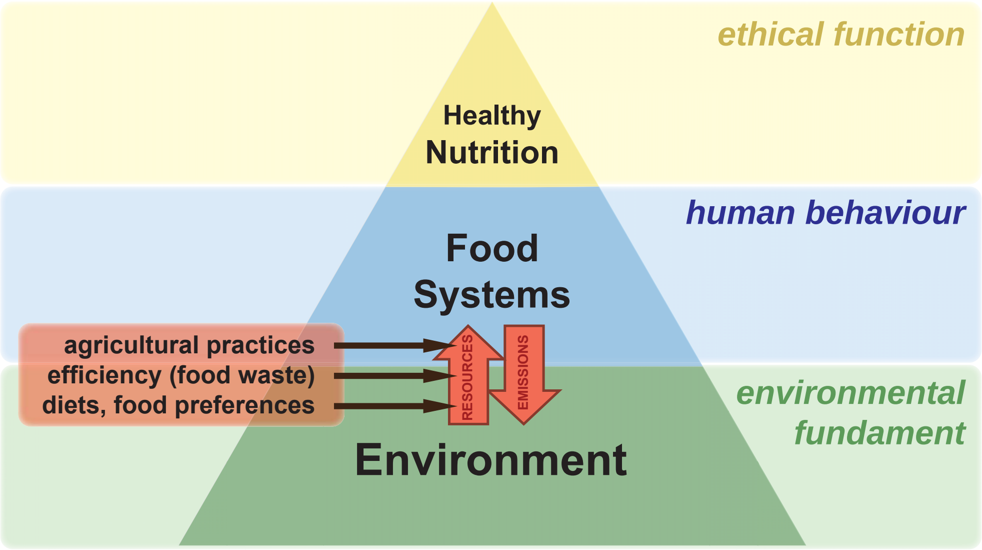

Figure 1.2: Illustration of the key role of food systems to humans. The ethical function of providing healthy nutrition is based on intact food systems, which depend on the availability of natural resources. Food systems are influenced by human activities. The environmental impacts of food systems (red arrows) consist of using resources, creating emissions to the environment, and changing ecosystems, e.g. by agricultural land use. Three parameters were identified as relevant in determining the impacts of food systems on the availability of natural resources: agricultural practices, the efficiency of the food system (mainly defined by the rate of FW), and food preferences and diets.

There is a debate about the first approach of improving agricultural practices to use resources sustainably and, in parallel, to increase the quantity and quality of the outputs (Seufert, 2015). Also the third approach is discussed controversially regarding the role of changing diets for a sustainable ecological footprint (Heller et al., 2013). In contrast, there is little debate about the importance of the second approach to reduce food losses and waste (FW). This approach might therefore be implemented more quickly and with lower effort than the other approaches.

A study by the European Commission (EC) estimated the potential climate benefits of a 20% FW reduction in Europe at 44 Mt CO_2-eq. (EC, 2014). According to Usubiaga et al. (2017) **20% of the European environmental footprint of the food system** could potentially be avoided by completely eliminating avoidable and possibly avoidable **consumer FW** (about 160 Mt CO_2-eq). Even though the greenhouse gas emission savings per kg of FW reported in literature vary due to methodological differences and uncertainties about FW composition (Bernstad and Cánovas, 2015), the studies agree that FW substantially contributes to the climate impacts of the food system. Relative to the total footprint of consumption, the potential savings of consumer FW prevention range between 3% for climate impacts and 15% for blue water consumption (Usubiaga et al., 2017). The **Resource Efficiency Roadmap** defined by the EC in 2011 calls for **halving the disposal of edible FW by 2020 in the EU 28** (European Union 28 Member States). Reaching the Roadmap's target only at consumer level, could save 2-7% of the total footprint of consumption, depending on the environmental impacts. This corresponds to a **10-11% decrease in inputs in the food value chain** (Usubiaga et al., 2017). These results confirm the conclusions of various studies highlighting the significant environmental benefits of avoiding FW (Gentil et al., 2011, Bernstad and Andersson, 2015, Martinez-Sanchez et al., 2016).

The United Nations recently released the **Sustainable Development Goals**, which include a specific target for '**halving per capita global food waste** at the retail and consumer levels and reducing food losses in the food value chain by 2030' (SDG 12.3). In addition to that, one of the most prominent goals includes 'ending hunger and achieving food security and improved nutrition'. For the implementation of this goal, which is mentioned directly after the top goal of 'ending poverty in all forms and everywhere', FW reduction is relevant or even indispensable.

1.1.3 Relevance of knowledge about food waste

In industrialized countries more than 40% of the food losses occur at retail and consumer levels, while in developing countries more than 40% of the food losses occur at post-harvest and processing levels (Gustavsson and Cederberg, 2011, Kummu et al., 2012). Effective measures for FW reduction are therefore variable in different regions of the world. **Strategies for FW reduction can only succeed if the origin, the reasons, and the quantity and environmental relevance of individual FW flows are known**. As an example, in developing countries know-how and efficient harvesting and storage technologies crucial, while in the industrialised world consumer awareness rising is more important. The latter is mainly due to the large availability and variety of fresh food and due to the consumers' wealth allowing them to buy more food than they need. This trend is increased by lower food prices than the real cost of the food, since many products are largely subsidised in most countries and often imported from low-income to high-income countries.

Local food systems sustain livelihoods at micro level, but are currently challenged by globalized food systems. This trend brings opportunities, but also ethical and environmental threats (Mcintyre et al., 2009). The personal relation of the consumers to agricultural production is often compromised by more globalized food systems and urbanization. It is therefore of growing importance to inform consumers and to strengthen their relation to the origin of food and their appreciation of the available food. **A scientific basis on the amounts, environmental impacts, and reduction potential of FW helps to inform the consumers and to raise their awareness**.

1.2 STATE OF RESEARCH

The topic of FW is a relatively new research field. In the following sections we summarize the state of knowledge regarding FW quantification and environmental impacts of FW and the potential for reduction.

1.2.1 Food waste quantification

There has been an increasing number of literature on FW quantification in the past years; however, there are still significant challenges, such as data inconsistency and a narrow temporal, geographical, and food supply chain coverage (Xue et al., 2017). Previous studies are either specific and do not include the whole food basket at all stages of the food value chain, or they are generic and based on relatively broad assumptions and extrapolations. Xue et al. (2017) examined 202 publications which reported FW data for 84 countries and 52 individual years from 1933 to 2014. They found that most existing publications are conducted for a few industrialized countries (e.g. the UK and the US), and over half of them are only based on secondary data, which signals high uncertainties in existing data about FW (Xue et al., 2017).

Table **1.2** lists a selection of relevant studies quantifying FW at different stages of the food value chain in different regions of the world. The selection mainly includes industrialized countries, since they are comparable to the Swiss food system, and countries exporting food to Europe.

We identified 6 studies that cover the entire food value chain and differentiate more than one food category. Monier et al. (2010) quantify FW in the EU27 countries based on statistical data from EUROSTAT and national studies, differentiating the stages ‘manufacturing and processing’, ‘wholesale and retail’, and ‘households’. Food categories are not differentiated. They emphasize that “the lack of frequent, consistent and reliable FW data remains a serious problem for the identification of trends” and that “the order of magnitude is probably broadly correct, but the details remain very uncertain” (Monier et al., 2010). In the same year Parfitt et al. (2010) published a literature review of FW amounts globally. They conclude that there is “no consensus on the proportion of global food production that is currently lost. Ranges between 10 and 40 percent of total global food production and as high as 50 per cent are quoted, but on closer examination, these estimates all link back to the same limited primary datasets, where much of the published data relates to fieldwork undertaken in the 1970s and 1980s” (Parfitt et al., 2010). The first study estimating global FW systematically was Gustavsson and Cederberg (2011). They differentiated 5 stages of the food value chain, 7 commodity groups and 7 regions of the world. However, they had to estimate FW percentages in regions where first hand data and statistical data from the FAO food balance sheets were not available, in order to fill gaps in the first hand data. The results suggest that roughly 1/3 of food produced for human consumption is lost or wasted globally. In Europe the rate is slightly larger, with more than 40% of the FW occurring at the retail and consumer levels (Gustavsson and Cederberg, 2011). Based on this study, Kummu et al. (2012) calculated the nutritional value of FW. They quantify FW in Europe at 720 kcal/person/day or 29% of the food supply. Eberle and Fels (2015) calculated FW in Germany, differentiating 5 stages of the food value chain and 8 food categories. This study is mainly based on data from Kranert et al. (2012), who quantified FW in Germany at all stages except agricultural production, and Peter et al. (2013), who estimated FW in agricultural production for 4 crops in Germany. Data gaps were completed with data from Gustavsson and Cederberg (2011). Porter et al. (2016) also calculated global FW amounts, similarly to Gustavsson and Cederberg (2011), based on statistical data from the FAO food balance sheets. However, their focus was less on data reliability of FW amounts and more on the historical development. Finally, Scherhaufer et al. (2018) quantified FW in Europe including 4 stages of the food value chain and 9 food categories. The mass of FW was mainly based on Gustavsson and Cederberg (2011). Additionally, Scherhaufer et al. (2018) estimated the shares of FW going to different methods of FW treatment.

Most studies quantify FW in terms of ‘wet weight’. Some studies use the unit ‘dry weight’, e.g. Mosberger et al. (2016) for FW from the Swiss processing industry. The unit ‘dry weight’ is mostly used for FW and by-products from the processing industry, where the ‘wet weight’ is an unsuitable indicator since the water content often varies during processing and distorts the results. A few studies calculate the energy content of FW, e.g. Pekcan et al. (2006) for household FW in Turkey, Kummu et al. (2012) for global FW, and Buzby et al. (2014) for FW in the US retail and household sectors.

Table 1.2: Overview of relevant studies quantifying FW, indicating which stages of the food value chain, which region or country, and if environmental impacts (env. Impacts) are addressed by the study. The list is not complete. The studies are ordered chronologically. AP = Agricultural Production, T = Trade, P = Processing industry, R = Retail, FW = Food services, HH = Households

Reference	Food value chain stages						Region	Env. Impact	Comments
	AP	P	T	R	FS	HH			
(Kantor et al., 1997)				x	x	x	US		8 food categories
(Andrini and Bauen, 2005)					x		Switzerland		Survey in the Canton of Bern
(Pekcan et al., 2006)						x	Turkey		Survey in 500 households; unit of FW: nutritional energy
(Baum and Baier, 2008)					x		Switzerland		Survey in food services in the Canton of Aargau
(Ventour, 2008)						x	UK		Compositional analysis combined with survey
(Palipane and Rolle, 2008)	x						Jamaica		Exotic fruits
(Defra, 2010)						x	UK		Combination of Ventour (2008) with food consumption to deduce the rate of FW in individual food categories
(Monier et al., 2010)	x		x			x	EU 27	(x)	Data from EUROSTAT and national studies; food categories not differentiated
(Parfitt et al., 2010)	x						global		Literature review -> 10-50% of global food production
(Gustavsson and Cederberg, 2011)	x	x	x	x		x	7 regions of the world		Based on literature, FAO balance sheets, and assumptions; differentiating 7 commodity groups
(Göbel et al., 2012)	x						NRW (DE)	x	GHG and material footprint based on 7 indicator products; FW treatment ignored
(Kranert et al., 2012)		x	x	x	x	x	Germany		No systematic differentiation of food categories
(Kummu et al., 2012)	x	x	x	x		x	7 regions of the world	x	Based on Gustavsson and Cederberg, 2011, and calculating nutritional value, blue water, cropland footprint, fertilizer consmpt.
(Schneider et al., 2012)					x	x	Austria		Compositional analysis combined with survey
(FAO, 2013)	x	x	x	x		x	7 regions of the world	x	Based on Gustavsson and Cederberg, 2011; GHG, land, water footprint; animal feed ignored
(Peter et al., 2013)	x						Germany		Wheat, potatoes, apples, carrots
(Quested et al., 2013)						x	UK		Compositional analysis in 1’800 households and diary; reduction in 2012 after a campaign compared to 2007
(Scholz, 2013)				x			Sweden		Including GHG emissions
(Oakdene, 2013)					x		UK		FW measurements in 480 food services
(Ayache et al., 2014)						x	France		Compositional analysis in 30 households
(Göbel et al., 2014)					x		Germany		Measurements in 5 food services
(Eberle and Fels, 2012)	x	x	x		x	x	Germany		Based on Kranert et al., 2012, and Peter et al., 2013
(Eberle and Fels, 2015)	x						Germany	x	GHG and ReCiPe; FW treatment ignored
(Noleppa and Cartsburg, 2015)	x						Germany	x	GHG and land use; FW treatment ignored
(Silvennoinen et al., 2015)					x		Finland		Measurements in 47 food services
(Hanssen et al., 2016)						x	Norway		Compositional analysis in 220 households
(Hrad et al., 2016)					x		Austria		Measurements in 50 food services
(Mosberger et al., 2016)		x					Switzerland		Avoidable FW measured in terms of dry weight
(Porter et al., 2016)	x	x	x	x		x	7 regions of the world	(x)	Based on food balance sheets, 7 commodity groups; focus on historical development; generic GHG emission factors
(Sheane et al., 2016)	x						UK		Strawberries and lettuce
(Waskow et al., 2016)				x	x	x	Germany		Detailed suggestions for reduction based on case studies
(Borstel et al., 2017)					x		Germany		Measurements in 269 food services
(Delley and Brunner, 2017)						x	Switzerland		Qualitative survey
(Scherhaufer et al., 2018)	x	x	x		x		Europe	x	Mainly based on Gustavsson and Cederberg, 2011; GHG, eutrophication, acidification, reported energy; animal feed ignored; environmental impacts based on 9 indicator products

We conclude that the present state of knowledge about FW quantification is at a broad level, mainly based on estimations and related with large uncertainties. We could not identify any study integrating available data on FW rates into an MFA covering the entire food value chain, including FW treatment and the entire food basket, and differentiating detailed food categories. However, in order to quantify the environmental impacts caused by FW in the food value chain of a specific region or country and to identify hotspots, FW needs to be assessed in detailed food categories across the entire food system of a region or country. For the differentiation of food categories, 3 aspects are important: (I) they should be as homogenous as possible in terms of perishability of the included products and (II) in terms of per-kg environmental impacts of the products and (III) data for FW quantification should be available. Considering these aspects, the more food categories are differentiated, the more appropriate the results of the environmental assessment and the more differentiated the conclusions regarding effective measures for FW prevention. Furthermore, the method of treatment differs depending on the type and the origin of FW (e.g. FW containing animal proteins is not allowed for animal feeding; fruits and vegetables are more convenient for composting than oils and fats). This can only be taken into account in a systematic MFA differentiating food categories and stages of the food value chain.

1.2.2 Environmental impacts of food waste

We identified 7 studies analyzing environmental impacts of FW across the entire food value chain and covering the entire food basket. The first study by Monier et al. (2010), mentioned in the previous section, multiplied global FW amounts by generic impact factors to estimate total environmental impacts, however without differentiating food categories. The next study was performed by Kummu et al. (2012), who calculated the blue water and cropland footprint and quantified fertilizer consumption related to the production of wasted food in 7 regions of the world. In the same year Göbel et al. (2012) estimated the greenhouse gas emissions and the material footprint of FW in North Rhine Westfalia, by multiplying total FW amounts in 7 food categories by characterization factors of 7 indicator products (e.g. salad). The treatment of FW was not included. FAO (2013) was the first study calculating climate impacts of FW including the entire food value chain *and* FW treatment, based on FW estimations by Gustavsson and Cederberg (2011) in 7 regions of the world. They took into consideration that the per-kg climate impacts increase with each stage of the food value chain at which the food is wasted. Additionally, they calculated water and land use associated with the agricultural production of wasted food. However, they did not include FW used as animal feed. They also neglected the substitution of useful co-products and energy from FW treatment and did not differentiate between FW from households and from food services. Eberle and Fels (2015) quantified greenhouse gas emissions and aggregated ReCiPe of FW in Germany, differentiating 8 food categories. However, they did not include impacts from FW treatment and did not separate impacts between stages of the food value chain. A study conducted by WWF Germany calculated greenhouse gas emissions and land use caused by FW in Germany, including 12 food categories and the entire food value chain; FW at agricultural level was partly ignored due to missing data. The impacts of FW treatment were neither considered (Noleppa and Cartsburg, 2015). Porter et al. (2016) multiplied global FW amounts by emission factors in order to calculate global FW climate impacts in 7 food categories and for 7 continents. However, they did neither differentiate the stages of the food value chain nor include FW treatment. Finally, the most comprehensive calculation of environmental impacts of FW in Europe was published by Scherhaufer et al. (2018). They collected impact factors from LCA studies for most relevant processes across the food value chain, for FW treatment, and differentiating 7 food categories and 4 impact methods (climate impacts, the eutrophication and acidification potential, and reported energy). They included environmental benefits from the substitution of electricity, heat, fertilizer, and peat by useful outputs from FW treatment. However, they did not include FW used for animal feeding. They approximated environmental impacts of their 7 food categories by 9 indicator products (e.g. 'dairy and eggs' by the indicator 'milk'). They did not differentiate FW from households and food services.

There are more studies calculating environmental impacts of FW for specific products or stages of the food value chain, e.g. Willersinn et al. (2016) for FW in the entire Swiss potato supply chain. However, we could not find a study modelling the environmental impacts of all FW in the food value chain of a region or country, differentiating the 5 or 6 major stages of the food value chain, individual food categories, and considering the most relevant methods of treatment (animal feed included). Many studies use a simplified approach and multiply the amount of FW by generic emission factors, without considering at which stage of the food value chain the food is wasted.

1.2.3 Food waste reduction

Studies measuring the effect of interventions on FW reduction are rare. Quested et al. (2013) compared household FW in the UK before and after the implementation of an extensive campaign for awareness raising. They combined FW composition analyses with kitchen diaries and surveys to cover all disposal routes. Waskow and Blumenthal (2017) carried out second measurements one year after the first FW measurements in five school canteens, which implemented measures for FW reduction in between. Based on case studies, Kallbekken and Sælen (2013) quantified the effect of smaller plates on plate waste in hotel restaurants.

1.2.4 Research gap

Based on the literature review in the previous sections, we spot major research gaps regarding the quantification and the environmental assessment of FW and the potential for reduction. More specifically, we identify the following research gaps:

- None of the previous studies combines an **MFA of FW** across the **entire food value chain** including **different FW treatment options (including animal feed)** with a process-related **life cycle inventory**, integrating **detailed food categories** covering the **whole food basket**, *and* considering the **substitution of useful outputs from FW treatment**.
- None of the previous studies was found to appropriately **allocate the environmental impacts to consumed and wasted food**, which is important for heterogeneous food categories (e.g. dairy products containing whey and cheese).
- Only a few studies estimated a **realistic potential FW reduction based on case studies** for specific stages of the food value chain, but none of them evaluated the quantitative and environmental reduction potentials **in a supply chain perspective** and **compared** them **with political targets**.
- We could not identify a **“bottom-up” environmental assessment of FW** with **sufficient detail for decision making** for a **whole region or country**.
- The role of **product-quality simulation tools** for improved supply chain management and avoidance of spoilage has not been explored.

Furthermore, in Switzerland only Almeida (2011) estimated the total amount of FW comparing available food from domestic production and imports with food consumption based on nutritional data. However, this thesis did not differentiate FW between different stages of the food value chain. Thus, in **Switzerland** a study analysing FW at all stages of the food value chain and including the entire food basket was still lacking.

Based on these circumstances, we developed four research goals presented in the next section.

1.3 GOALS AND RESEARCH QUESTIONS

The *main goal* of this study is to **provide methods and data to identify FW hotspots in terms of amounts and environmental impacts and to assess reduction measures**. In order to reach this goal, we defined *3 subgoals*.

The *first subgoal* is to provide an overview of the food system and the amount and nutritional energy of consumed and wasted food. The *second subgoal* includes quantifying the environmental impacts and to identify environmentally relevant processes within the food system. The *third subgoal* is to estimate the quantitative and environmental FW reduction potential, which individual or several actors of the food value chain can realize.

In order to reach these goals, we formulated the following 5 research questions (RQ):

RQ1: How much food is wasted at each stage of the food value chain and which stages are environmentally most relevant?

RQ2: Which food categories are hotspots of quantitative and environmental relevance?

RQ3: How important are the environmental impacts of FW treatment compared to FW prevention?

RQ4: What is the environmental reduction potential of exemplary actors in the food value chain?

RQ5: Is the collaboration between actors of the food value chain beneficial for effective FW reduction compared to isolated measures?

These research questions shall be analyzed exemplarily for the case of Switzerland, however developing a methodology adoptable to any other country.

1.4 STRUCTURE OF THE DISSERTATION

This PhD thesis is a cumulative dissertation encompassing four peer-reviewed scientific articles. Each research question was analysed in a separate publication and is presented in one of the chapters 2-5. Each chapter is documented in more detail in one of the appendices A-D. Figure 1.3 illustrates which parts of the food system and its interaction with the environment are addressed by each chapter.

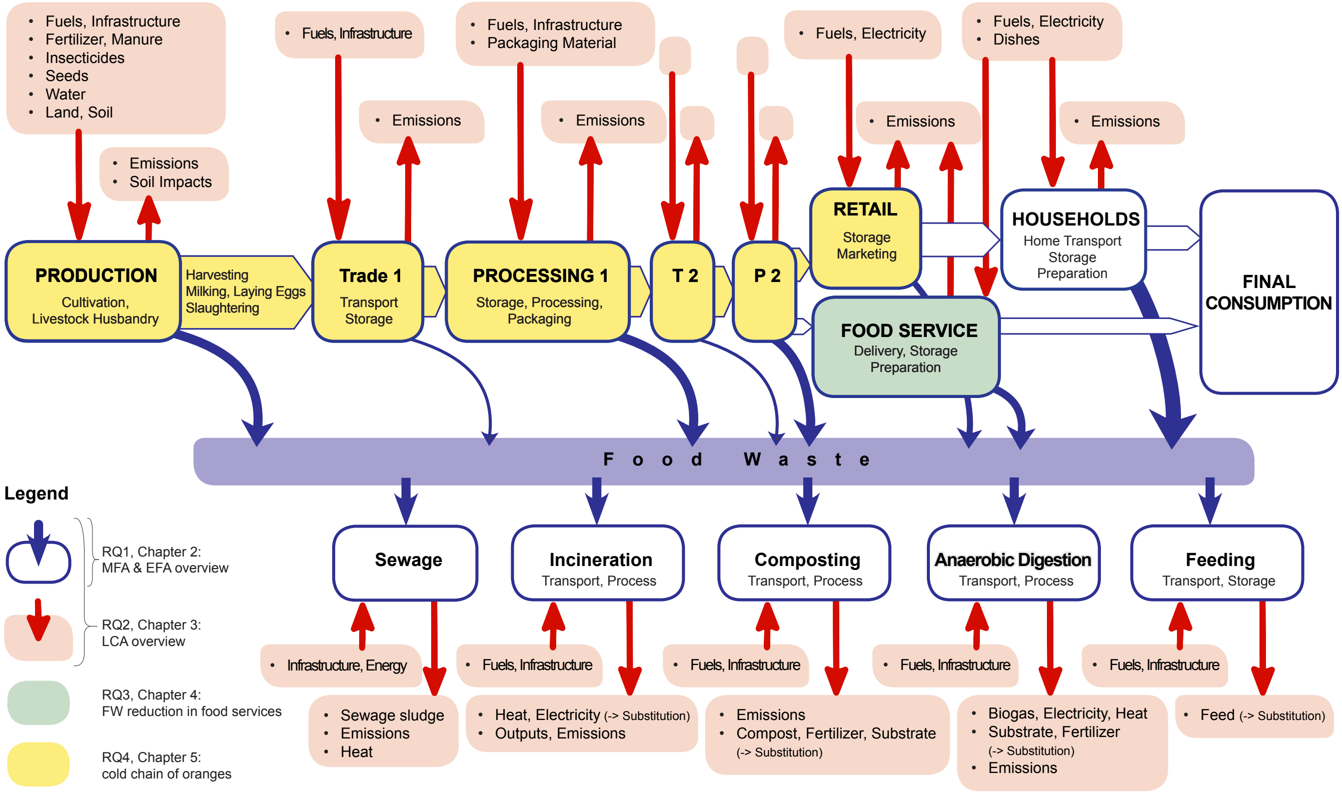

Figure 1.3: Concept of the model combining mass flow analysis and life cycle assessment: The boxes illustrate the stages of the food value chain and four FW treatment methods (sewage treatment, incineration, composting, anaerobic digestion, feeding). The processes of the food value chain and of FW treatment (e.g. cultivation, livestock husbandry, transport, storage) cause emissions to the environment (e.g. greenhouse gases) and in some cases by-products (e.g. heat and electricity from incineration), and use resources (e.g. fuels, fertilizer). The colours show which parts of the system are addressed by each research question (RQ) and chapter (see legend).

Chapter 2 addresses RQ 1 and 2 and consists of a **mass and energy flow analysis of the Swiss food system, including FW treatment**. A 'mass flow analysis' (MFA, also called 'material flow analysis') is a 'systematic assessment of the flows and stocks of materials within a system defined in space and time' (Brunner and Rechberger, 2004). In the case of food systems, the assessed material is food (waste). In Figure 1.3, the MFA is illustrated by the boxes (processes of the food value chain) and arrows (food and FW flows) with a blue border. The **food value chain** includes the **6 stages** 'agricultural production', 'trade', 'processing' (for some food categories two steps of processing are considered, e.g. milling cereals and baking bread), 'retail', 'households', and 'food services'. Final consumption includes food consumed in households and food services. At each stage of the food value chain food is wasted (blue arrows in Figure 1.3) and sent to a **FW treatment method** ('feeding', 'anaerobic digestion', 'composting', 'incineration', 'sewage'). The MFA is conducted for **33 food categories** and aggregated to 'plant products', 'dairy products and eggs', 'meat and fish' and to **the entire food basket** of Swiss food consumption. All food and FW flows are presented in terms of mass and in terms of nutritional energy (energy flow analysis).

In **Chapter 3** we address the environmental aspects of RQ 1-3. We therefore couple the MFA with life cycle inventory (LCI) data and perform a **life cycle assessment (LCA) of the Swiss food system with focus on FW**. We adopt and extend the system boundary of the MFA in order to take the entire life cycle of all inputs into account. The LCI includes water, energy, and raw material inputs to the food system, land use, and releases to air, land, and water (illustrated in red in Figure 1.3). The emissions to the environment include greenhouse gases (GHG) and other organic and inorganic substances. The environmental impacts are modelled for most processes of the food value chain and generally include cultivation and harvesting, animal husbandry, seed and fertilizer production, energy consumption, transport and storage, processing, packaging, food preparation, and FW treatment processes. FW treatment processes are approximated for the case of Switzerland, even if some food is wasted in the foreign supply chains of imported products. **Useful co-products from FW treatment** are assumed to **replace products with the same functionality** and are indicated with ‘substitution’ in Figure 1.3. With this procedure we take into account that the additional production of the mentioned products, which is needed to substitute the functions of FW treatment, reduces the potential environmental benefits of FW prevention.

Chapters 4 and 5 jointly address RQ4 and 5. In **Chapter 4** we analyse in more detail the stage of **food services**, which is marked with green background in Figure 1.3. We chose this sector because, together with the sector of households, it provides the highest average rate of FW (chapter 3) and because the Swiss Federal Office for the Environment (FOEN) showed a special interest into the food service sector since they plan to start their strategy for FW prevention in this sector (Sanders, 2018). In addition to the analysis in chapter 2 we **differentiate** the **5 subsectors** ‘restaurants’, ‘hotels’, ‘school and university canteens’, ‘business canteens’, and ‘hospital and care centres’. This differentiation requires a larger number of FW measurements. We therefore include FW measurements carried out in 4 other European countries (Germany, Austria, Finland, and the UK).

Furthermore, in this chapter we estimate the **realistic potential for** mid-term and long-term **FW prevention**. This is based on case studies of food service institutions, in which **measures for FW reduction** are **implemented and their effect measured**. We then estimate the potential mid-term FW reduction in each subsector, if all food services achieved the same reduction as our case studies in their corresponding subsector. The FW reduction differentiates individual food categories and thus allows for the calculation of the achieved **environmental benefits**. We additionally model an extended scenario of FW reduction, in which food services **reduce FW in the previous food value chain** by using non-standard products which otherwise would have been wasted in agricultural production and trade. In order to roughly estimate the long-term potential of FW reduction, a progressive restaurant specialised on FW minimization in Switzerland is investigated.

Chapter 5 exemplarily investigates the entire **cold chain of oranges** imported from the major two import destinations ‘South Africa’ and ‘Spain’ to Switzerland. The system is highlighted with a yellow background in Figure 1.3. The main purpose of this chapter is to analyse the **importance of an integral supply chain management in order to reduce the environmental impacts of FW** and, as a consequence, of the entire orange supply chain. We therefore compare different cold chain options and their effect on orange quality. The cold chains include **3 different ways of cooling the oranges** and **3 different package systems**. The different cold chains vary in how quickly the oranges are cooled down to the optimal storage temperature, which has an influence on their quality. Furthermore, they differ in the amount and the type of energy as well as the amount of packaging needed per kg of orange. The results are used to assess the environmental importance of considering FW and food quality when comparing different cold chains.

In an overall perspective, the combination of MFA, EFA, and LCA provides several advantages over the isolated application of these tools. Using an MFA of the investigated food system as a basis for the process models in the life cycle inventory ensures mass conservation (Dalemo et al., 1997). This allows for assessing environmental impacts while, for example, considering capacity restrictions and food availability. Furthermore, MFAs represent a comprehensive overview on the assessed food system. The direct coupling of MFA with life cycle inventories facilitates the generation of input-dependent LCAs, for instance in order to calculate different scenarios of FW reduction while taking the composition and treatment of FW into account. The integration of EFA into the allocation of environmental impacts to consumed and wasted food allows for evaluating heterogeneous food categories more appropriately than with mass-based allocation (e.g. environmental impacts allocated to whey and cheese). Furthermore, by combining LCA with quality evolution modelling of the assessed food products it is possible to identify trade-offs between FW reduction and the reduction of direct environmental impacts of cold chains. This supports the decision-process towards environmentally more favourable supply chains.

The conclusions in **Chapter 6** provide a synthesis of the whole dissertation and discuss the scientific and practical relevance of the thesis. We conclude the chapter with an outlook on future research work.

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CHAPTER 2

QUANTIFYING FOOD LOSSES AND THE POTENTIAL FOR REDUCTION IN SWITZERLAND

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ABSTRACT

A key element in making our food systems more efficient is the reduction of food losses across the entire food value chain. Nevertheless, food losses are often neglected. This paper quantifies food losses in Switzerland at the various stages of the food value chain (agricultural production, postharvest handling and trade, processing, food service industry, retail, and households), identifies hotspots and analyses the reasons for losses. Twenty-two food categories are modelled separately in a mass and energy flow analysis, based on data from 31 companies within the food value chain, and from public institutions, associations, and from the literature. The energy balance shows that 48% of the total calories produced (edible crop yields at harvest time and animal products, including slaughter waste) is lost across the whole food value chain. Half of these losses would be avoidable given appropriate mitigation measures. Most avoidable food losses occur at the household, processing, and agricultural production stage of the food value chain. Households are responsible for almost half of the total avoidable losses (in terms of calorific content).

2.1 INTRODUCTION

Food loss over the entire food value chain represents a significant loss of resources invested in food production, transport, and storage. Since resources (land, energy, fresh water, agricultural inputs) are limited in nature, they should be applied efficiently and sustainably. Further negative externalities of food production include ecotoxicity from pesticides, eutrophication, soil erosion, organic matter loss, and biodiversity loss (Pretty et al., 2005). Between 20 and 30% of the environmental impact of products is caused by food consumption (Tukker et al., 2006). Thus, food loss may cause substantial environmental impact. Furthermore, economically avoidable food losses are of high importance in the efforts to combat hunger and to improve food security, not only in developing but also in developed countries. Improving the efficiency of the food value chain could help bring down the cost of food to the consumer and thus increase access for low-income households (Gustavsson and Cederberg, 2011). A multidisciplinary research project in the UK found that reducing food losses across the entire food value chain will be a critical component of any strategy to sustainably and equitably feed the rapidly growing global population (Foresight, 2011).

A survey from the Swiss Federal Institute of the Environment (Baum and Baier, 2008) analysed the flows of biogenic goods in Switzerland. The results show that 1.8 mio. tonnes of plant products and 0.1 mio. tonnes of animal products (dry matter) were consumed in 2006. Baum and Baier (2008) also analysed various flows of disposal, but without differentiating between food and other biogenic goods. The most extensive statistical analysis of food consumption in Switzerland is carried out annually by the Swiss Farmer's Union (SBV, 2009). The analysis encompasses agricultural production, import, export, storage variation, and consumption at the retail level.

Two recent publications estimate food losses over the entire food value chain from agricultural production to final consumption. According to Lundqvist et al. (2008), 1'400 kcal/capita are lost globally every day. Gustavsson et al. (2011) differentiates between seven regions, one of them being Europe. Here, the avoidable losses are estimated at 280 kg/cap/a.

A "preparatory study on food waste across the EU 27 Member States" (Monier et al., 2010) estimates the food losses in each country, based on the EUROSTAT database, a literature review, stakeholder consultations, and specific hypotheses. The losses over all stages of the food value chain except agricultural production are estimated between less than 50 kg/cap/a (Greece) and more than 500 kg/cap/a (Netherlands), with an average of 180 kg/cap/a for EU 27. The major contribution is from households (42%).

The most recent study at a national level was carried out in Germany, induced by a report of the European Parliament on how to avoid food losses and on strategies for a more efficient food value chain in the EU (Caronna, 2011). The study quantifies the amount of food losses over all stages of the food value chain except agricultural production. They estimate food losses in Germany to be between 8 and 15 mio. tonnes per year (100-180 kg/cap/a, calculating with a population of 82 mio.). The major contribution is from households (61%), followed by the processing and the food service industry (17% each) (Kranert et al., 2012).

In Switzerland, quantitative data about food loss is incomplete and rare. A market study from 2001 by McKinsey & Company estimated the losses from the retail sector, based on the consultation of several food companies. The result gives a rough estimate of 14-36 kg/cap/a (numbers refer to fresh substance); 10% of this amount is estimated to fulfil qualifications for food donation to underprivileged people (Schweizer-Tafeln, 2010). In the Canton of Aargau, 21 kg/cap/a were wasted in 2007 from the food service industry alone (Baier and Reinhard, 2007). In the Canton of Bern, the corresponding amount has been estimated at 19.4 kg/cap/a in 2005 (Andrini and Bauen, 2005).

Data on food losses in Swiss households are lacking, despite their importance. A large study performed in the UK, based on a physical waste analysis of 2'138 households, illustrated that the avoidable and possibly avoidable losses correspond to 17.7% of the weight of the food and drink purchased; the food losses, excluding drinks, make up 21.3% of the purchases (Quested and Johnson, 2009). Another study in Germany, based on online diaries in 200 households, concluded that 12% of food purchased by households is lost (Cofresco, 2011).

The goals of this paper are (a) to quantify the scale of food loss in Switzerland across the entire food value chain from agricultural production (harvesting) to final consumption (intake) and with differentiation into a number of relevant food categories, (b) to group them into avoidable, possibly avoidable, and unavoidable losses and (c) to suggest some initial measures for the reduction of food losses.

2.2 METHODOLOGY

2.2.1 Definitions

In the literature *food losses* are defined in different ways. The definition employed in this paper refers to *food which is originally produced for human consumption but then directed to a non-food use or waste disposal (e.g. feed for animals, biomass input to a digestion plant, disposal in a municipal solid waste incinerator)*.

Food losses are grouped into three categories, based on the definitions in Quested and Johnson (2009):

1) *Avoidable losses* refer to food and drink thrown away because they are no longer wanted, e.g. because they perished or exceeded their date of expiry. Most *avoidable* losses are composed of material that was, at some point prior to disposal, edible, even though a proportion is not edible at the time of disposal due to deterioration (e.g. rotting, decomposition).
2) *Possibly avoidable losses*, in contrast, refer to food and drink that some people eat and others do not (e.g. apple peels), or that can be eaten when prepared in one way but not in another (e.g. potato or pumpkin skins), or that is sorted out due to specific quality criteria (e.g. bent carrots).
3) *Unavoidable losses* comprise waste arising from food and drink preparation that is not, and has not been, edible under normal circumstances. This includes apple cores, banana skin, tea leaves, coffee grounds, and inedible slaughter waste. Additionally, harvesting, storage, transportation, and processing losses that are not avoidable with best available technologies and reasonable extra costs are also classified as unavoidable (see also Section A.4.19 in appendix A).
   This definition of *food losses* differs from that in Gustavsson and Cederberg (2011) by including the *unavoidable losses*, which are omitted in the cited study.

According to Gustavsson and Cederberg (2011), *food waste* is often used for *food losses* occurring at the end of the food value chain (retail and final consumption), where most losses are caused by wasteful behaviour. Nevertheless, in this paper both terms are used synonymously and refer to all *food losses*, because a distinction between wasteful behaviour and other reasons for *food losses* was difficult to perform.

The *food value chain* is the system of organizations, people, and activities involved in moving food from its producer (usually the farmer) to the consumer. In the present work, it also comprises the consumption phase itself and losses that occur at the end consumer.

For the present study, a multitude of data sources was used. Background information about these sources, data quality and calculations is provided in the supporting information, (appendix A).

2.2.2 Data acquisition

Table 2.1 contains an overview of the numbers and types of organisations that provided data about food losses. In order to model the whole food value chain, several data gaps had to be filled with data from the literature and with additional assumptions (details in the sections A.1 and A.4 in appendix A).

Table 2.1: Overview of the number and types of firms, institutions and associations providing data (the number of organizations is shown in parentheses). Details about the individual data providers are given in Table A.1 in appendix A.

FIRMS (31)	
	Agricultural producers (5)
	Food trading and logistics industry (5)
	Food processing industry (6)
	Food service settings, e.g. restaurants (2; data from 201 settings**)**
	Retailers (4)
	Bakeries (5; data from 29 branches**)**
	Food banks (4)
TRADE AND PRODUCER ASSOCIATIONS, e.g. farmers' union (10)	
FEDERAL INSTITUTIONS, e.g. federal statistical office (3)	

2.2.3 Food categories

In this paper 22 food categories are analysed (Table 2.2). The categories were defined according to their importance for the Swiss consumer basket and characteristics regarding food losses. For example, berries were defined as separate category because of their high perishability, although they only contribute 0.2% of the calories of total food consumption. In order to avoid double counting of ingredients, the food categories were defined at the level of ingredients. For example, in the category of breads and pastries only wheat was modelled; the other ingredients like sugar and eggs were attributed to other categories.

Table 2.2: Food categorization. The second column quantifies Swiss food consumption at the retail level (input to households and catering trade), the third column the average calorific content of each food category.

Food category		Consumption per year (2005-2007) [tonnes of fresh substance/a]	Calorific content [kcal/100g]
Fruits			
1	Apples	121’483	52
2	Fresh fruits excluding apples and berries	388’538	52
3	Berries	49’757	43
4	Canned fruits	24’894	70
Vegetables			
5	Potatoes	339’860	77
6	Fresh vegetables	417’807	37
7	Storable vegetables	139’269	37
8	Processed vegetables	131’824	36
Cereals			
9	Bread wheat (Breads and pastries)	392’332	359
10	Durum wheat (Pasta)	87’580	370
11	Rice	39’249	358
12	Maize	11’542	366
Sugar			
13	Sugar	323’581	402
Oils and fats			
14	Oils and fats	174’249	908
Dairy			
15	Milk/other dairy products	1’246’686	59
16	Cheese	199’970	271
17	Butter	77’775	767
Eggs			
18	Eggs	83’506	162
Meat			
19	Pork	186’119	378
20	Poultry	72’310	172
21	Beef and other meat / offal	116’742	243
Fish			
22	Fish	64’848	152
TOTAL		5’142’173	158

2.2.4 System boundary

The analysis in this paper covers the entire food value chain that is related to Swiss food consumption, from agricultural production to the consumer. Food waste in other countries, resulting from the production of food imported for consumption in Switzerland, was included in the analysis, assuming the loss rates to be equal to production in Switzerland. Food waste resulting from the production of food for export was not included. Agricultural production was defined as potential crop yield in edible quality at the time of harvest in the present farming system, including inedible parts that are separated later in the food value chain (e.g. apple cores, peelings). For milk and eggs, the point of reference was the edible amount at the time of milking or laying eggs. For meat, it was the whole body of the animals at the time of slaughtering, for fish at the time of harvest. Suboptimal yields due to suboptimal farming systems and losses that are not avoidable with current best available technologies and reasonable extra costs were not accounted for in this analysis.

2.2.5 Assessment of data reliability

The quality of each data source was assessed according to the pedigree matrix used in the ecoinvent database v2.0 (Frischknecht et al., 2007). Losses were defined for each food category and each stage of the food value chain. For loss entries that originate from several references, each reference was assessed separately for its *reliability* and its *temporal, geographical,* and *technological correlation*. However, *completeness* and *sample size* were assessed once for all the references of a loss entry. Assessment details are described section A.5, and an overview of the assessment of each reference can be found in the Tables A.9 and A.10 in appendix A.

2.2.6 Derivation of losses

The following sections describe for each stage of the food value chain how the shares of loss are calculated and estimated. Detailed information about the derivation of food losses for each food category is available in appendix A (section A.4 and Tables A.11-A.12); an overview of the stages of the food value chain from agricultural production to consumption is provided in Figure 2.1.

Storage losses were attributed to the phase in which they occurred. For example, the storage losses of a producer of fresh pasta were attributed to processing, the storage losses of an apple trader to postharvest handling and trade, and the storage losses on farms to agriculture.

2.2.6.1 Production Losses

Losses during crop production are highly variable, depending on the geographical region, season, weather, type of crop, and on its cultivation and harvest method. Due to the high variability and lack of data, it is difficult to determine reliable values. The losses of vegetables, cereals, oils and fats, and the losses of dairy products and eggs were estimated from five farmers from the regions of Basel and Zurich and from Gustavsson et al. (2011), which estimated the average losses for Europe. The fruit losses caused by quality standards in agriculture were estimated by a Swiss fruit trading firm; the losses from fruit trees that are not harvested were ignored. For meat production, the losses due to illnesses were estimated by a farmer (Tannenhof, 2011) and the slaughterhouse waste resulting from the production of pork and beef was based on the measurements of a Swiss slaughterhouse (SBA, 2011). The losses of chicken were based on estimations by the centre of competence of the Swiss poultry industry (Aviforum, 2011).

2.2.6.2 Losses in postharvest handling and trade

The fruit and vegetable losses in postharvest handling and trade were analysed using data from two major trading companies and a minor vegetable trader. The losses for other food categories were roughly estimated, based on farmers' interviews, on data from a supplier of food service settings, and on the FAO's estimates for Europe (Gustavsson and Cederberg, 2011).

2.2.6.3 Processing losses

The estimations and measurements were based on data from eight firms engaged in the fields of vegetable and fruit processing, pasta and sugar manufacturing, baking, and dairy processing. The firms were assumed to be representative for the Swiss market. In other fields of food processing, data from literature and from public institutions was used.

2.2.6.4 Losses in the food service industry

In the food service industry, data from two studies (Andrini and Bauen, 2005, Baier and Reinhard, 2007) and from *SV Group* (SV Group, 2011) was considered. *SV Group* has done measurements of food waste in 225 out of its more than 300 restaurants and bars; Baier and Reinhard's study is based on data from 40 food service installations; Andrini and Bauen's study on data from 20 restaurants. The mentioned studies include restaurants, canteens, bars, cafeterias, care homes, hospitals, and military institutions. Compared to the Swiss average, staff restaurants and canteens are over-represented (Gastrosuisse, 2011; SV Group, 2011). Nevertheless, no correction was made because the losses of the analysed staff restaurants and canteens do not substantially differ from the average losses of all food service installations. However, gourmet restaurants are lacking in the mentioned analysis. Therefore, a separate analysis of the gourmet restaurant *Stucki* was undertaken. The plate and kitchen waste of one day (49 guests) was collected, sorted according to its avoidability, and weighted. The percentage of the waste's weight and the total food consumed was calculated (Stucki, 2011). The losses in the gourmet restaurant *Stucki* were included in the calculation with a weight of 1%, based on the number of restaurants being members of the *Gilde* (178 with 3-4 crowns; Gilde, 2011) relative to the total number of food service installations in Switzerland (21'000 according to Gastrosuisse, 2011). Thus, although the values for the gourmet restaurants are based on only one restaurant, the large uncertainty within this sector will not be important in the overall analysis, due to the small share of 1% within the foodservice sector. Since Baier and Reinhard nor Andrini and Bauen did measure plate waste separately, we assumed the *SV Group's* numbers for plate waste to be representative for all restaurants except gourmet restaurants (Table 2.3).

The allocation of the losses in individual food categories, for plate waste, is based on the analysis of 1'504 canteen guests' plate waste (ETH-Mensa, 2012); for kitchen waste the relative contribution of each food category is assumed to be equal to household waste (details in section A. 3.16).

Table 2.3: Calculation of the losses in the food service industry. The original data is in *kilogram per person per year* and in *gram per meal*. The numbers are converted into *percentage of the total food input into the food service sector (including kitchen waste)*, assuming a portion size of 500 g/average meal (excluding kitchen waste) and a mean consumption of 166 meals/year/capita in food service installations (Baier and Reinhard, 2007, Statistisches_Amt_Aargau, 2009, SV_Group, 2011). Possibly avoidable and avoidable losses include kitchen and plate waste.

Reference	Total losses	Unavoidable losses	(Possibly) avoidable losses	Weight
Baier and Reinhard, 2007	20.6 kg/cap/a	**10 %** (10 kg/cap/a)	**10.6 %** (10.6 kg/cap/a)	33 %
Andrini and Bauen, 2005	19.4 kg/cap/a	**2 %** (1.9 kg/cap/a)	**17.5 %** (17.5 kg/cap/a)	33 %
SV Group, 2011	115 g/meal	**11.7 %** (70.7 g/meal)	**7.4 %** [of which**2.9 %** plate waste] (44.3 g/meal)	33 %
➔ Average		**7.9 %**	**11.8 %** [of which **2.9 %** plate waste]	
Stucki, 2011	396 g/meal	**29 %** (248 g/meal)	**17.3 %** [of which **7.6 %** plate waste] (148 g/meal)	1 %
➔ Total weighted		**8.1 %**	**11.8 %** [of which **2.9 %** plate waste]	

2.2.6.5 Losses in the retail sector

Two supermarket chains and one discounter provided data to estimate the overall food loss in the retail sector. However, data from one of the supermarket chains only was available referring to one major branch; the other loss rates referred to all branches of the chains. The weighted average of the two supermarket chains was calculated, considering the proportions of their volumes of sales. Then, the weighted average of the supermarkets' losses and of the discounter's losses was calculated. The weighing refers to the proportions of the volumes of sales of the two major supermarket chains and the three major discounters in Switzerland. Only one retailer delivered quantitative data about its losses in detailed food categories and referring to all its branches. The relative composition of food losses between these food categories was multiplied to the overall losses to derive loss values per category also for the other retailers.

Particular attention was attributed to fruits and vegetables, because they are especially perishable. Here, we distinguished between losses in the stores and losses in the distribution centres.

The analysis of bread is a special case. Data from this category was derived not only from supermarkets, but also from five bakeries (details in section A.4.15).

2.2.6.6 Losses in private households

Since no analysis of household waste in Switzerland was found, data from two English studies (Quested and Johnson, 2009, defra, 2010) was adapted to the Swiss consumer basket by multiplying the loss rates per food category (Quested and Johnson, 2009, defra, 2010) with the amounts consumed in Switzerland (SBV, 2009). The losses referring to mass were then converted to energy.

2.2.6.7 Allocation to methods of disposal and recycling

Reliable quantitative data about recycling and disposal is scarce in Switzerland. Thus, in the flow analysis, only a distinction between feeding and other losses was made (based on Spycher and Chaubert, 2011, and on SBV, 2009).

2.2.6.8 *Attribution of avoidability*

Each food loss record in the model was attributed to one of the reasons for losses listed in Table 2.4 and thus categorised as avoidable, possibly avoidable or unavoidable. The categories in Table 2.4 were developed during the process of data acquisition. Each new loss record was attributed to one of the previously defined reasons. Sometimes the attribution was evident. For example, unsold products in retail, that were wasted because they had been stored for too long, were classified as avoidable. In other cases, the allocation was less obvious. For instance, in the sorting process of apples, the distinction between rotten apples and apples sorted out because of aesthetical imperfections not tolerated by the quality standards is subjective. In some cases, quantitative information for the allocation was available, e.g. to distinguish the amount of plate waste and of inedible parts in the food service industry. However, most of the allocations were based on qualitative information from interviews with the experts providing food loss data (experts from the organisations listed in Table A.1 in appendix A). The boundary between edible and inedible food is often subjective. Tables A.11 and A.12 link each loss to a reason and to its avoidability. Detailed explanations can be found in section A.4.

Table 2.4: List of reasons for food losses considered in this paper, categorized by avoidability. Each loss record in the model was attributed to one of these reasons and thus defined as avoidable, possibly avoidable or unavoidable. The measures to avoid losses represent an incomplete set of suggestions from the authors. It should be further analyzed how realistic the implementation of individual measures is.

Reason for losses	Description	Measures to avoid losses
I Avoidable losses		
purchased too much	buying more than is consumed before the food is no longer good to eat or runs past its consumption date	pre-shop planning, avoid temptation of special offers and large portions
left over after cooking	cooking more than is consumed before the food is no longer good to eat or runs past its consumption date	reduce cooking and warming portions
left over after meal	plate waste after meals, excluding inedible parts (bones…)	reduce plate portions to the amount the person is sure he or she wants to eat
stored for too long	food decreased in quality, went mouldy or ran past consumption date	optimize consumption prevision; ad-vance booking; reduce the range of perishable products; donate; process-ing of products before running past consumption date; optimize storage conditions
• too long on the retail shelves	decreased quality, rotting (mainly fruits and vegetables)	
• out of use-by /best-before date	out of date because of being stored for too long in the retail shelves due to lower-than-expected demand or surplus stocks	
• out of sell-by date		
not harvested because of low demand	crops not harvested because of low demand (mainly for highly perishable fruits and vegetables with little possibilities to be processed and with peaking crop yields, e.g. raspberries)	consumers should be well informed about the seasonal offers AND consume in accordance with them
over-production	to produce more than what can be consumed (served, sold, eaten) before the product goes off	reduce production and preparation portions of perishable products and complement the offers by long-life or quickly prepared products; find distribution channels for surplus food
"surplus" cocks	male chicken in egg production (they are often gased, because meat production is less profitable with laying hens than with broilers)	financial support of meat production with laying hens (hybrids); sex determination of eggs (currently under research)
change in the production line	during the phase of switching from one product to another in a production line, unpure products can result (e.g. ravioli containing both spinach and mushrooms)	reduce the frequency of product switches; find distribution channels for unpure products
method of processing	losses due to suboptimal method of processing	apply best available technology

II Possibly avoidable losses		
taste preferences	wastage of edible parts of food because the person doesn't like its taste or smell or because of inappropriate methods of preparation (e.g. bread crust, potato skin, offal)	adopt various methods of preparation; be less delicate; give unfavoured parts of food to other people
no demand because of reduced quality	too long storage because of inferior quality (irrelevant in terms of food safety) and thus little demand, al-though the demand for this type of product is present (often aesthetic aspects)	consumers: be less delicate and choosy; sellers: price reduction of substandard products
quality sorting	sorting out products because of high quality standards, although the products would be edible and healthy (often aesthetic aspects)	find distribution channels for inferior quality (processing, price-reduction, donations)
III Unavoidable losses	**Description**	
basic food sorting	sorting out inedible products (generally inedible, not due to deterioration after harvesting)	
manual harvesting	losses associated with a specific, manual method of harvesting, not avoidable with reasonable extra costs (see also section A.4.19)	
technical harvesting	losses associated with a specific, technical method of harvesting (best available technology)	
contamination	disposal of contaminated products	
illness	disposal of food due to crop or livestock illnesses	
storage problems	deterioration due to storage problems despite best available storage conditions (e.g. plant disease, mould)	
failure	deterioration due to a failure during preparation (e.g. burnt bread)	
transportation	deterioration due to transportation damage (despite best available technology)	
inedible parts (apple cores, meat bones…)	separation of inedible parts	
method of processing	losses caused by a specific method of processing, applying best available technology (e.g. weight loss of baking, by-products of apple juice production)	
weather conditions	damaged food due to bad weather conditions	

2.2.7 Mass and energy flow analysis and quantification of food efficiency

Data from firms of the food value chain were always specified as losses relative to the mass input and expressed in percentages. An overview of the losses in each food category and at each stage of the food value chain is displayed in Tables A.11 and A.12. To model the absolute mass and energy flows for the supply of the Swiss food demand, including the net imports, data about Swiss food consumption had to be quantified for each of the 22 food categories analysed in this paper (see Table 2.2). Most data originates from the Swiss Farmer's Union (SBV, 2009) and refers to consumption at the retail level (input to households and to the food service industry). The share of home consumption versus consumption in the food service industry was derived in section A.2; feed flows were based on the Swiss feed balance (SBV, 2009) and on Spycher and Chaubert (2011).

The mass flows were defined as fresh substance. They were also converted into energy flows indicating the energy available to human bodies. Data about the calorific content was taken from the Swiss Farmer's Union (SBV, 2009), from the feeding recommendations and nutritional tables for ruminants (Arrigo et al., 1999), and from a nutrient database (Yazio.de, 2011). The calorific content of slaughtering waste of cattle, swine, broilers, and laying hens was estimated based on its main components.

The food flows were calculated in Excel and then exported to STAN 2 (Cencic and Kovacs, 2007).

The efficiency of vegetarian products from harvest to final consumption depends on the amount of food loss in the food value chain. The efficiency of meat products, in contrast, first depends on the ratio of calorific output of the animal products for human consumption and the calorific input of the feed consumed by livestock. For poultry, for example, the analysis was based on typical feed consumption and typical meat yield per chicken. In the case of dairy and egg production, the output of the meat resulting as by-product was included in the reported efficiency. The subsequent losses in the food value chain, again, were calculated using data from the energy flow analysis.

2.3 RESULTS AND DISCUSSION

2.3.1 Energy flow analysis of all food categories

The energy flow analysis reveals that total crop production (food and feed, including foreign production for import to meet the Swiss food demand) amounts to 165’000 TJ per year. From this, 130’000 TJ (79%) are used as feed for animal production and only 32’400 TJ (21%) constitute the production of plant-based food. The comparison of the outputs of plant-based food and animal products, excluding the losses at the stage of production, gives the opposite pattern. Here, animal products only contribute 12’000 TJ (9% of the energy of the feed consumed). So, from the total agricultural output of plant-based and animal products, plant-based products make up 73% and animal products 27%, in term of energy supplied for human diets.

The highest absolute losses occur at the stage of processing. However, these losses are mainly unavoidable (see section 2.3.2.3) and, in the end, mostly used for feeding. Households produce the highest losses that are not used for animal feeding. The final intake makes up only 16% of the calories of the food and feed grown on agricultural lands (Figure 2.1).

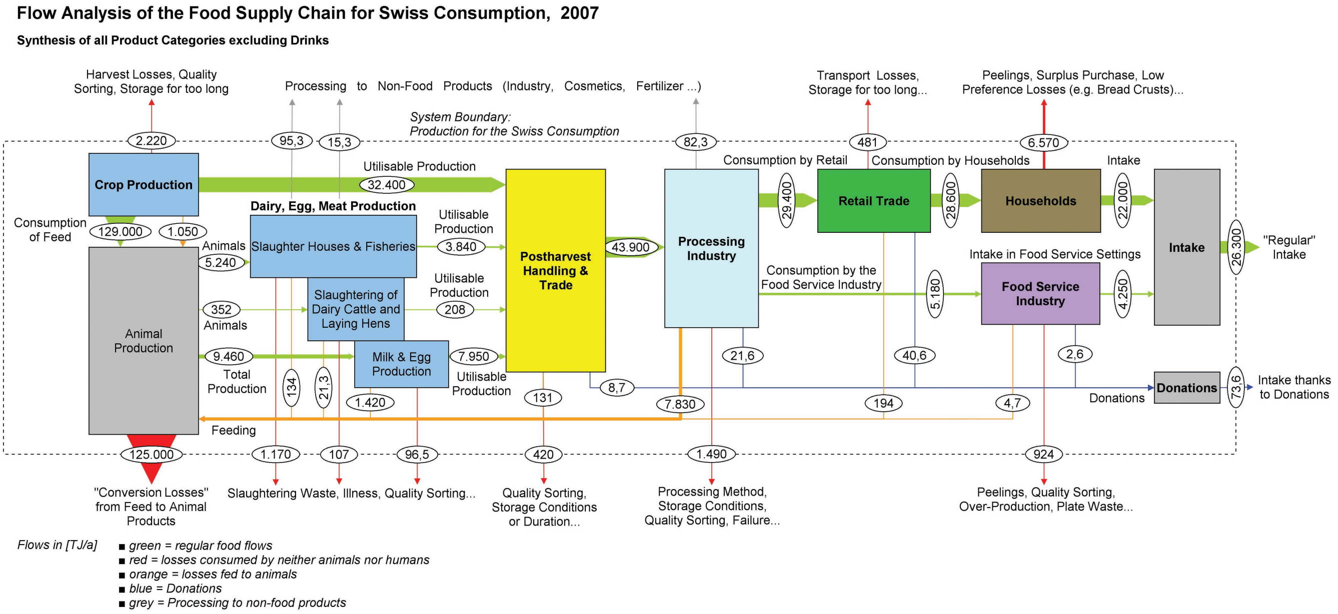

Figure 2.1: Energy flow analysis of the food value chain destined to meet the Swiss food demand, including the net import of products. Green arrows illustrate the regular food flows leading to human consumption. Orange arrows represent food losses directed to livestock feed, grey arrows losses used for the generation of non-food products, red arrows display the remaining food losses, and blue arrows the food that is donated. The numbers are defined as TJ/a. The dotted line shows the system boundary, the boxes the stages of the food value chain.

The energy balance in Figure 2.2 shows that from the net output of the stages agricultural and animal production (50’833 TJ), including slaughtering waste and postharvest losses, around 52% is finally ingested, while around a quarter is (theoretically) avoidable food loss. From this, nearly half is in perfect quality and discarded because of inefficient delivery from producer to consumer.

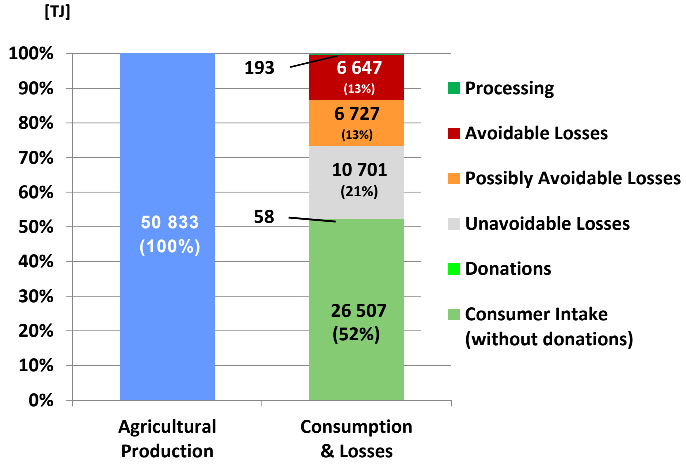

Figure 2.2: Energy balance of the food produced to meet the Swiss food demand. The left column shows the net output agricultural and animal production, including slaughtering waste and inedible parts that are removed later in the production chain. In the right column, food consumption and food losses are displayed. Avoidable losses refer to inefficient distribution (mainly spoilage), possibly avoidable losses to unsatisfied quality standards. The category "non-food use" refers to losses used for manufacture of non-food products (e.g. cosmetics, leather, fertilizer).

2.3.2 Losses at each stage of the food value chain

In this section, all loss values refer to the calorific content and are expressed as percentages of the input into the correspondent stage of the food value chain.

2.3.2.1 Production losses

In the production of plant-based and animal products, including slaughtering and fishing, the losses are estimated at 14%, thereof 5.5% being avoidable or possibly avoidable. The unavoidable losses are mainly technically induced harvesting losses and, for animals, slaughter waste. The avoidable and possibly avoidable losses are mainly caused by high quality standards and by unpredictable demand of fresh, perishable products.

2.3.2.2 Losses in postharvest handling and trade

The losses in postharvest handling and trade (e.g. damaged products from transportation or apples rejected due to unsatisfying quality) are estimated at around 1%. They are relatively low thanks to high technological standards in Switzerland.

2.3.2.3 Losses in the processing industry

The analysis reveals losses of processing of 21% in terms of energy, thereof 7% being avoidable. Avoidable losses mainly consist of wheat (high quality standards for baking), rice, whey, buttermilk, and other products with low demand. Besides quality criteria, the main reasons for losses of fresh products are assumed to be suboptimal organisation and coordination between actors, and high consumer expectations concerning the availability of a broad range of products.

2.3.2.4 Losses in the food service industry

The average food losses in the food service sector are estimated at 20% (Table 2.3). However, the losses vary up to a factor of 10 (Baier and Reinhard, 2007).

The amount of food losses is not suitable as a sole indicator for the potential to reduce food losses. Only a more detailed analysis of the restaurant, distinguishing between avoidable and unavoidable food losses, between kitchen and customer plate waste, and analysing the reason for losses, allows one to deduce measures how to reduce food losses. As an example, the losses of the analysed gourmet restaurant amount to more than 200% of the estimated average losses (Table 2.3). However, 44% of the losses in the gourmet restaurant are associated with the production of meat sauce (mainly bones); an additional 23% are inedible parts of fruits and vegetables. So, a large fraction of losses is unavoidable. This can be explained by the special preparation method of meat sauce, the preparation of fresh products, and by the high proportion of exotic fruits associated with large inedible parts (Stucki, 2011).

2.3.2.5 Losses in the retail sector, including bakeries

In supermarkets and discounters, the rate of unsold products is a good indicator for food losses because the fraction of unsold food that is not lost thanks to donation is less than 5%[1]. The rate of unsold food products varies between 1 and 5% between the retailers analysed, with an average of 2.2%. However, for individual food categories the range is larger (between 0 and 12%) and the rate for single products can be much higher, especially for rare and perishable products with high fluctuations in demand.

In small shops the rate of unsold products tends to be higher, mainly because of lower sales volumes and higher fluctuations in demand. Nevertheless exceptions exist, e.g. in the analysed whole food shop, where most unsold products are donated or distributed to staff.

The analysis of the fruit and vegetable logistics centre of a major retailer shows that the losses between producer and retailer are relatively small for fresh fruits and vegetables. Between 0.35 and 0.44% of the delivered products are lost due to damages during transport and due to spoilage and unsatisfied quality standards. Compared to the losses in the stores (8-9%), they are of minor relevance. One reason for the small loss fraction is, however, that most substandard products are already sorted out earlier in the food value chain, i.e. in the agricultural sector.

For bread and pastries, the average losses are estimated at 3-7%, with an average of 5.1%. The results show that the losses are variable, depending on bakery size, location, strategy, and variety of products. One city bakery with between 20 and 30 branches estimated its losses in the major branches at 5%, in the smaller branches up to 20%, with average losses of 8%. Thereof, 1.6% are reused in their own production (e.g. as bread crumbs) and 0.4% are donated. The remaining 6% are fed to livestock. An old, traditional bakery with a narrow range of steady customers has kept its original philosophy not to overproduce. Most unsold products are consumed by the staff or reused. The losses fed to animals were roughly estimated at 1% of the volume of sales.

This data is coherent with estimations from two supermarkets, where the baked goods that are written off were in the same range. However, the rate of losses fed to animals has decreased since a new legislation was introduced in July 2011. In this analysis, it is assumed that 15-20% of the retail losses are used for biogas (based on BLW, 2010).

2.3.2.6 Losses in private households

Losses in households were estimated from a study conducted in the UK (Quested and Johnson, 2009). We assumed that Swiss households waste the same proportions as UK households in each food category. Considering the Swiss consumer basket and the average calorific content of each food category, 23% of the energy of the food purchased are wasted. From this, 16% is avoidable, 5% possibly avoidable, and 2% unavoidable. The food categories with the highest avoidable losses are bread and pastries, potatoes, unprocessed vegetables, apples, rice, and pasta (31-39%). A table with all the values is displayed in section A.4.16. Overall, households produce 45% of all the avoidable losses across the food value chain (Figure 2.3).

These food loss amounts are higher than the avoidable losses reported by Quested et al. (2009). This is mainly explainable with drink waste, which is included in the UK study, but not in this study. Moreover, the percentages in this study refer to the calorific content of the food, whereas Quested's numbers refer to mass.

However, the losses reported by Cofresco (2011) are significantly lower (12% of the food purchased, without unavoidable losses). A reason for the differences may be the method of data acquisition. Unpublished analysis by WRAP indicates that quantities of waste recorded in diaries are approximately 40% lower than those obtained from analysis of waste streams (Quested and Johnson, 2009).

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[1] In one of the most progressive supermarket chains in Switzerland in terms of food donations, the amount of donated food is estimated around 5% of the unsold products, assuming an average food price of 10 CHF/kg.Hence, the Swiss average of food donations in the retail sector is expected to be lower than 5% of the unsold products.

2.3.2.7 Food donations

In Switzerland, most donations are organised by four institutions. In 2009, around 8,000 t of food were donated. In the same year, the Swiss food consumption amounted to 5,400,000 t (SBV, 2009). Consequently, the food donations accounted for 0.15% of the mass of the food consumed at the retail level (consumption of households and the food service industry). There is a high potential to increase food donations (Tdd, 2011).

2.3.3 Comparison of food losses at the various stages of the food chain

As shown in Figure 2.3 the largest contribution to food losses occurs in households and in processing with a waste share of more than 20% of their input. However, nearly two thirds of the losses in processing are unavoidable, while most of the losses in households are avoidable. The second largest contribution to the avoidable losses, relative to the input, is caused by the food service industry (12% of the food purchased). Nevertheless, the contribution to the total avoidable losses is only 5%, because food service outlets only consume 15% of the food, while 85% is consumed in households (section A.2). The avoidable losses in agriculture account for 18%. This fraction is in reality higher than indicated here, since crops remaining unharvested are not included in this model due to lack of data. Retail and trade losses are low thanks to technological measures and a high level of organisation in Switzerland.

In the case of fresh vegetables, the avoidable losses in agriculture and households are much higher than the average losses for the other food categories. The main reason is the gap between supply and demand, which results from their unpredictability and from the high perishability of fresh vegetables. The latter is also the main reason why 38% of the edible parts purchased are thrown away by households.

Avoidable cereal losses in the food value chain of bread and pastries are primarily caused by quality sorting in mills and agriculture. Since most of the substandard breadstuff is fed to livestock, these losses are ecologically less relevant. In contrast, many of the losses at home and in restaurants are entirely lost.

In the case of eggs, households contribute more than three quarters to the avoidable losses. However, the total losses are relatively low. This is typical for animal products, since they are generally more expensive. The avoidable losses in agriculture primarily result from meat of laying hens, which is in lower demand than poultry.

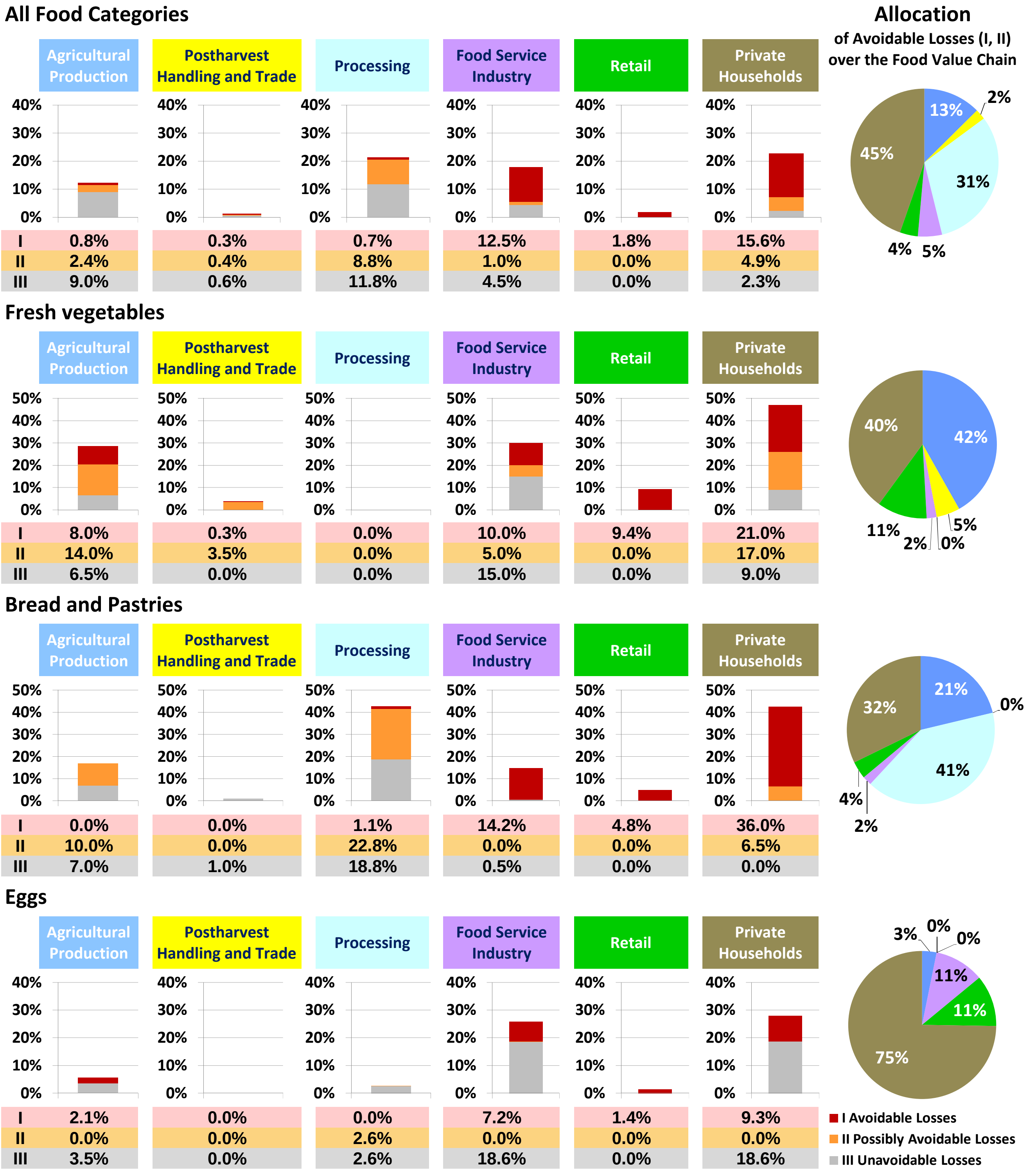

Figure 2.3: Losses at each stage of the food value chain, in percentage of the food input into the corresponding stage. In the case of agriculture, the food input corresponds to the amount of edible food that could be harvested at harvest time. Grey are unavoidable food losses, orange possibly avoidable, and red avoidable losses. The results are shown for all food categories (graphs on the top) and for three characteristic food categories associated with relatively high loss rates (fresh vegetables, bread and pastries, and eggs). The pie charts on the right hand side show the relative contribution of the avoidable losses at each stage of the food value chain to the avoidable losses over the entire food value chain. All values refer to the calorific content of the food.

2.3.4 Total potential

Generally, there are two approaches to improve the efficiency of the food value chain with current best available technology. The first approach is an optimisation of the distribution system from the point of production to the consumer. The theoretical potential for increasing food availability with this measure is 25% relative to present food energy consumption. Secondly, 25% more calories could be saved for human intake if all the edible parts of the products were eaten and appropriate methods of cooking and preparation were adopted (e.g. recipes for bread from previous days). In total, with these measures, 50% more food calories could be available for consumption from the same agricultural land as today (Figure 2.4).

A third, long term approach to improve the efficiency of the food value chain is technology improvement and innovation. However, the corresponding potential of reducing food losses is not quantified in this paper.

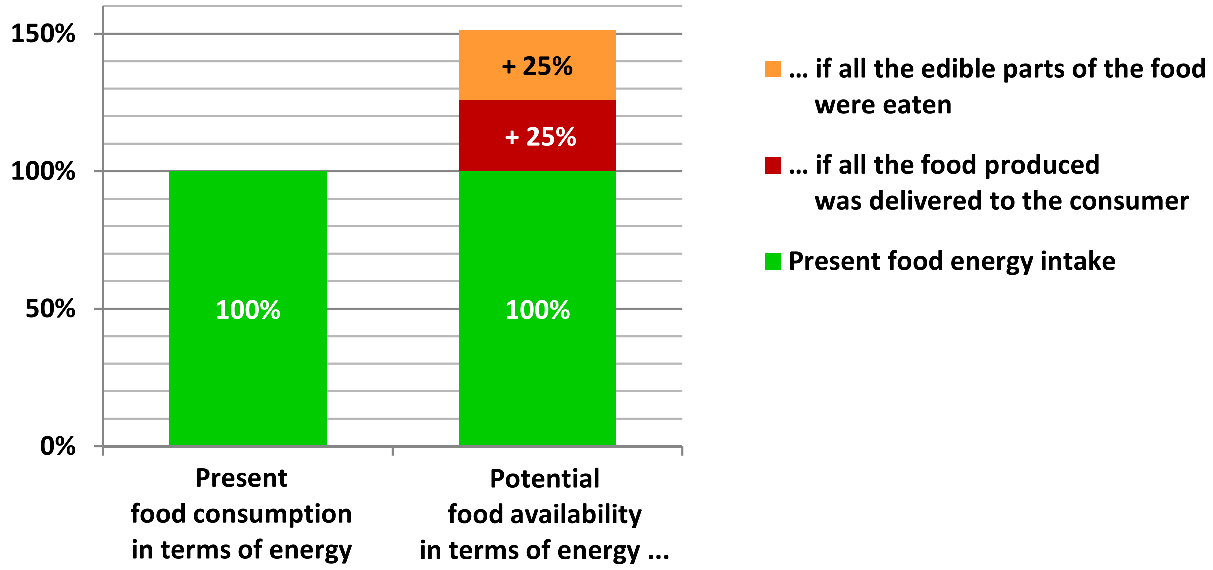

Figure 2.4: Total potential of avoiding food losses in Switzerland (without technology improvement beyond current best available standard): In a theoretical scenario of perfect distribution and the use of all the edible parts of the food 150% of the presently consumed food calories would be available for consumption.

2.3.5 Data reliability and uncertainty

The pedigree matrix for uncertainty estimation reveals uncertainty factors between 1.11 and 2.02 for the losses in different food categories and at different stages of the food value chain (Tables A.9 and A.10). The overall losses in retail are considered most reliable, followed by household losses and foodservice losses. The highest uncertainty is attributed to the losses of eggs, sugar, canned fruits, and cereal products at the stages of agricultural production, postharvest handling and trade, and processing. The losses in the processing industry are uncertain because they vary fundamentally between different products, methods of processing, and external factors. For example, the quality losses of cereals are very variable from year to year, depending on weather conditions and quality standards (SBV, 2011).

Household food losses have been analysed in several countries, but only the UK study is based on both a representative number of households and on measurements instead of only questionnaires (Sonesson et al., 2005, Pekcan et al., 2006, Sibrián et al., 2006, Quested and Johnson, 2009, Thönissen, 2009). According to Stuart (2009), consumers substantially underestimate their losses when self-reporting. Thus, there is a lack of reliable data about the variation of household food waste amounts in different European countries. However, there are significant disparities in food habits across European countries. For example, southern European populations generally consume greater amounts of cereals, fish and seafood, and fresh fruits and vegetables than the rest of Europe (Trichopoulou et al., 2002). These food categories are correlated with higher-than-average household losses, leading to the hypothesis that household food waste varies from country to country.

Furthermore, major data uncertainty lies in the losses in agricultural production (especially for fruits and vegetables), in the fishing industry, and in the processing sector. These sectors are very heterogeneous and therefore require extensive individual analyses for different food categories. The estimations of agricultural losses were based on five Swiss farmers' interviews and on values from literature, the latter referring to Europe. In the processing sector, the losses in cheese production, pasta production, bread baking, and vegetable and fruit processing were estimated and partially measured by six firms of the Swiss food industry. For the remaining food categories, the losses in processing were based on literature (details in Tables A.9 and A.10 in appendix A). However, more farms and processing companies should be analyzed in order to get reliable results.

Loss data in the retail sector is relatively reliable. However, discount supermarkets are underrepresented in the current analysis and quantitative data from small retailers is lacking, even though they are assumed to be heterogeneous in terms of food losses. A more detailed analysis of discounters and of a representative number of small retailers would be desirable.

The food loss rates of imported products can differ substantially from those of Swiss products. Losses that were due to cross-boundary transport were considered in the present paper, as these were reported by the retailers and distributors, but not the losses that occurred at the production site. However, the differences in weather, climate, and soil mainly affect the unavoidable losses. The potential for the reduction of food losses is expected to depend mainly on the Swiss consumers' expectations and the retailers' quality standards that do not differ between imported and Swiss products. Nevertheless, in a future analysis the losses of imported products should be analysed separately.

The total avoidable losses estimated in this paper (299 kg/cap/a) are consistent with FAO's estimate of 280 kg/cap/a for Europe (Gustavsson and Cederberg, 2011). While these overall figures and the result that household losses make up the major part of the losses are rather robust, further studies are needed to further narrow down uncertainties for individual stages and food categories.

2.4 CONCLUSIONS AND OUTLOOK

Roughly one third of the edible calories produced for Swiss consumption are lost over the whole food value chain. Thus, reducing food losses is an effective way to increase efficiency and reduce the environmental impact of food consumption.

The ecological relevance of food losses does not only depend on the amount, but also on the type of food, where in the food value chain it is lost, and how it is recycled or disposed of. For example, carrots remaining in the fields are ecologically less relevant than carrots wasted by households after being transported, stored, packaged, and processed. Cereals sorted out in mills and used for feeding are less relevant than the same amount of baked bread thrown to waste in a restaurant. Therefore, food losses should not only be quantified, but also evaluated by life cycle assessment. This would allow more accurate quantification of the environmental benefits of reducing food waste and help us define fields of priority.

However, measures to avoid food losses have to be taken at all stages of the food value chain. The implementation of measures requires all actors to be involved, including the government. This is particularly so because some food losses are not only caused in the stage where they arise. The consumers' expectations concerning aesthetic characteristics, freshness, remaining duration of storage, variety and availability cause many good products to be rejected (Göbel et al., 2012). For example, fruits and vegetables rejected in agricultural production are a consequence of cosmetic standards defined by the trade sector. These standards, in turn, are partly developed according to customers' preferences. Therefore, an effective reduction of food losses is often only possible if several actors collaborate. Food donations are another measure to reduce food losses and they are socially and ecologically highly beneficial. However, donations alone cannot solve the problem of food losses, mainly due to logistic, political, and hygienic limitations.

As already confirmed by previous studies (Quested and Johnson, 2009), households are the major source of food losses. Thus, consumer awareness, good planning, and correct storage of food are crucial. Since food loss amounts highly depend on agricultural infrastructure, food processing technologies, climatic conditions and income, the results of this analysis cannot be simply extrapolated to developing countries, but the methods used could be applied to these regions. However, for developed countries with similar climatic and economic conditions as Switzerland, the results of this analysis could be an indication for their scale of food losses.

More research is required to understand and solve the problem of food losses. This should not prevent us from taking immediate measures to avoid food losses already now. For example, even without a more detailed environmental assessment, it is clear that waste in the households is highly relevant and often unnecessary and, thus, should be reduced.

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CHAPTER 3

ENVIRONMENTAL IMPACTS AND HOTSPOTS OF FOOD LOSSES: VALUE CHAIN ANALYSIS OF SWISS FOOD CONSUMPTION

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ABSTRACT

Reducing food losses and waste is crucial to making our food system more efficient and sustainable. This is the first paper that quantifies the environmental impacts of food waste by distinguishing the various stages of the food value chain, 33 food categories that represent the whole food basket in Switzerland, and including food waste treatment. Environmental impacts are expressed in terms of climate change and biodiversity impacts due to water and land use. Climate change impacts of food waste are highest for fresh vegetables, due to the large amounts wasted, while the specific impact per kg is largest for beef. Biodiversity impacts are mainly caused by cocoa and coffee (16% of total) and by beef (12%). Food waste at the end of the food value chain (households and food services) causes almost 60% of the total climate impacts of food waste, because of the large quantities lost at this stage and the higher accumulated impacts per kg of product. The net environmental benefits from food waste treatment are only 5-10% of the impacts from production and supply of the wasted food. Thus, avoiding food waste should be a first-line priority, while optimizing the method of treatment is less relevant.

3.1 INTRODUCTION

Twenty to thirty percent of the environmental impacts of an individual's consumption are caused by food (Tukker et al., 2006). At the same time, approximately one third of all food produced for human consumption is lost or wasted (Gustavsson and Cederberg, 2011). According to Ceren et al. (2016) the **amount of avoidable food waste and losses (FW)** is **growing** globally, with non-CO_2 greenhouse gas (GHG) emissions (CH_4, N_2O) having increased by more than 3 times from 1965 to 2010. The ongoing expansion of cropland and pastures, that is driven by FW among other things, is a primary source of ecosystem degradation and biodiversity loss (e.g. Donald and Evans (2006)). With respect to climate change, not only agricultural production, but also emissions from consumer transport of purchased food and consumer preparation can have a large impact on overall results (Schott and Cánovas, 2015). Therefore, it is relevant to know at which stage of the food value chain (FVC) the food is wasted (Parfitt et al., 2010).

The direct global **economic cost** of total FW is about USD 1 trillion each year. In addition, environmental costs reach around USD 700 billion and social costs around USD 900 billion (FAO, 2013). As negative environmental, social and economic impacts of FW are becoming more apparent, tackling the problem of FW is increasingly crucial to achieve more sustainable consumption (Papargyropoulou et al., 2014).

In recent years several countries have attempted to quantify FW at different levels of the FVC. Recent studies for FW **quantification** have been done in Austria (Schneider et al., 2012), Germany (Kranert et al., 2012), the UK (Quested et al., 2013) for the household level and in Norway for the whole FVC (Hanssen and Møller, 2013, Hanssen et al., 2016). In Switzerland we analyzed FW across the whole FVC in 2012, based on primary data from 43 companies and institutions and data from literature (Beretta et al., 2013).

The FAO quantified the carbon footprint of the production of wasted food at 700 kg CO_2-eq/cap/a on a continental and global level, without benefits from FW treatment (FAO, 2013). Scherhaufer et al. (2015) estimate the **environmental impacts** of FW with LCA at the EU level. These studies identify environmental data on a product category level and data on recovery and disposal options for FW, especially for the valorization as animal feed, to be relevant data gaps for further research.

A study analyzing the environmental impacts of FW **over the whole FVC that distinguishes the stages of the FVC, detailed food categories, and includes FW treatment**, is still lacking in literature. Therefore, the goal of the present paper is to update the mass flow analysis by Beretta et al. (2013), to complement it with an environmental assessment of the complete FVC (agriculture, trade, processing, retail, food services, households) and FW recovery and treatment, and to compare the results with literature (Appendix B.12). This helps to identify the most relevant FW flows, as a basis to develop effective measures to lower the impact of FW in the future.

3.2 METHODS

3.2.1 Definition of food waste

In this paper FW refers to food which is originally produced for human consumption but then directed to either a non-food use or waste disposal. In contrast to the FUSIONS definitional framework (Östergren et al., 2014), food diverted to animal feeding is included due to its environmental relevance (the production of the food is usually more environmentally relevant than the production of the feed which can be substituted). Unavoidable FW, which cannot be avoided with realistic efforts and current technologies (e.g. losses from cleaning production lines using best practice methods) or which consists of inedible parts of food (bones, shells, peels, residues), is per definition not considered in the potential of food waste prevention (more details in the definitions on page xvi).

3.2.2 Modeling the food value chain

In order to quantify the environmental impacts of FW and to compare them with the impacts of food consumption, we created a model of the whole Swiss food value chain (FVC), covering agricultural production (including fishery), trade, processing, retail, the food service sector, private households, and FW disposal.

The first part of the model consists of a **mass and energy flow analysis** of all the food that is consumed in Switzerland. This approach covers FW in foreign agricultural production of imported products and excludes Swiss FW related to exports, with the advantage that the per capita results can be compared with other countries without distortion between net importing and net exporting countries (Chapagain and James, 2011). The mass flow analysis (MFA) of Beretta et al. (2013) was updated, integrating recent literature and distinguishing 33 instead of only 28 food categories (Appendix B.1.1) because of substantial differences in environmental impacts and FW amounts between these additional categories (exotic/citrus table fruits and juices, legumes, nuts/seeds/oleiferous fruits, cocoa/coffee/tea). Major updates related to FW in agricultural production of exotic fruits, in milk, dairy, and cereal processing, in the FVC of potatoes, in the retail and the food service sector, and the mass flows for FW treatment (Appendix B.1.2). The reference period for food consumption is 2011-2012.

The second part of the model consists of a **life cycle assessment (LCA)** of the FVC and FW treatment, using the software *Simapro 8.2* (Pré, 2016) and additional Excel calculations for the assessment of land and water use impacts. We use attributional LCA because of our primary goal to quantify the present environmental impacts of FW and to identify current environmental hotspots of FW. We mainly base our **life cycle inventories (LCI)** on the LCA databases *ecoinvent 3.2 "allocation recycled content"* (www.ecoinvent.org), *World Food LCA Database 3.0* (Bengoa et al., 2015), *Agri Footprint 2015* (www.agri-footprint.com), *AGRIBALYSE v1.2* (www.ademe.fr), a food inventory collaboration with *ZHAW* and *Eaternity* (Kreuzer et al., 2014, Eymann et al., 2015), and data from the *Swiss Federal Office of Energy SFOE (Dinkel et al., 2012).* The *World Food LCA Database, which includes datasets not yet published in ecoinvent 3.3,* and *AGRIBALYSE* are linked to the *ecoinvent 2* database, which may provide some inconsistency. However, the differences between *ecoinvent v2* and *v3.2 "recycled content"* are irrelevant for most agricultural products (Steubing et al., 2016). For **agricultural food production**, most LCA datasets listed in Appendix B.3.1 are used in their original version, however some are modified according to the methodology documented in the subsequent sections and Appendix B. **Land occupation data** is taken from Pfister et al. (2011) for food crops and animal feed. For animal products, pasture and crop land occupation is calculated based on Scherer and Pfister (2016) **Blue water consumption** (irrigation water from surface or groundwater resources) is based on Pfister et al. (2011) and Pfister and Bayer (2014).

Water use (34 l/kg) and electricity consumption (18.8 MJ/kg) in **food services** are estimated based on data from SV Group (SV_Group_AG, 2015), and include cooking, cooling, ventilation, lighting, and cleaning based on measurements in 15 gastronomic businesses. The numbers tend to be over-estimated, since total electricity and water use (including cafeteria, production of snacks, desserts etc.) are allocated to the main meals only. The average portion of main meals is estimated at 500g (SV_Group_AG, 2017). The transport distances are also based on estimations from SV Group, where half of the food is delivered by the main supplier over an average distance of 90 km by a chilled 18t lorry and the rest by local suppliers over an estimated distance of 45 km by 3.5-8t lorry, half of it as chilled transport.(SV_Group_AG, 2017) Load factors are taken from *ecoinvent 3.2* and the *World Food LCA Database 3.0*.

Electricity consumption at **household** level is based on a survey among 1200 Swiss households, analysing cooking, baking, refrigerating, freezing, and dish washing (Huser et al., 2006). As a simplification, the minority of Swiss households that cook with gas or wood is not modeled separately. Infrastructure is not included, since it was found not to be relevant in the mentioned household activities (Bengoa et al., 2015). The main four means of transport for shopping (car, bus, tram, bicycle) are modeled, covering 89% of the shopping tours. The remaining 11% is done by foot, train, motorcycle, and others. The distances are based on data from the *Swiss Federal Statistical Office* (BFS, 2012). Half of all the rides for shopping are assumed to be done for food purchases and allocated to food products proportionally to mass. The resulting shopping distances are 1.1 km/kg of food by car, 0.14 km/kg by bus and tram, each, and 0.03 km/kg by bicycle (Appendix B.3.2.3). The methodology and assumptions for the life cycle assessment in **transport**, the **processing industry**, and in **retail** are described in Appendix B.3.2.

The inventory of **FW treatment** is mainly based on *ecoinvent 3.2* (ecoinvent, 2016) and LCA datasets published by the *SFOE* (BFE, 2011, Dinkel et al., 2012), which are adapted to individual food categories. We apply system expansion (avoided burden approach) for useful co-products of FW treatment. As reference systems for the substitution, we use the Swiss electricity consumption mix, heat from natural gas, fertilizer (inorganic nitrogen [N], phosphorus [P], and potassium [K]), peat (improved soil effect), and animal feed for swine. The substitution of forage is modeled with an optimization tool defining an optimal feed mixture of barley, wheat, soy grits, phosphate, and lysine supplements (Vadenbo et al., 2016). For incineration we assume average electric and thermal efficiency of Swiss incineration plants, for anaerobic digestion we model the biogas yield and then calculate the electricity and heat output according to typical Swiss facilities. Individual food categories are differentiated based on energy and water content. For anaerobic digestion and composting, inorganic fertilizer is substituted based on the content and the utilization rates of N, P, and K for compost, liquid, and solid digestate. The improved soil effect is quantified with peat substitution in growth media based on typical compost densities. Peat and fertilizer substitution in private gardens is based on surveys reporting utilization and replacement rates (Andersen et al., 2010, Andersen et al., 2012). As a simplification, FW arising in the FVC of imported products is assumed to be treated equally to FW arising in Switzerland. Since the corresponding processes are of minor relevance for the overall results, this simplification was deemed acceptable. The contribution of different components of FW treatment (e.g. substitution of heat, energy, peat, heavy metal emissions, etc.) to the environmental impacts and benefits of different FW treatment options (composting, anaerobic digestion, feeding) is documented in the Appendix B.4.3.

3.2.3 Allocation of environmental impacts to food consumption and losses

A part of the environmental impacts of agricultural food production is allocated economically to by-products (e.g. leather, fish bycatch, bonemeal fed to animals). The other impacts and the impacts of the supply of food and the treatment of the unavoidable FW are then attributed to consumption and losses proportionally to the metabolizable energy of the consumed food and avoidable FW. The impacts and benefits of the treatment of the avoidable FW are fully allocated to the losses since they would be avoided with FW prevention (Appendix B.2.2).

Metabolisable energy is a relatively good, simple measure for the original nutritional value of wasted food and for how much food can be substituted by avoiding FW (avoided burden approach). Economic allocation would not be appropriate in the case of FW, because FW does not have market prices reflecting its potential value for consumers. We assume that the wasted products originate from the same mix of countries as the consumed products within a food category. The impacts attributed to FW depend on the stage of the FVC where the food is lost, since the impacts of the upstream FVC up to the point where the wasted food is accounted for, in addition to the impacts of the treatment, and the credits from substituted products (fertilizer, animal feed, etc.) are attributed to the losses (Appendix B.2.2).

3.2.4 Life cycle impact assessment (LCIA)

The LCA is completed for climate change impacts with the methods ***global warming potential 100a*** (IPCC, 2013) and ***global temperature change potential 100a*** (Frischknecht et al., 2016), and for the ***regionalized land and water impacts on biodiversity***. Biodiversity loss was assessed here because it is the planetary boundary most exceeded (Steffen et al., 2015) and because land and water use are primary drivers of biodiversity loss (Millennium-Ecosystem-Assessment, 2005). Agricultural activities for producing food are the dominating driver of both land- and water-use impacts (Ramaswami et al., 2016), and, hence, these impacts are essential to assess in the context of FW. In choosing these indicators, we also follow the recent global guidance document of the UNEP-SETAC Life Cycle Initiative on Life Cycle Impact Assessment (Frischknecht et al., 2016) for two of the indicators used in this study (climate change according to IPCC (IPCC, 2013) and land-occupation biodiversity impacts according to Chaudhary et al. (2015), using the updated country-aggregated characterization factors published in Frischknecht et al. (2016)). For Water consumption we deviated from these guidelines in order to be able to use a method that is compatible to the land-use assessment (Pfister and Bayer, 2014, Scherer and Pfister, 2016) and to keep the discussion to two main indicators. In Appendix B we additionally provide the LCIA results for ***eutrophication***, which is also an important category for agricultural products, as well as the aggregated LCIA scores according to the method ***Recipe*** (Goedkoop et al., 2013) and ***Method of Ecological Scarcity*** (Frischknecht et al., 2013) (Appendix B.4.1). ***Global biodiversity loss*** considers endemic species richness and is expressed in global potentially disappeared fraction of species (gPDF) (Chaudhary et al., 2015, Frischknecht et al., 2016).

3.3 RESULTS AND DISCUSSION

3.3.1 Overview of the life cycle impacts of Swiss food consumption and losses

Figure 3.1 shows GHG impacts of Swiss food consumption. The vertical flows on the top represent the impacts arising at the various stages of the FVC, the flows at the bottom the net environmental benefits of FW treatment, considering credits from the substitution of resources and energy (forage, fertilizer, electricity, heat, improved soil effect). The horizontal flows visualize the cumulated impacts of the upstream processes of the FVC, including FW treatment. The attribution to consumption (green) and waste (red) is based on the metabolizable energy content of the food and the avoidable FW. The results show that the agricultural production of an average Swiss consumer's food basket (Appendix B.1.1) represents the most relevant stage of the FVC. The second largest impact fraction is caused by households (66% of the GHG are from car rides for shopping, only 6% from public transport for shopping and 28% from electricity consumption for refrigeration, cooking, and dish washing). The trade and the processing industry cause similar total emissions as households. Food services and retail cause ~10% of emissions compared to agricultural production. More than half of the net environmental benefits of the treatment of avoidable FW are coming from feeding, 30% from anaerobic digestion, 8% from composting (fertilizer and peat substitution), and the rest mainly from incineration. The total impacts of consumed food, including consumption in households and food services and food donations, amount to 1.5 t CO_2-eq, the net impacts of FW to 0.49 t CO_2-eq. In household food consumption 15% of the emissions are caused by FW at household level, 10% by FW at the previous stages of the FVC, and 75% by actual food consumption. In food services, the respective numbers are 12%, 9%, and 79%. Food donation institutions save food with value chain impacts of 2 kg CO_2-eq/cap/a. For the storage and distribution of food they emit 0.2 kg CO_2-eq/cap/a (8% of the saved emissions) (Figure 3.1).

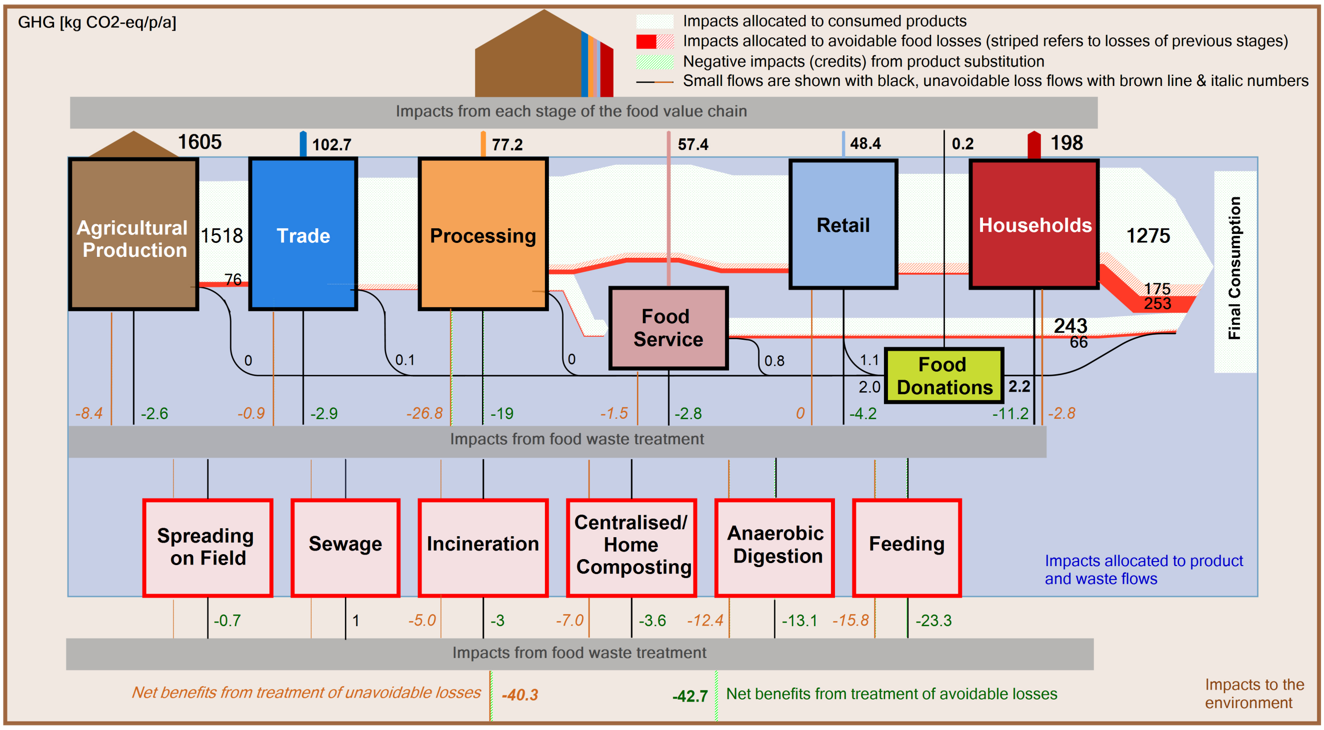

Figure 3.1: GHG impacts of Swiss food consumption, including the production and treatment of avoidable and unavoidable FW. The size of the arrows is proportional to the impact; however, small flows are highlighted with a black line for better visibility.

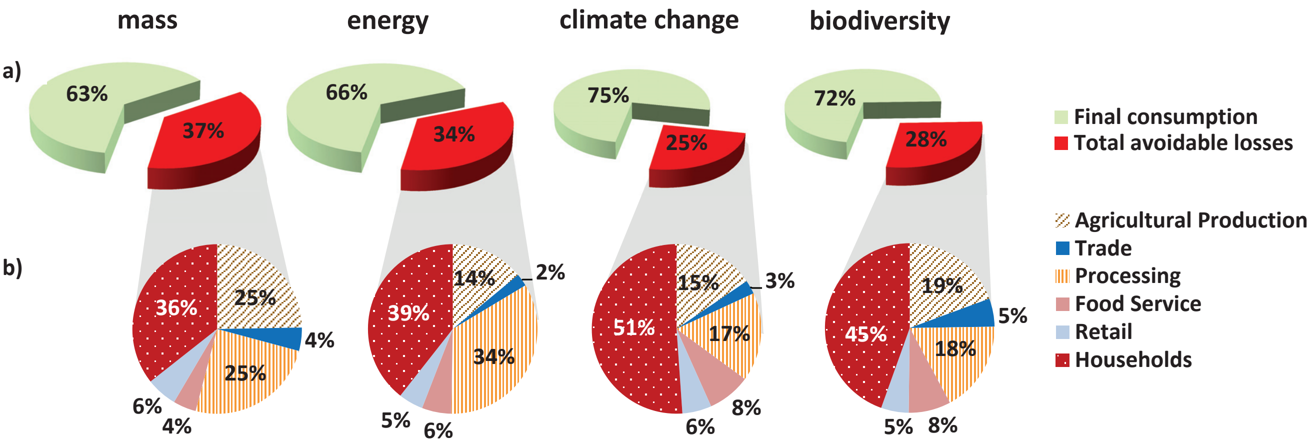

Figure 3.2: Share of FW and final consumption (a) and share of FW arising at the various stages of the FVC (b) in terms of mass, metabolizable energy, and impacts on climate change and global biodiversity.

In terms of climate change the **FW related emissions** are estimated to be 25% of the total emissions of consumed food. The share is lower than for energy (34%) and for mass (37%) (Figure 3.2), because products with a high GHG impact per kg of food (e.g. animal products) tend to be wasted less than average. In terms of biodiversity, the share of impacts caused by FW is similar as in terms of GHG (23%).

When analysing the **importance of FVC stages**, the GHG contribution of FW caused by households (51%) and food services (8% of total FW) is higher than in terms of energy (39%, 6%) and mass (36%, 4%). The main reason is the cumulation of impacts along the FVC. The losses in the processing industry are highest in terms of energy (34%), whereas in terms of GHG they only make up 17%. This means that the losses are environmentally less relevant than average losses (Figure 3.2); notably cereals declassified for animal feeding have relatively high calorific values, but low environmental impacts per kg due to substitution effects. Regarding biodiversity most impacts are caused in agricultural production, since land and water use are relatively low in the later stages of the FVC. This explains why the early stages of the FVC cause higher and the later stages lower impact shares than in terms of GHG.

3.3.2 Hotspots of environmental relevance

If different **product categories** are compared, the major GHG emissions [GWP 100a, IPCC (2013)] attributed to the average FW of Swiss consumers are caused by fresh vegetables (mainly tomatoes, cucumbers, and lettuce), dairy products, beef and pork, and bread and pastries (Figure 3.3a; the horizontal red lines show the net GHG impacts of production, supply, and treatment for food categories with treatment savings of more than 1 kg of CO_2-eq/cap/a). However, the emissions per kg of FW are highest for beef, chocolate and coffee, and animal products in general (Figure 3.3b). The high relevance of vegetable, bread, and dairy waste is therefore mainly caused by high FW amounts (high FW rates as illustrated in Figure 3.3c combined with large amounts consumed), whereas the relevance of beef is mainly caused by high impacts per kg (relatively low FW rate in Figure 3.3c). Graph a) in Figure 3.3 also shows that the food losses with the highest impacts are arising in households (red) for most food categories. Exceptions are cheese (whey losses in processing), fresh vegetables (over-production and sorting by cosmetic norms in agricultural production), and breads and pastries (cereals declassified for animal feeding). The relatively high impacts from losses in the processing of oils and fats are uncertain since they are based on estimations of average oil crop losses in Europe (Gustavsson and Cederberg, 2011).

The **treatment of FW** leads to net GHG savings in all food categories. However, they are low compared to the impacts allocated to the production and supply of the food that is wasted (Figure 3.3a; note that the negative and positive vertical axes are not scaled equally). Only in the case of cereals the substitution of feed can save a relevant amount of emissions (about 90% of the climate impacts of agricultural production of the cereals that are fed to animals, illustrated with the negative bar in Figure 3.3a). The reason is that the production of bread cereals only has about 10% higher GHG impacts than the production of the modeled, substituted feed (barley and soy grits; details in Appendix B.3.3.6). In the case of whey used for animal feeding the environmental benefits from feed substitution are also relevant, especially if fed to calves and shoats instead of swine (illustrated with a shaded bar in Figure 3.3a) because of the specific protein composition of whey (Kopf-Bolanz et al., 2015). Figure 3.3b shows that the specific GHG emissions per kg of FW vary more between food categories than between the stages of the FVC where they arize. Generally, they increase along the FVC because of the accumulation of impacts. However, for fish the FW impacts in processing are lower than in agricultural production because of the credits for feeding fish to animals (Figure 3.3b). If the environmental impacts are analyzed per kcal of FW, fresh and other vegetables and exotic fruits become more relevant than in the per-kg-perspective, since they have a relatively low calorific content (Appendix B.7.1.1). In Figure 3.3b we show the per-kg-perspective since it may be easier to perceive the mass of FW than its calorific content. Figure 3.3c shows the amount of losses relative to the consumed food. The loss rate of vegetal oils, processed vegetables, and of nuts and seeds is lower in terms of energy than in terms of mass because of losses before processing (lower calorific content), in the dairy industry because whey and buttermilk have lower calorific contents than cheese and butter.

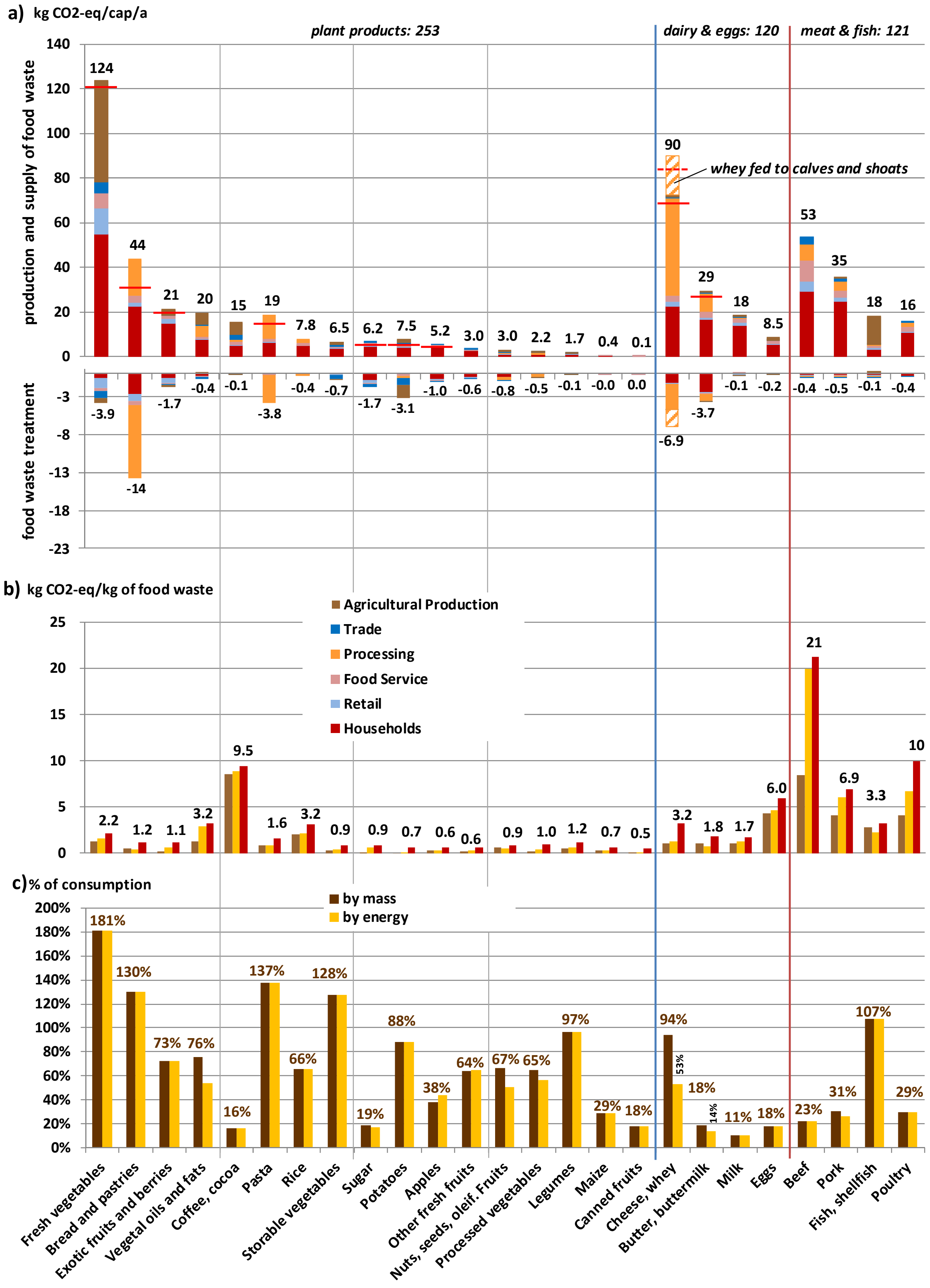

Figure 3.3: a) GHG emissions (GWP 100) per person and year caused by the production and supply of food that is wasted at the various stages of the FVC and GHG savings from FW treatment. b) GHG emissions per kg of FW from the production, supply, and treatment of food, including credits for FW treatment. The results are shown for food wasted in agricultural production, the processing industry, and in households. c) Relative FW amounts compared to final consumption (=100%) by mass and energy. The corresponding results for global temperature change (GTP 100) are shown in Fig. B27 in Appendix B.

Regarding biodiversity impacts the results show that cocoa waste from Swiss consumption in 2012 has the highest **impacts on global biodiversity** with about 26x10^{-7} gPDF-eq*a (16% of total FW impact), even though the food loss estimates are relatively low with 600 g/p/a (0.18% of total FW) (Figure 3.4). A reason for the high impacts of cocoa is the relatively low yield of 40 g/m2/a and the provenance from tropical areas with high endemic species richness. Other relevant food categories are beef, wheat, coffee, grapes, and sunflowers each contributing 4 - 11% to total FW impacts. The biodiversity impacts from water use are generally lower than for land use, with almonds, grapes, and olives being the top contributors (Figure 3.4).

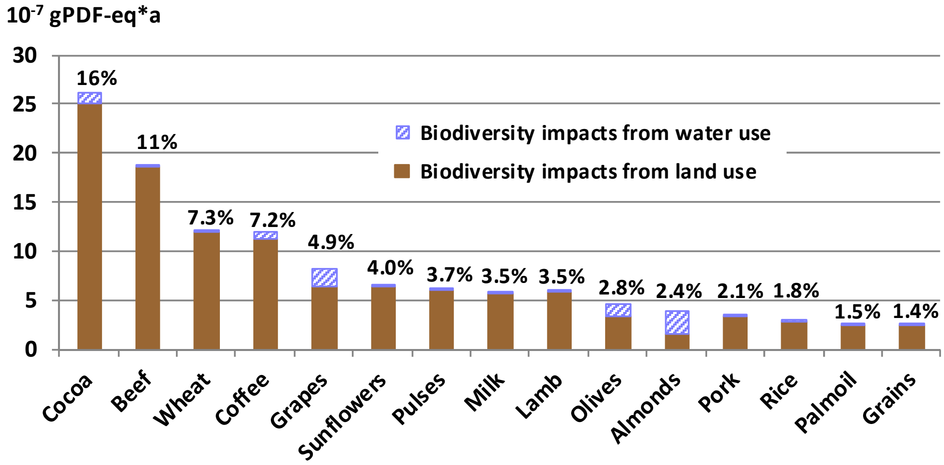

Figure 3.4: Global biodiversity impacts of the top 15 products contributing to land and water use of total Swiss food losses, with respective shares of the total FW impacts.

3.3.3 Regionalized impacts

In contrast to GHG emissions, the environmental impacts of land and water use depend on the location. Figure 3.5b) shows the share of **imported products** for total FW (42% by mass and 47% by energy). Regarding land occupation, 66% of the area and 79% of the biodiversity impacts are occurring outside Switzerland. Similarly, for water consumption and the related impacts on biodiversity, the vast majority of impacts in agricultural production is taking place in countries exporting food to Switzerland (>90%). For water use the main reason is that water scarcity is low in Switzerland and small amounts of irrigation water from surface or groundwater resources are consumed. For biodiversity the number of endemic species is low in Switzerland compared to many countries that export food products to Switzerland.

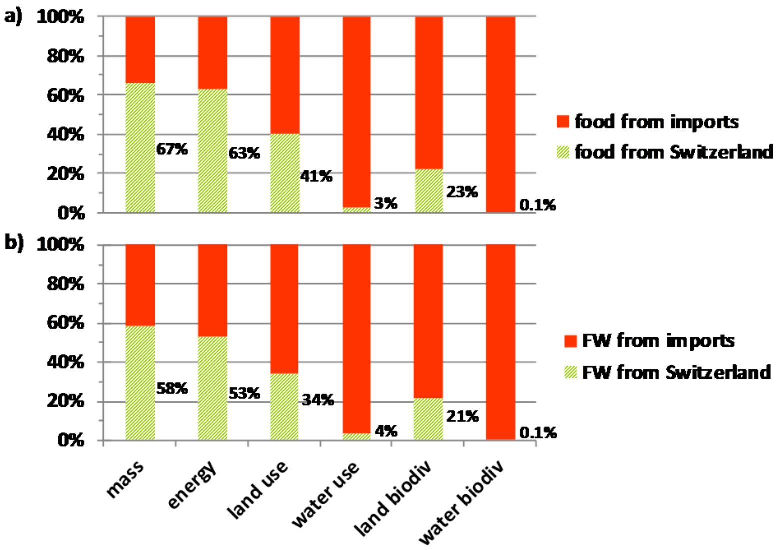

Figure 3.5: Share of the amounts (mass and energy) and the environmental impacts (land use, blue water use, biodiversity) of domestically produced a) food consumed and b) FW occurring in Switzerland.

3.3.4 Data quality and sensitivities

The data quality of the rates of FW for all food categories has been extensively characterized in Beretta et al. (2013), following a pedigree approach (Frischknecht et al., 2007). FW rates in the agricultural production of cereals, sugar, eggs, and canned fruits were identified as particularly uncertain (Beretta et al., 2013). With regard to the composition of the food basket, the most sensitive food categories with regard to climate change impacts (GWP 100 and GTP 100) can be seen in Figure 3b and Appendix B, with beef, pork, and coffee and cocoa being most sensitive. The uncertainty of the life cycle inventory of agricultural products is analyzed in section 11 in Appendix B with a pedigree approach. The results are presented in Appendix B.17 and show that most datasets are appropriate in terms of geographical correlation, reliability, and product specifications in order to describe the food categories of the Swiss food basket; major uncertainties are related to the agricultural production of rice, berries, and exotic and citrus fruits. The uncertainties in the biodiversity assessment methods are reported with confidence intervals by Chaudhary et al. (2015). Further uncertainties of the analysis are discussed in Appendix B.11.3.

3.3.5 Indirect effects of behavioural changes

The environmental effects allocated to FW in this study reflect the direct potential savings of FW prevention, i.e. the benefits of producing less food, of treating less FW, and the impacts of replacing the recovered co-products from FW. However, the indirect effects of related consumers' changed behaviour are not included. Preventing FW can potentially have five consequences: (I) buying less food and spending the saved money on alternative products and services with an additional impact, (II) spending the money on more expensive food, (III) donating the saved money, (IV) reducing income by working less or saving the money, or (V) eating more food. According to Martinez-Sanchez et al. (2016) the rebound effects of FW prevention may be highly relevant, depending on the type of activity on which the money saved is spent. Salemdeeb et al. (2016) estimate that rebound effects may reduce GHG savings from FW prevention by up to 60%. Therefore, a holistic approach is needed when developing FW prevention policies in order to mitigate rebound effects (Salemdeeb et al., 2016).

3.3.6 Comparison with literature

This study represents the first detailed environmental assessment of the complete FVC of Swiss food consumption, focussing particularly on FW. However, in other countries several previous studies on MFA/EFA or on the environmental assessment of parts of the FVC exist (see introduction) and can be compared to our results. FW quantification is consistent with other studies at most stages of the FVC (Appendix B.12). However, for household FW the reported amounts differ significantly from each other. Since methodologies and definitions differed between studies, most numbers are not directly comparable. Household FW in this study is based on UK numbers by Quested and Johnson (2009), because in Switzerland a quantitative analysis of all relevant streams of FW disposal (e.g. incineration, biomass collection, garden compost, pet feed) is still lacking and Quested and Johnson's methodology is judged as most reliable while considering all streams of FW disposal.

The life cycle impacts of food consumption reported by Eberle and Fels (2015) for Germany and by Jungbluth et al. (2011) for Switzerland in terms of climate change and Ecological Scarcity ecopoints are mostly consistent with our results (Appendix B.12). In terms of climate change we estimate the FW related emissions to be 25% of the total emissions of consumed food, which is rather high compared to Scherhaufer et al. (2015) who estimate the FW related GHG emissions at 16% to 22% of the total emissions of consumed food. A reason for the lower number in Scherhaufer et al. (2015) may be that their system boundary does not include animal feed as food loss due to lack of data. Concerning FW, FAO (2013) identified global hotspots of environmentally relevant FW flows and, similarly to our results for Switzerland, found wastage of cereals, vegetables, and meat to be most important. Our results for the impacts of FW are also similar to those reported by Schott and Cánovas (2015), but they deviate from values reported by FAO (2013) for Europe, by Eberle and Fels (2015) for Germany, and by Hamilton et al. (2015) for Norway by about 20-50%; however, differences between countries (e.g. FW going to landfill), system boundaries (e.g. exclusion of agricultural FW), and methodologies (e.g. in quantifying household FW) may explain most deviations (detailed comparison in Appendix B.12).

3.3.7 Policy implications and practical relevance of the results

FW in Switzerland causes **4 mio t CO_2-eq, about 4% of the emissions of the total carbon footprint of Swiss consumption** (BAFU, 2014), or **50% of the 1t CO_2-eq/cap target** (promoted as a political target in the ETH Zurich energy strategy and widely adopted as a vision to prevent climate warming above 2 degrees celsius; more details in Appendix B.12) (Boulouchos et al., 2008). The main climate change impacts are generated from agricultural production, especially for animal products with high impacts per kg. The impacts of the later stages of the FVC are also relevant; for some products with relatively low impacts from production, e.g. potatoes, they are even dominant. Thus, the environmental relevance of FW increases along the FVC and varies a lot depending on the product. The hotspot along the FVC is FW at the **household level** due to relatively high volumes and the accumulation of impacts along the FVC. Therefore the consumers are key actors to be addressed in FW prevention policies. In the UK the "Love Food Hate Waste campaign" (LFHW; www.lovefoodhatewaste.com) and an agreement with the food industry to help consumers reduce FW (the "Courtauld Commitment") have avoided an estimated 1.3 million tonnes of household food and drink waste, which corresponds to a 23% reduction of avoidable FW between 2007 and 2012 (Quested et al., 2013). Assuming the same reduction in all food categories wasted in Swiss households, 23% of the 253 kg CO_2-eq/p/a caused by household FW (red flow in Figure 1) could potentially by avoided. In terms of climate change, the most relevant food categories are **fresh vegetables** and **cereals** (high FW amounts) and **meat** and **cheese** (high specific impacts). In terms of biodiversity, the highest impacts of FW are caused from **cocoa**, **beef, wheat,** and **coffee**. Consumer awareness and FW prevention strategies should therefore focus on these food groups. In the FVC of cereals and dairy products, notably bread cereals declassified to animal feed and whey and buttermilk may provide high environmental benefits if valorized as food (Kopf-Bolanz et al., 2015). Since the impacts on biodiversity are **largely taking place outside of Switzerland**, FW prevention should also be communicated as a question of responsibility towards the rest of the world and strategies for FW prevention should include the supply chains of imported products, notably cold chains which affect the potential life period of products.

The **treatment of FW** mainly leads to **environmental benefits**, but compared to the impacts of production they are low (7.9% of the GHG). For the optimization of FW treatment, today the environmentally best option for products with high calorific and nutrient contents (e.g. bread, cereals and dairy) is feeding to livestock (Appendix B.7.6). For oils and fats, anaerobic digestion and incineration are most favourable; however, the major benefits are related to the substitution of natural gas for heating and may decrease in future scenarios with more renewable energy. For the other FW categories, composting and anaerobic digestion are environmentally more favourable than incineration, but only if potential benefits from the substitution of inorganic fertilizer and peat with high-quality compost and digestate are taken into account. Higher compost and digestate availability may also lead to increased eutrophication (Gebert, 2015).

Finally, the importance of tackling FW at the consumers' level is not only sustained by its high potential environmental benefits, but also by the fact that consumers and stakeholders alike perceive FW as obviously unethical, making it a good starting point for individual consumers to become engaged in sustainability (Aschemann-Witzel, 2016). If communicated in the light of sustainability, the danger of additional impacts from increased alternative consumption can be turned into the chance of higher environmental awareness in all consumption activities.

3.3.8 Outlook

This paper identifies hotspots of environmental relevance for FW prevention and treatment. It therefore serves as a basis to prioritize activities tackling the problem of FW. For the quantification of the potential environmental benefits of specific measures and especially for monitoring the performance of FW prevention further analyzes are needed. The present study is an important basis to develop such measures, as it helps to prioritize and identify the environmentally most important FW flows, products, and stages of the value chain.

3.4 ACKNOWLEDGEMENTS

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CHAPTER 4

POTENTIAL ENVIRONMENTAL BENEFITS FROM FOOD WASTE PREVENTION IN THE FOOD SERVICE SECTOR

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ABSTRACT

Approximately 88 Mt of food are wasted every year in the European Union and are responsible for 15–16% of the environmental impact of its entire food value chain. The United Nations' Sustainable Development Goal (SDG) 12.3 demands per capita global food waste (FW) at the retail and consumer levels to be halved by 2030. This study aims to identify whether the SDG 12.3 is realistic and to assess the associated climate, biodiversity, and aggregated environmental benefits from FW prevention in the food service sector. The FW reduction potential is assessed in 13 case studies that implemented measures for reduction. We estimate status quo avoidable FW at 108 g/meal (13% of purchased food), causing 238 g CO2-eq/meal. FW reduction achieved in the case studies ranges from 32% of status quo in the education subsector to 62% in the business subsector. On average, a 38% decrease in FW amounts reduces climate impacts of FW by 41% and biodiversity impacts by 30%. In an extended reduction scenario, food services use 50% non-marketable vegetables that would otherwise be wasted throughout the food value chain. In combination, FW amounts are reduced by 70%. We conclude that the SDG 12.3 is realistic and can even be exceeded in the long term. Initial investments and political support are important to reach individual food services.

4.1 INTRODUCTION

The United Nations recently released the Sustainable Development Goals including a specific target for halving per capita global food waste (FW) at the retail and consumption stage by 2030 compared to 2015 (SDG 12.3). The European Commission (EC) also tackles the problem of FW with the Resource Efficiency Roadmap, which contains the goal of reducing the resource input into the food chain by 20% and halving the disposal of edible FW by 2020 (Usubiaga et al., 2017). Currently one third of global food production is lost or wasted during the various phases of the food value chain from farm to final consumption (Kummu et al., 2012). Scherhaufer et al. (2018) estimate that ~88 Mt of food are wasted in the European Union (*excl. FW used as animal feed*), causing 186 Mt CO_2-eq. With this, the climate, acidification, and eutrophication impacts of FW contribute 15-16% to the environmental impact of the entire food value chain (Scherhaufer et al., 2018). According to our previous publication, 20% and 25% of the climate impacts of food consumption are caused by FW *excluding and including FW used as animal feed* in Switzerland, respectively (Beretta et al., 2017). FW at the consumption stage is usually high in developed countries (Gustavsson and Cederberg, 2011, Kummu et al., 2012). Therefore, a key element to making our food system more efficient and sustainable is the reduction of food losses in households and the food service sector (Beretta et al., 2017). However, the environmental impacts of FW differ substantially between food categories (Beretta et al., 2017) and FW amounts and composition differ between subsectors of food services (care, business, education, restauration, and hotels) (Hrad et al., 2016, Borstel et al., 2017).

There is an increasing amount of literature quantifying FW in food services (Andrini and Bauen, 2005, Baier and Reinhard, 2007, Oakdene, 2013, Hrad et al., 2016, Borstel et al., 2017). However, food categories are often not differentiated or detailed enough for an environmental assessment. Furthermore, data is lacking on the effect of FW reduction measures in different types of food services and subsectors. Waskow and Blumenthal (2017) analysed FW reductions achieved in school canteens, but the published results are not detailed enough to allow for a meaningful environmental assessment. Two studies analysed the environmental impacts of FW in Europe (Scherhaufer et al., 2018) and worldwide, differentiating continents (FAO, 2013), but both studies do not differentiate FW from the food service sector and households, and they also do not consider biodiversity impacts.

In order to create a basis to evaluate measures for FW reduction, we defined three goals in this study. The **first goal** is to **quantify status quo FW amounts** and **composition** in different food service subsectors. Quantification of the **environmental impacts** of FW in each subsector is done by combining the mass flows with life cycle assessment (LCA). The **second goal** is to estimate how **realistic** it is to reach SDG 12.3 in the Swiss and European food service sector, based on **FW reduction** measures that were implemented in different case studies and based on the comparison of similar food services with different serving systems. A progressive restaurant is used as a proxy for the long term **potential** of **FW reduction**. As a **third goal** we compare quantitative FW savings with their environmental benefits in different case studies and deduce recommendations for **how to improve** the **environmental performance of FW reductions**.

4.2 METHODS

4.2.1 Definition of food waste

As in Beretta et al. (2017), food waste (FW) refers to food which is originally produced for human consumption but then directed to either a non-food use (including animal feed) or waste disposal. Thus, FW prevention per definition does not include inedible parts of food (bones, shells, peels, residues etc.); for more details see the definitions in the appendix.

4.2.2 System boundaries

This paper includes studies analysing FW from food services in Switzerland, Germany, Austria, Finland, and the UK (Table C.3 in the appendix) and considers how food services can reduce FW that arises throughout the entire supply chain. The reduction scenarios are based on 13 case studies in Switzerland and Germany. An extrapolation of the total amounts and environmental impacts of FW is carried out for Switzerland. We consider all food categories including beverages with high nutritional value (milk, whey, juices) and coffee (high biodiversity impacts). Alcoholic beverages are excluded due to missing data. Status quo FW refers to the year 2017, since the majority of case study measurements have been carried out in this year. However, data from literature used for the quantification of FW includes measurements between 2005 and 2017.

4.2.3 Case studies

4.2.3.1 Food waste measurements in food services

We collected 20 datasets from FW measurements in 29 locations (3 health, 5 education, 4 staff caterings, 13 hotels, 4 restaurants: Table C.1). Datasets based on more than one location (e.g. hotels of a hotel chain) were analysed as one dataset if only aggregated data over all locations was available. For eight datasets the measurements were carried out by our team, another eight food service institutions did internal measurements carried out by their own staff, and four school canteens in Germany did measurements for a scientific project, sharing primary data for this paper. The physical assessment was partly combined with interviews with staff members to ensure appropriate interpretation of quantitative data. In most datasets we differentiated inedible trim waste, potentially edible waste from preparation (e.g. apple peels), over-production in the kitchen, surplus food from the buffet, and the guests' plate waste. FW from each source was separated into food categories (e.g. rice, beef) or types of dishes (e.g. riz Casimir, spaghetti carbonara) and weighed (fresh matter). Since a broad variety of menus was offered in the different food services and some projects were initiated independently, it was not possible to harmonize food categorization for all studies, resulting in 1'081 different types of wasted dishes (Table C.17 in the electronic appendix). For FW quantification they were classified into food categories according to their main ingredient.

4.2.3.2 Food waste reduction

FW reduction is estimated for each subsector individually (health, education, catering, hotel, restaurant), based on 13 FW reduction case studies comparing FW measurements before and after implementation of FW reduction measures. In 11 case studies, measures for FW reduction, such as for example smaller portion sizes (see Table C.1 for the set of measures and the study duration in each case study) were implemented. In two further case studies, we compared different serving systems; in a company with different staff canteens on the same campus we measured FW in a buffet canteen and newer plate service canteen, which was introduced as a measure to prevent FW. In a school canteen careful management practices reduced FW to a minimum before the first measurement (secondary school 3 in Figure 4.1). We used this example as a case study with reduced FW. However, after rebuilding the canteen and switching to a fixed price per menu "all-you-can-eat" buffet service, FW increased substantially (secondary school 4 in Figure 4.1). We therefore classified this case study as status quo. In total, FW reduction measures were implemented in 13 case studies (Table C.1).

In addition to the aforementioned FW reduction case studies, a progressive restaurant focusing on FW minimization was used to estimate the long term **potential FW reduction** (Mein_Küchenchef, 2018). Overproduction is avoided entirely with the sous-vide technique (method of cooking in which food is placed in a plastic bag or glass jar, and cooked in a water bath for longer than normal cooking times at a regulated temperature lower than with conventional cooking). The meals are cooked in one to five portions and vacuum packed in order to make over-production conservable (a base amount that is sure to be consumed is cooked in larger portions). Plate waste from guests is reduced by serving small portions (350-400g) with the option for refills and providing information about the relevance of FW. Vegetable and cereal losses in the supply chain are avoided using a two week average of 77% unmarketable vegetables and only wholegrain cereals. Additionally, using products close to their shelf lives from a retail store is assumed to save them from being wasted. Preparation losses are reduced to a minimum by training the staff to use efficient cutting techniques.

4.2.4 Average food waste in food services in Europe

4.2.4.1 Localisation and number of food services analysed

We use data from 1'042 food services to quantify **FW amounts** in Europe (212 health care institutions, 145 hotels, 136 restaurants, 396 staff caterings, 133 school and university canteens, and 20 unspecified: Table C.3). Thereof, 361 food services have been analysed in Germany (Borstel et al., 2017), 50 in Austria (Hrad and Obersteiner, 2015), 480 in the UK (Oakdene, 2013), 47 in Finnland (Silvennoinen et al., 2015) and 104 in Switzerland (Andrini and Bauen, 2005, Baier and Reinhard, 2007). The **composition of status quo FW** in each subsector was based on 13 detailed measurements (Table C.1).

4.2.4.2 Quantification of status quo food waste amounts and reduction potential

For the estimation of the **status quo FW amounts per meal** in Europe we calculated average FW per meal in each subsector (health care, restaurants, hotels, staff caterings, education) and weighted the subsectors based on the share of main meals served per year using the following formula:

$$\text{mass of average food waste per meal } m_{FSS} = \sum\nolimits_{s=1}^{5} m_{\phi,s} \times n_s; \quad m_{\phi,s} = \frac{\sum_{i=1}^{x} m_{i,s} \times s_{i,s}}{\sum_{i=1}^{x} s_{i,s}} \tag{1}$$

with $m_{i,s}$ = *mass of FW per meal in study i and subsector s*, $s_{i,s}$ = *sample size of study i in subsector s*, $m_{\emptyset,s}$ = *average FW mass per meal in subsector s*, n_s = *share of meals consumed in subsector s,* and m_{FSS} = *average FW mass per meal in the food service sector*. The studies are listed in Table C.3. The share of meals served in each subsector is based on estimations in Switzerland (Figure C.5), Austria, Germany, and the UK (Figure C.6).

For a **base scenario of FW reduction** we multiplied the rates of in-house FW reduction achieved within each subsector with the corresponding status quo FW amounts and impacts. Additionally, we calculated an **extended FW reduction scenario.** It is called "extended" since it shows that food services cannot only reduce in-house FW, but also FW in their supply chain. In this extended scenario, all food services buy 50% of their vegetables from a non-marketable origin. We consider this a realistic amount, since it corresponds to only 33% of all non-marketable vegetables wasted in Switzerland; non-marketable vegetables are those that are edible but wasted in the agricultural and processing state of the food value chain, despite being storable or further processible into storable products (salads, cucumbers, and melons are excluded) (Beretta et al., 2017).

In order to exemplarily quantify the overall reduction potential of FW in food services in an industrialized country, we multiplied the average status quo FW amounts per meal calculated in each subsector in Europe by the number of meals consumed in each subsector **in Switzerland**. With this procedure, we ignore FW reductions already achieved in some food services. However, these are still a minority and assumed to be negligible. The estimation of total meals in the Swiss food service sector is based on Baier and Reinhard (2007), by extrapolating from the Canton of Aargau to Switzerland proportionally to population. The number of meals in the business and care sectors are based on statistics by the corresponding inter-trade associations (SVG, 2015, GastroSuisse, 2017). The share of meals consumed in restaurants, hotels, and schools was adopted from Oakdene (2013) (Figure 4.5).

4.2.5 Environmental impacts and benefits of case studies

For the **life cycle assessment (LCA)** we multiplied FW amounts per subsector, calculated in formula (1), with the per-kilo environmental impacts of the corresponding subsectors. These are calculated as an average of the food services analysed in the corresponding subsector (Table C.1). The per-kg environmental impact of FW in a food service institution is calculated with the following formula:

$$\text{environmental impact of average FW per kg}\; e_{FS} = \sum_{c=1}^{1081} m_c \times e_c \qquad (2)$$

with *m_c = mass of component c per kg of FW; e_c = environmental impact per kg of component c, when it is wasted in food services and sent to anaerobic digestion*

The per-kg environmental impacts of each of the 1’081 wasted components reported in the primary data are estimated based on their composition, attributing them to one or two of the 169 food categories, ingredients or compound dishes listed in Table C.6 and estimating their shares. For more liquid dishes (e.g. soups) the water content was estimated visually during the measurements or later, based on photos of the dishes (estimations are reported in Table C.17 in the electronic Appendix C). For 30 food categories the environmental impact factors are based on Beretta et al. (2017) and for 112 more specific food products **life cycle inventory (LCI)** datasets of agricultural production are available (Table C.6A). The per-kilo environmental impacts of the food value chain (transport, cooling, processing, preparation) and the rate of unavoidable losses are assumed to be constant within each food category and taken from Beretta et al. (2017). For cooked rice, pasta, tofu, and nuts and olives we model additional, product specific preparation factors based on Souci (2008), Betz (2013), and SBV (2016); the other inventories refer to the edible parts of uncooked food. Out-of-season green asparagus, fresh beans, and papaya were assumed to be imported from the countries of origin by plane transport. For 6 mixed food categories (e.g. dairy products not specified) the average Swiss consumption mix is assumed (Table C.6B), for 21 compound dishes simplified recipes are modelled (composition and per-kilo environmental impacts are listed in Table C.6C). For the LCI and impact assessment we used the same data as Beretta et al. (2017), which was mainly based on the LCI databases *ecoinvent 3.2* (ecoinvent, 2016), *World Food LCA Database 3.0* (Bengoa et al., 2015), and *Agri Footprint 2015* (Blonk, 2016).

In Switzerland, most of the FW from the food service sector is sent to **anaerobic digestion** (Baier and Deller, 2014). The environmental impacts were modelled as in Beretta et al. (2017) by applying system expansion (avoided burden approach) for useful co-products of FW treatment (biogas, heat, electricity, digestate). The environmental impacts of FW treatment were found to be of minor importance compared to the savings from FW prevention for most food categories in Beretta et al. (2017). The results are expected to be similar for other European countries, except if FW is sent to landfills and causes methane emissions, e.g. in the UK (Oakdene, 2013) and Turkey (Pekcan et al., 2006).

The **life cycle impact assessment (LCIA)** is completed for climate change impacts with the method ***global warming potential 100a*** (IPCC, 2013), for ***regionalized land and water impacts on biodiversity*** (Pfister and Bayer, 2014, Chaudhary et al., 2015, Scherer and Pfister, 2016), and for an aggregated LCIA with the ***ReCiPe*** (Goedkoop et al., 2013) method. Global biodiversity loss considers endemic species richness and is expressed in global potentially disappeared fraction of species (gPDF). Biodiversity loss is assessed because it is classified as a “core” planetary boundary exceeded (Steffen et al., 2015) and because land and water use from food production represent primary pressures of biodiversity loss (Millennium-Ecosystem-Assessment, 2005). In the Supporting Material we additionally provide the aggregated LCIA scores according to the Swiss ***method of ecological scarcity*** (Frischknecht et al., 2013) (Appendix C.1.12).

4.3 RESULTS AND DISCUSSION

4.3.1 Case studies

4.3.1.1 Status quo food waste amounts and composition

FW amounts per meal differ substantially between different food services, even within the same subsector. The highest amounts of total FW were measured in a luxury restaurant with a high fraction of unavoidable losses (>450 g/meal, mainly exotic fruit peelings and bones), whereas the highest amounts of avoidable FW were measured in a hospital (300 g/meal, 2/3 plate waste) and in a school and a business canteen, both with “all-you-can-eat” buffet service (about 200 g/meal) (Figure 4.1). The lowest amounts of avoidable FW, measured in a university canteen, were up to ten times lower (about 30 g/meal). However, this canteen had already implemented regular staff trainings at an earlier stage. Edible trim waste from preparation is outsourced since they mostly use pre-prepared food. Five other examples in all subsectors besides health care show that avoidable FW slightly above 50 g/meal is realistic. The main origin of avoidable FW is always over-production at the counter or the buffet or plate waste from the guests. The composition of wasted food categories is highly variable, which is the reason that environmental impacts often differ substantially from amounts (graphs C and D in Figure 4.1, compared to B). Generally, meat and fish are more dominant in terms of climate impacts in spite of low amounts, while coffee, cocoa and some exotic fruits (e.g. citrus fruits in the beer hall restaurant) are more dominant in terms of biodiversity impacts.

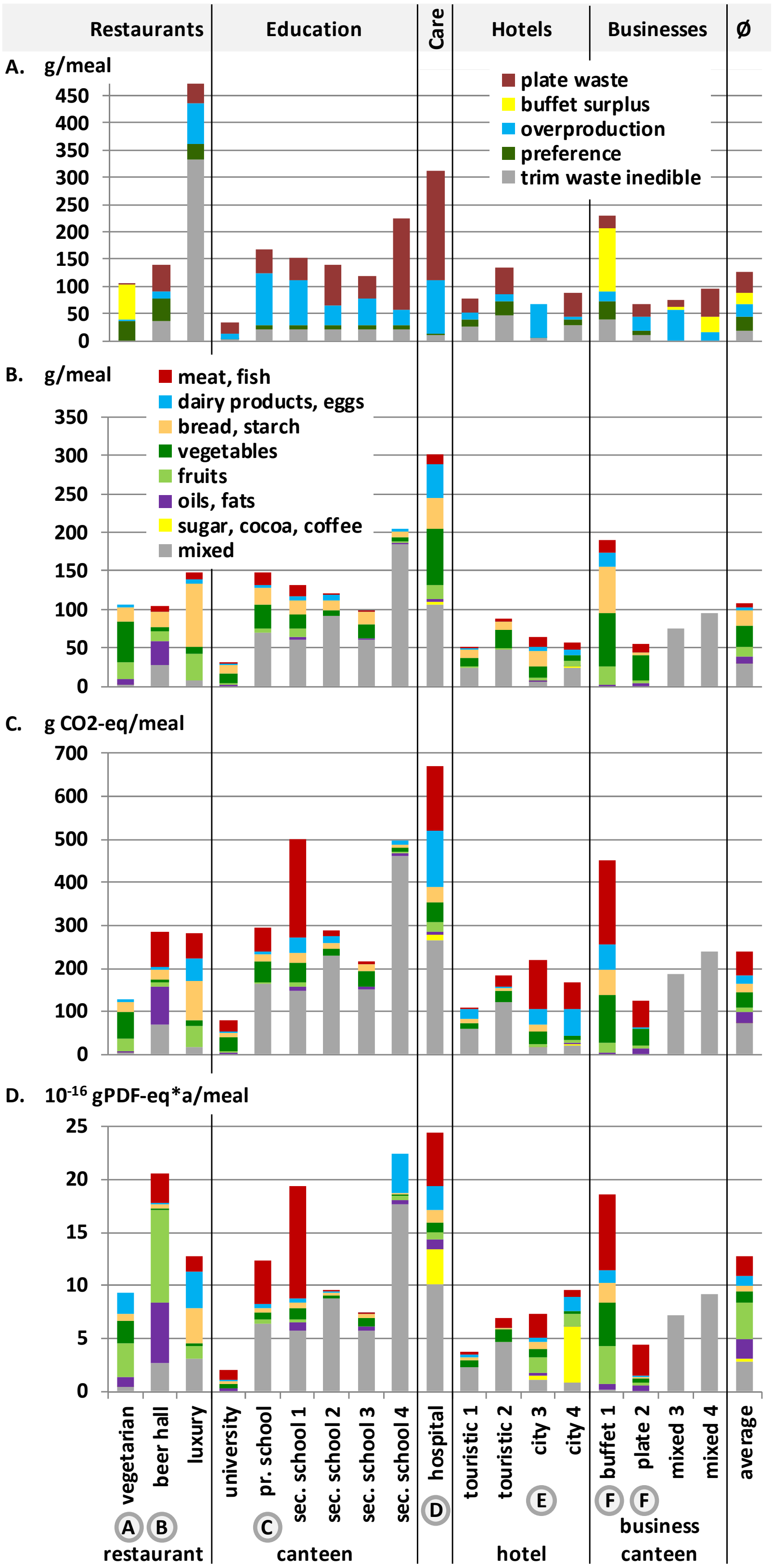

Figure 4.1: FW (gram per meal, charts A and B) and its climate (gram CO2-equivalents per meal, chart C) and biodiversity impacts (global potentially disappeared fraction of species year per meal, chart D) in 18 food services of the main five subsectors (care, businesses, canteens, hotels, restaurants). The status quo weighted average includes studies from Germany, Austria, Finland, and the UK and excludes food services which have already implemented measures for FW prevention (business canteen 2, secondary school 3). The studies are weighted according to the number of food service locations analysed, the subsectors according to the number of meals consumed (Figure 4.6). Inedible trim waste is only included in Chart A. The grey circles A-F refer to the case studies in Figure 4.2.

4.3.1.2 *Food waste reduction examples: quantities versus environmental benefits*

From the 13 case studies analysed we present six case studies (A. to F.) in the following paragraph with a focus on food categories and their environmental relevance (Figure 4.2). We selected the one case study from each sub-sector with the most detailed differentiation of food categories. For the largest sub-sector ‘restaurants’ we present two case studies, including one vegetarian restaurant and one specializing in meat based dishes. More details about individual case studies can be found in Appendix C1.1.

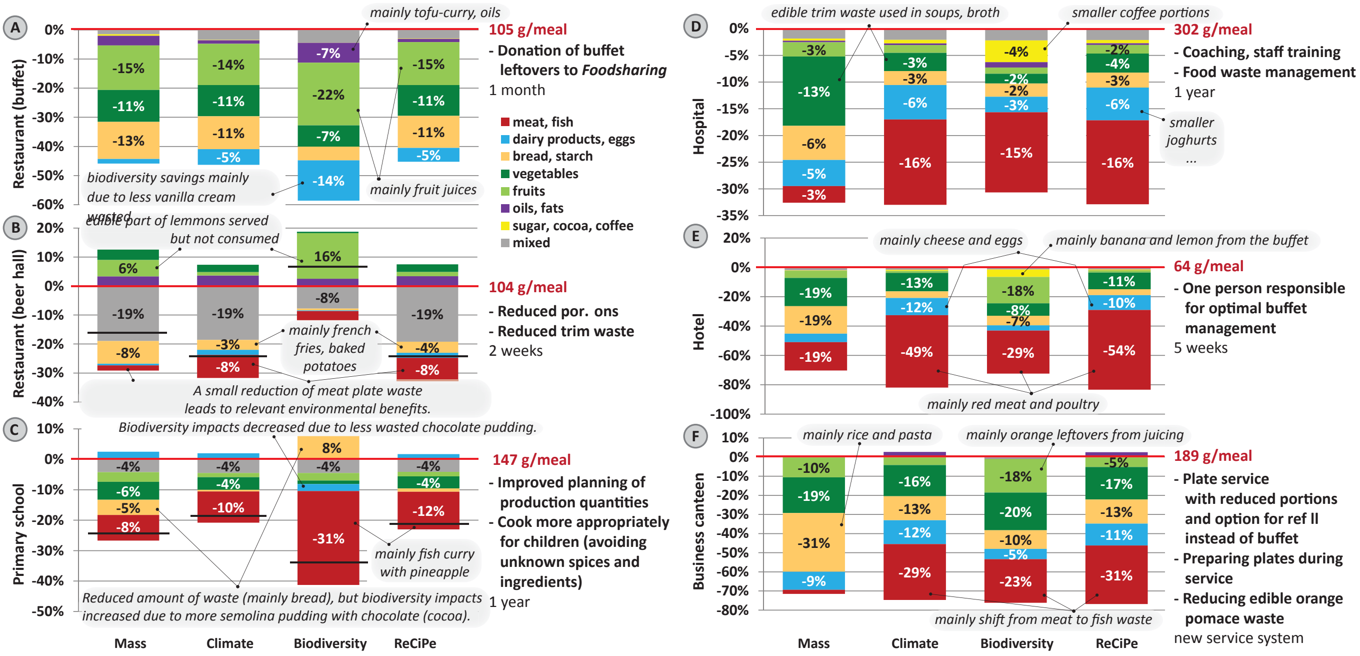

Figure 4.2: FW reduction in terms of mass, climate impacts, biodiversity loss, and aggregated impacts (ReCiPe) in 6 case studies A to F, relative to status quo FW. The black horizontal lines show the net reduction. At the right-hand side of the graphs the average FW amounts before implementation (red) as well as the measures implemented for FW prevention and the duration between the 1st and 2nd measurement are listed.

Case study A: In the **vegetarian restaurant** most of the avoidable FW is surplus food from the **buffet** (buffet restaurant in Figure 4.1). Thanks to the introduction of a collaboration with the association ***Foodsharing*** (Foodsharing, 2018), **48 g/meal were donated** (**70% of the avoidable FW** excluding trim waste). Food donations are assumed to be consumed. This lead to a 46% reduction of avoidable and possibly avoidable FW (including preparation losses) and to a reduction of biodiversity impacts by nearly 60% (assuming all donations are consumed). The reduction in biodiversity impacts was influenced in particular by reducing the FW of vanilla cream, (exotic) fruit juices, and oils and fats.

Case study B: In the **beer hall** restaurant more than 1/3 of status quo avoidable FW was plate waste from the guests (Figure 4.1). This is not surprising since big portions are one of the highlights communicated to the guests. Two weeks after the first measurement they **reduced the portions by roughly 10%** during a test period. The results of the second measurement showed that starch side dish leftovers could be reduced (e.g. French fries, baked potatoes), whereas fruit and vegetable waste increased (mainly because more lemons were served as a decoration on some types of dishes and beverages). Regarding climate impacts, the benefits from avoided starch waste are minor compared to the benefits from **reduced meat waste (-8% of total initial impacts)**, even though the amount of meat waste was only reduced by 2%. The case study demonstrates the importance of avoiding large meat portions and, instead, offering second helpings. Since edible preparation waste strongly depends on the type of menus offered, the observed reduction might not be representative. There is still an important potential to reduce biodiversity impacts by avoiding lemon waste (e.g. serving thin slices instead of quarters) and oil waste from roasting (Figure 4.1).

Case study C: In the **primary school,** better planning and cooking foods better suited **to the children’s taste** proved to be successful strategies for FW reduction. For example, in the first measurement most of the biodiversity impacts were caused by a pineapple fish curry dish, which contained unknown and spicy flavours. During the second measurement, the served dishes were adapted well to the children's taste and **biodiversity impacts of FW dropped by about 1/3**. The case study also shows that even an increase in FW can lead to environmental benefits and vice versa, if the composition of FW changes (e.g. pudding with 20% cocoa can cause 20-30x more biodiversity impacts per kg than pudding with other flavours).

Case study D: In the **hospital** status quo avoidable FW was highest of all case studies with 302 g/meal (Figure 4.1). Thereof, more than half of the waste was plate waste from the patients and an additional 15% was from untouched trays. The related climate impacts are more than 670g CO_2-eq/meal (Figure 4.1). The management made a list of 31 measures to reduce FW. **After one year** of implementation the **amount and environmental impacts of FW were reduced by roughly 1/3**. More than half of the reduction was achieved in the kitchen, by reducing overproduction of soup, starch, and vegetables. Vegetable waste reduction corresponded to 13% of the initial waste, but only to 2-4% of the environmental impacts. However, the 3% FW reduction consisting of meat lead to environmental benefits of 15-16% (Figure 4.2D). There is still considerable potential for FW reduction by increasing communication between the kitchen and the management office in order to optimize production quantities and avoid **untouched trays (>50 g/meal)**.

Case study E shows the reduction in a city **hotel** achieved within 9 weeks (city hotel 3 in Figure 4.1). In this case, most food is served during breakfast. **Introducing a staff member who is responsible for the buffet in the last hour before closing** reduced avoidable FW considerably (although the exact number of -70% is uncertain due to a relatively high share of liquids disposed together with the FW). The massive reduction was achieved by, in the last hour of the buffet, serving food per order rather than continuously filling the buffet with perishable food. In terms of mass, most of the reduction was achieved with vegetables, bread, and meat (-19% each), whereas in terms of climate impacts meat was most dominant. In terms of biodiversity, in addition to meat, banana and lemons provided substantial benefits.

Case study F: In a **business canteen** of a large company all employees can eat from a buffet for free (buffet 1 in Figure 4.1). The measurements during breakfast and lunch show that large amounts of FW originate at the **buffet (116 g/meal)**, from **preparation (33 g/meal)**, plate waste from the **guests (22 g/meal)**, and kitchen **overproduction (18 g/meal)**. When introducing a new canteen on the same campus (plate 2 in Figure 4.1). the company introduced a **new service system**. The guests can still consume without limits for free; however, in order to avoid both excessive portions and surplus buffet food, the guests can choose to take a pre-prepared dish or select individual components **at the counter**, which are served in limited portions. Overproduction was slightly increased by 4 g/meal, but all buffet surplus was avoided. The results show that bread and starch could be reduced by 31% and vegetables by 19%. **Total FW was reduced by over 70%.** The reduction of environmental impacts was similar. However, bread and starch only contributes to an impact reduction of 10-13%, while the small 2% reduction of meat & fish waste, including a shift from meat to fish, provides the largest environmental benefits of all food categories.

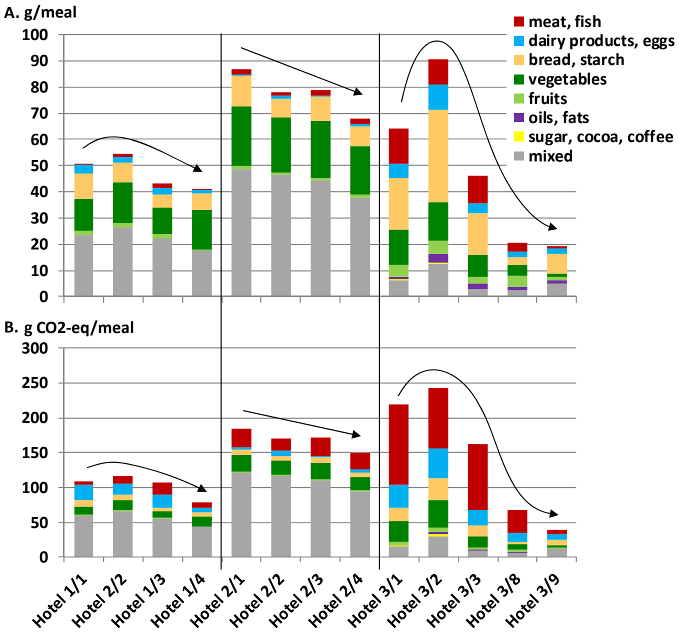

Figure 4.3: (A) Time series of FW amounts and (B) its climate impacts in the touristic hotels 1 and 2 from week 1 to 4 and in the city hotel 3 in the weeks 1-3 and 8-9 (in between no measurements were carried out).

In the three hotels illustrated in Figure 4.3 we analysed a sequence of either four or five weeks after FW reduction measures had been implemented. At hotels 1 and 3, FW actually increased in the initial phase before FW prevention was successful. This may be due to a staff adjustment period during the implementation of new FW tracking and food management systems. Before FW reduction is successful, there may be a brief staff learning phase.

4.3.1.3 *Progressive restaurant in a food value chain perspective*

Average avoidable FW across all food services investigated is 108 g/meal, causing 238 g CO_2-eq/meal. While slighly more FW is produced in the supply chain of food services (144 g/meal), the climate impact is lower with 142 g CO_2-eq/meal due to lower supply chain impacts of the wasted food (Figure 4.4) (Beretta et al., 2017). The restaurant “Mein Küchenchef”, whose strategy is to avoid FW across the whole supply chain, causes **10x less avoidable FW** per meal **(26 g/meal)**. FW related **climate impacts** per meal, including impacts from additional plastic bags used for sous-vide cooking, are **7x lower (52 g CO_2-eq/meal)** than average food services. **Overproduction is avoided entirely with the sous-vide cooking technique**, since all produced food is vacuumed in small portions and conservable for at least several days. The maximum climate impact of plastic bags used for sous-vide cooking is based on the assumption that all meals are cooked in bags of five portions per bag (see section 4.3.4). Plate waste is only 2.3 g/meal due to the **small portion size of the initial serving, with an option for refill**, **communication between staff and guests** respecting special wishes, and constant **quality feedback to the kitchen**. Edible trim waste is 4.4 g/meal. Using 106 g/meal of **unmarketable vegetables** directly from the farmers and the processing industry avoids vegetable FW at the agricultural level, which would otherwise be composted or fed to livestock. Using **wholegrain flour** avoids 12 g/meal of wasted bran from the milling industry (we assume average Swiss flour consumption). **Using products at the day of their ‘expiry’ or ‘best before date’** saves an additonal 7 g/meal (assuming that they would otherwise be wasted at the retailer).

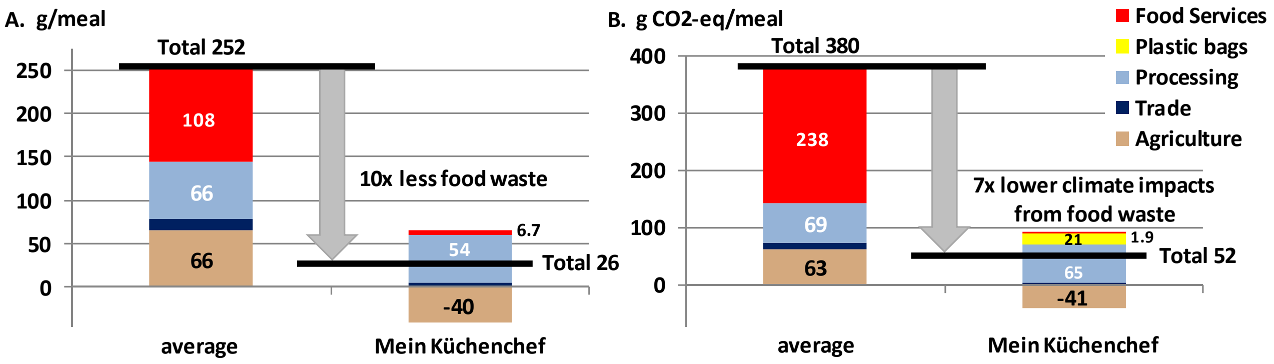

Figure 4.4: Average avoidable FW of Swiss food services and the progressive restaurant "Mein Küchenchef", including FW in the supply chain. Chart A shows the amount of FW, chart B the climate impacts, including plastic bags used for sous-vide cooking. Note: negative FW means avoiding FW arising in the supply chain by sourcing food products which otherwise would have been wasted.

4.3.1.4 Food waste reduction per subsector and progressive restaurant

Average FW reductions ranged from -32% in the education subsector to -62% in business caterings. The reduction in terms of climate change and aggregated ReCiPe impacts is similar in most subsectors; in hotels environmental benefits are higher due to a high share of avoided animal product waste in the case studies. In school canteens the previously wasted meat dishes contain ingredients particularly relevant to biodiversity impacts (case study C. in section 4.3.1.2 and case study G. in section C.3.1 in the appendix), explaining why a 32% FW reduction leads to a reduction of biodiversity impacts by roughly 50% (Figure 4.5). Adapting the recipes and production quantities to the customer segment is crucial, especially for young guests. The beer hall case study (4.3.1.2, example B) showcases the effect of fruits and oils on driving higher biodiversity impacts in restaurants, indicating that food services with special meals and/or preparation methods can dominate results and restaurant specific priorities should be set.

The 60-70% reduction in the business subsector includes the example of a company that introduced a new canteen with plate service (business 2 in Figure 4.1) instead of the "all-you-can-eat" buffet style (business 1 in Figure 4.1) with the intention to reduce FW. The new canteen is comparable in terms of guest type (employees from the same company), but it is smaller and thus might facilitate better communication between staff and guests. A second special case is the school canteen that rebuilt its service area from plate service at the counter to an "all-you-can-eat" buffet. It exemplifies how system changes can dramatically influence FW amounts while other parameters remain constant (e.g. number and type of guests). We used the plate service system as a case study with reduced FW. Except for these two special cases, the measures applied in the case studies could be implemented in other food services within a few weeks or months. Thus, **FW reduction is a quick opportunity to substantially reduce environmental impacts of consumption**. The progressive restaurant "Mein Küchenchef" shows that there is still an important potential for FW reduction in the food service sector in the long term, notably through avoiding over-production and implementing the use of non-marketable products. For example, more vegetables that can be further processed and stored are wasted in the agricultural and processing stage of the Swiss food value chain than all food services consume (section 4.2.4.2).

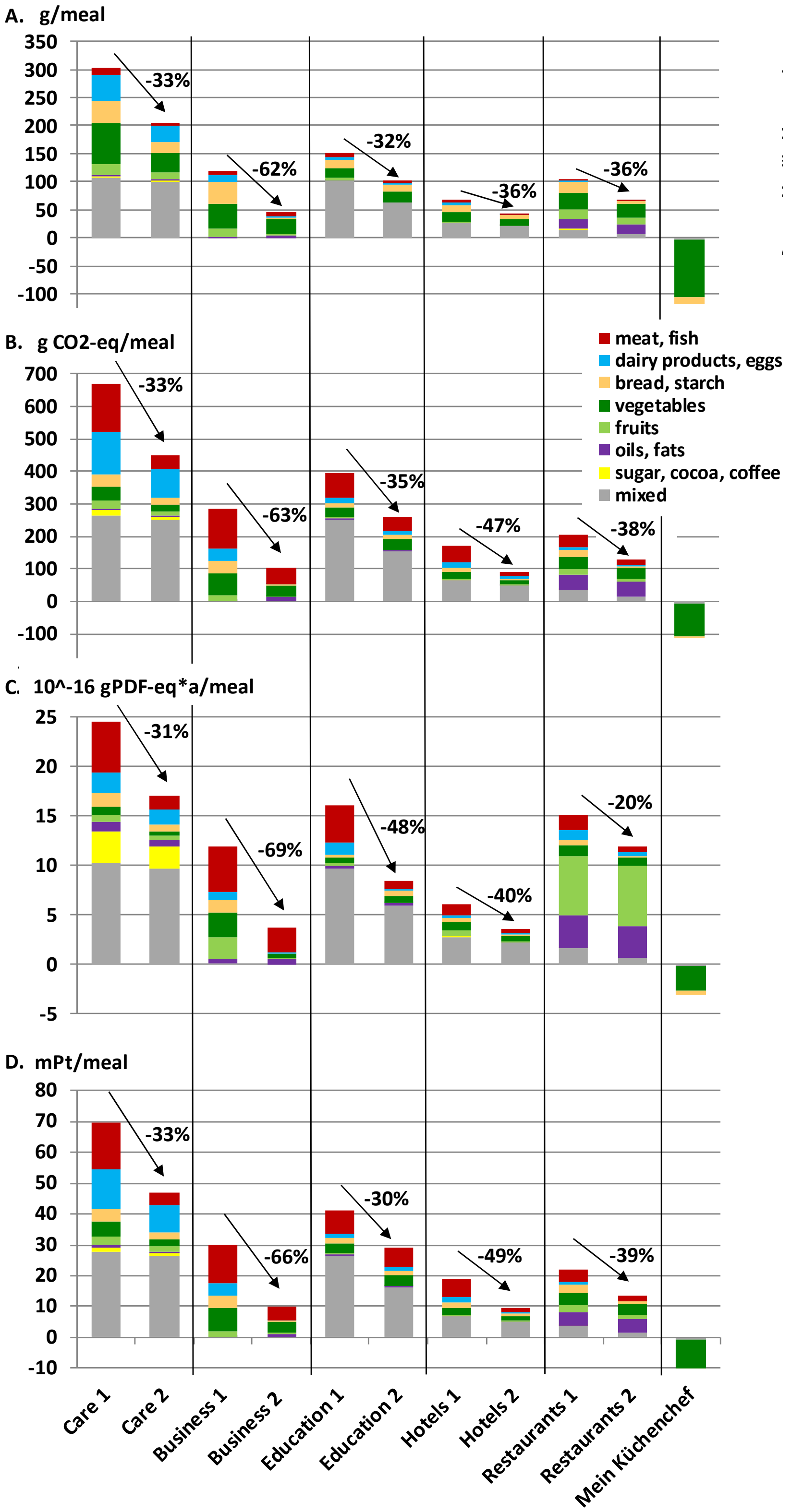

Figure 4.5: Avoidable FW and its impacts on climate change (g CO_2-eq), biodiversity loss (gPDF-eq*a), and aggregated ReCiPe impacts (µPt) per meal (without impacts from packaging). The values represent the average of all case studies in the corresponding subsectors, which have implemented measures for FW reduction and measured FW (1) before and (2) after implementation (Table C.1). The percentages indicate the reduction relative to status quo. “Mein Küchenchef” represents a progressive restaurant specializing in FW minimization (section 4.3.1.3; FW arising in the supply chain is not included in this Figure, in contrast to Figure 4.4).

4.3.2 Status quo food waste amounts in Europe

In Figure 4.6 the amounts of avoidable FW from studies in Germany, Austria, Finland, and the UK (calculated in Figure C.1 – C.4) are compared to the case studies from Switzerland in each subsector. The results show relatively high variability between studies, especially for health care, education, and staff caterings. This is an indication that parameters other than the subsectors might be relevant in determining the amount of FW, such as the serving system, the degree of convenience, or the variety of menus offered.

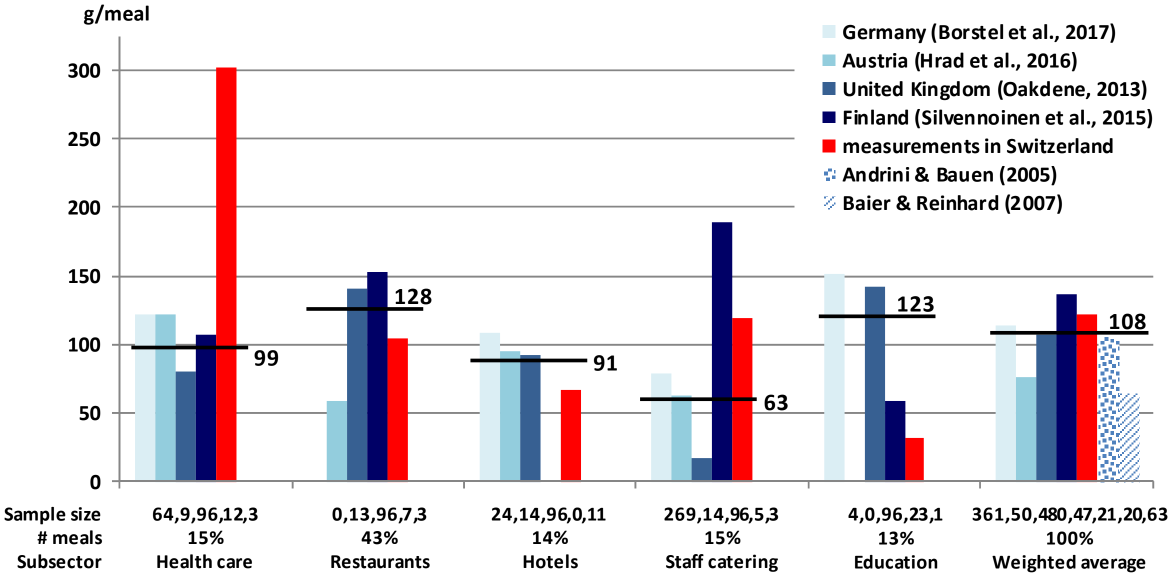

Figure 4.6: Comparison of FW amounts per meal in the studies considered in our calculations (Oakdene, 2013, Silvennoinen et al., 2015, Hrad et al., 2016, Borstel et al., 2017) and the measurements in Switzerland (red) in each of the five subsectors. For the average of all subsectors two additional studies from Switzerland are considered (Andrini and Bauen, 2005, Baier and Reinhard, 2007). The black horizontal lines show the average of all studies, weighted according to the corresponding sample size (number of food service locations analysed in each study). The subsectors are weighted according to the share of meals consumed in each subsector, indicated at the bottom of the graph (# meals). Additional details are in Table C.3.

4.3.3 Base and extended scenario of food waste reduction in food services

The **base scenario** of FW reduction is shown in Figure 4.7 A-C. Status quo FW is based on the measurements and papers from different European countries considered in Figure 4.6; FW reduction is based on the case studies presented in Figure 4.5 for each subsector (Table C.1). The subsectors are weighted based on their share of consumed meals estimated for Europe (Figure 4.6). The environmental impact factors are based on the Swiss food value chain and might differ in other countries (section 4.3.5). Noticeably, in the status quo a small amount of meat (~5 g/meal, 5% of all FW) causes 23% of the climate impacts. Conversely, a larger amount of bread and starch (~19 g/meal, 18%) only contributes 8% of the climate impacts. Accordingly, the largest quantitative reduction has been achieved in the category of bread and starch, whereas the largest climate benefits result from saved meat. In an **extended reduction scenario** all food services utilize 50% presently non-marketable vegetables, preventing them from being wasted in agriculture and trade, and thus save an additional 41 g CO_2-eq/meal.

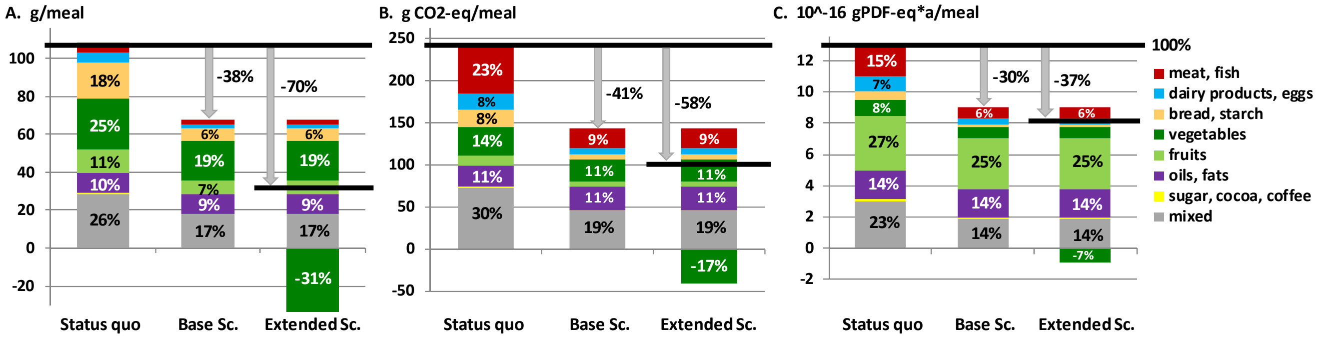

Figure 4.7: Status quo FW (A) in terms of mass (g/meal), (B) climate impacts (g CO_2-eq/meal), and (C) biodiversity impacts (gPDF-eq*a/meal) and base and extended reduction scenarios, differentiating among 8 food categories. The negative bars in the extended scenario show FW “saved” from the food value chain (see text), the horizontal black lines the net FW amounts and impacts caused in food services in the extended scenario versus status quo.

We estimate that 1.43 billion meals per year are consumed **in food services in Switzerland** and more than half of them in restaurants (Figure 4.8, Figure C.5). The share of the subsectors deviates slightly from Europe (Figure 4.6). If all food services reduced their FW to the level of the case studies in their respective subsector (Figure 4.5), **status quo FW** from food services (164’000 t) could be **reduced by ~60’000 t** (-36%). Estimated climate benefits are 140 kt CO_2-eq (-39%) and biodiversity benefits 6x10^{-7} gPDF-eq*a (-29%). The aggregated environmental impacts calculated using the Swiss method of ecological scarcity are reduced by 360 million ecopoints (-36%), which is proportional to the reduction by mass (Figure C.8). **Restaurants are the subsector with the highest reduction potential** (Table C.11). However, it may be more difficult to implement measures at their level since small individual companies have to be reached, compared to subsectors with more institutional caterers with central management. Further relevant subsectors are the education and healthcare subsectors, which might be more easily influenced by the authorities.

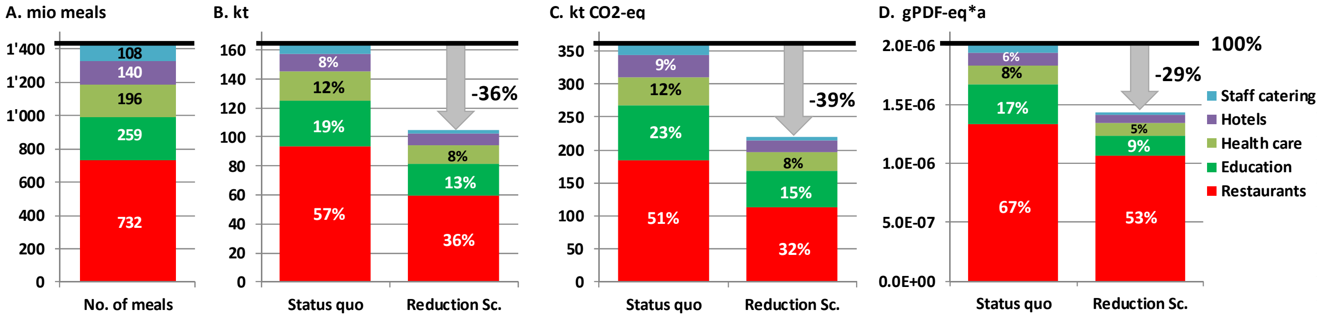

Figure 4.8: (A) Number of meals estimated in each subsector in Switzerland (Figure C.5) and (B) comparison of FW amounts, (C) climate impacts, and (D) biodiversity impacts in the status quo versus reduction scenario. Status quo FW is based on averages per meal in each subsector (Figure 4.6) and the reduction scenario is based on the relative reduction in each subsector (Figure 4.5). The extended scenario is presented in section C.6.1 in the appendix.

4.3.4 Data quality, sensitivities, suggestions

FW measurements were carried out with different goals, at different levels of detail, and by different actors (scientists, kitchen staff, student assistants). Generally, members of the kitchen staff are working with time constraints and FW measurements are a second priority to their main tasks. **Incomplete datasets**, **inconsistent practices** (e.g. menus offered, food classification, or consideration of liquids), **short measurement periods** and high variability between individual food services are possible reasons for uncertainties.

FW amounts are based on studies in countries of Central (CH, AU, DE), Northern (FI), and North-Western (UK) Europe. However, **parameters influencing the amount and environmental relevance of FW** might differ between countries. For example, plate waste might be lower in countries with lower **income**. The environmental impacts per kg of FW might be higher in countries with a larger **share of meat** consumption than Switzerland (e.g. France), more **carbon intensive electricity mixes** (e.g. UK, DE), and FW disposed of in **landfills** (e.g. UK). Without considering these aspects the results of this study cannot be generalised to other European countries. Furthermore, secondary behavioural changes due to FW reduction measures are ignored, e.g. if customers take left-overs home and waste more food elsewhere (rebound effects).

The environmental impacts of FW can be heavily influenced by a few ingredients with large environmental impacts per kg, e.g. vanilla or cocoa for biodiversity impacts. Since FW is categorized into **simplified food categories** and the real recipes are usually unknown and thus **approximated with similar recipes**, the environmental impacts are uncertain. It is therefore important to extend LCA databases and include more relevant food products and environmentally relevant ingredients, including spices and herbs, in order to reduce the degree of simplification of FW composition. The environmentally most relevant products and ingredients should be quantified more precisely than others (e.g. the amount of cocoa in a recipe). We generally took into consideration **preparation factors** for dishes with large differences between raw and cooked weight (e.g. pasta, rice), but for less usual dishes and combinations we neglected preparation factors. For dishes with a large **share of liquids** (e.g. soups, sauces) we estimated the water contents (Table C.17; further details in Chapter 7 in the appendix).

4.3.5 Comparison with literature and outlook

Since we based the **status quo amount of FW** on our case studies and recent literature, our estimations are consistent with the present state of knowledge. In addition to the values from literature used in our calculations, FW measurements in 2 restaurants and 2 school canteens in Sweden revealed that 15-22% of the foods that enter the kitchen are wasted (92 g/meal in average), which is slightly lower than our estimates of 108 g/meal avoidable FW (Engström and Carlsson-Kanyama, 2004). Dias-Ferreira et al. (2015) estimate plate waste over 8 weeks in a general hospital in Portugal at 953 g/patient/day. Assuming 3 meals per day, this is 5 times more than our estimation (Table C.3). Pirani and Arafat (2016) quantified plate waste and overproduction in 45 hotels and restaurants in the United Arab Emirates at 13 to 45% of food input (60-400 g/meal assuming served portions of 450g). These large amounts, mainly reported in lunch buffets, are an indication that cultural changes might be important parameters determining FW patterns.

The large variation between studies (Figure 4.6), notably between food services of the same subcategory, suggests that more research is needed to subdivide the food service sector into subcategories with homogeneous FW characteristics and to reliably determine the reasons and amounts of FW in each subsector. Relevant parameters for appropriate categorization might be, for example, preparation methods, degree of processing of purchased food, types of menus, customer segments, or service systems. To obtain large, comparable datasets, methodologies need to be **harmonized** and the scope and system boundaries of studies well-coordinated, e.g. using the **tree structure** proposed by Eriksson et al. (2018) as a general framework for FW quantification. Reliable and comparable FW quantification in food services is important to **monitor FW reductions** and to **improve strategies for prevention**.

The **FW reduction** of **38%** achieved in our case studies is consistent with Borstel et al. (2017). Based on FW measurements in 393 German food services and experiences during the collaboration with members of the staff, they conclude that a **30-50% FW** reduction is **challenging, but realistic**.

According to Usubiaga et al. (2017) the food categories with the highest environmental intensity relating to mass are meat and processed products. This is mostly consistent with our results; however, **processed products** do not necessarily have high per-kg impacts since the impacts depend on the ingredients and the method of processing (e.g. ready-made mashed potatoes).

The **progressive** restaurant "Mein Küchenchef" (4.3.1.3) represents a realistic future scenario for restaurants. However, it is based on one case study and therefore doesn't necessarily apply to other circumstances and types of food services. Further case studies with a similar philosophy to "Mein Küchenchef" should be realized in different subsectors, combining FW prevention with other measures to improve sustainability.

4.4 CONCLUSIONS

4.4.1 Status quo amount of food waste

The results of this study confirm that status quo avoidable FW in food services is relevant with 108 g/meal. Extrapolated to Switzerland this amounts to 164’000 t and contributes **6% to total avoidable FW** in Switzerland (2% more than estimated in our previous publication Beretta et al. (2017), Figure C.7). The **climate impacts** of 360 kt CO_2-eq account for **10%** and the **biodiversity impacts** for **9%** of total avoidable FW.

4.4.2 Food waste reduction

The results of the 13 case studies across all subsectors show that it is possible to **reduce FW in food services** substantially **within a few weeks or months** (**by 38%** in our case studies across all subsectors; Figure 4.7). If in-house FW reduction is combined with the **use of products which otherwise would have been wasted in the supply chain**, FW can be reduced even more (**by 70%** in the extended scenario of using presently unmarketable vegetables, Figure 4.7). With these findings, the **SDG 12.3 of halving per capita FW by 2030** is **a realistic goal** for food services. However, it is **challenging to** induce changes in all food services and **reach the goal in the entire sector**. The current study only worked with food services that were already interested in the topic of FW and volunteered to implement measures for FW prevention. Notably, different types of food services require different measures for FW reduction. The measures for FW prevention depend on various parameters (e.g. serving systems, customer segments, preparation methods) and **should be adapted to individual food services**. Further case studies are necessary to determine which parameters are relevant to define different types of food services and the corresponding FW reduction measures most appropriate in each food service. The results show that the **five subsectors** care, hotels, restaurants, business, and education canteens are heterogenous and **need further differentiation**.

4.4.3 Prioritization of food categories and environmental benefits

In some case studies the environmental impacts of FW increased despite quantitative reductions of FW. In the beer hall example FW was reduced by 17% compared to status quo, but biodiversity impacts increased by 7% (mainly because the 8% reduction of cereal losses has lower biodiversity impacts than the 6% increase in lemon losses, Figure 4.2). However, in other case studies the environmental benefits exceed the quantitative FW reduction (e.g. hotels reduced climate impacts on average by 47% with a mass reduction of 36%; Figure 4.5). For the implementation of strategies for FW prevention it is therefore important to **prioritize the reduction of food categories with high environmental intensity** (e.g. meat, cocoa, vanilla, products imported by air, products grown in heated greenhouses).

On average, the FW reduction of -38% achieved in the case studies could reduce climate impacts slightly more (-41%) and biodiversity impacts slightly less (-30%). This is not only relevant compared to impacts of FW, but also compared to total food consumption in food services. The **base reduction scenario saves 4.9%** and the **extended** scenario **8.3% of the climate impacts of food consumption**. The **progressive restaurant** “Mein Küchenchef” **needs 31% less food** per meal by reducing its FW and using food which would otherwise probably be wasted. Therefore, the **climate impacts per meal** are **18% lower** compared to average food services (Figure C.18).

4.4.4 Policy implications and practical relevance

In order to reach the SDG 12.3 of halving per capita FW by 2030, measures for FW reduction have to be implemented in most of the **32’417 food services in Switzerland**. The biggest 728 catering chains only contribute 12% to the volume of sales of the food service sector (BAFU, 2017). Therefore, **strategies to reach small individual caterers** and implement effective measures are crucial. In order to coach several thousand food services within a decade, strong political support is needed. **FW reduction in food services should get high political priority** since **relatively low efforts lead to high environmental benefits** and since FW prevention in food services can positively affect the **customers’ motivation to also reduce their own FW**. The extended FW reduction scenario presented in section 4.4.3.3 estimates **potential climate savings at 239 kt CO_2-eq** (67% of total FW impacts in Swiss food services, Table C.14). Furthermore, FW reduction in food services not only saves environmental impacts, but also provides considerable potential for financial savings in the food service sector. Political investments can therefore not only be justified with environmental targets, but also a **positive effect on the economy** (Oakdene, 2013). In one of the case studies the cost of FW relative to total food purchases was reduced from 17% to 11%. The resulting food cost savings after only one year were 11 times higher than the initial investments into food tracking, coaching, implementation of measures and awareness rising (Gut, 2018). However, further research is needed in order to quantify potential economic savings from FW prevention at the national level.

Since decisions in food services can also reduce FW in the preceding food value chain (e.g. using wholegrain flour, unmarketable fruits and vegetables or follow-up products such as bouillon), it is important to tackle the problem of FW in a supply chain perspective and **involve all actors of the food value chain**.

4.5 ACKNOWLEDGEMENTS

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CHAPTER 5

ENVIRONMENTAL TRADE-OFFS IN FRESH-FRUIT COLD CHAINS BY COMBINING VIRTUAL COLD CHAINS WITH LIFE CYCLE ASSESSMENT

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ABSTRACT

Refrigeration is vital in fresh-produce supply chains for minimizing food losses. However, it requires energy and impacts the environment. To optimize the control and logistics of postharvest cold chains, we need to better identify trade-offs between maintaining fruit quality and reducing environmental impacts. Therefore, we propose a novel computational method, by combining life cycle assessment with virtual cold chains. This holistic approach allows us, on the one hand, to track the thermal history of the cooling process and fruit quality decay of each single fruit in an entire pallet throughout the cold chain, using computational fluid dynamics. On the other hand, the carbon footprint of the supply chain is quantified. This pioneering method enriches life cycle assessment with more customized input data from multiphysics modeling, and at the same time assesses food quality evolution. Significant differences between ventilated carton designs (63 g CO_2-eq/kg) and cold chain scenarios (11 g CO_2-eq/kg) were identified, namely 10% and 1.6% of the environmental impact of the entire supply chain, respectively. If solar electricity is used for precooling, the environmental impact was reduced by 55 g CO_2-eq/kg of fruit (or 8.5%), while still providing similar fruit quality retention. By combining climate impact with the predicted quality retention, this method will help retailers to choose the most optimal package design and cold chain scenario to make their food supply chains more sustainable. This approach can be applied as well for life cycle assessment of biogas conversion of food waste, amongst others.

NOMENCLATURE

Symbols

A	quality attribute [-]
c	constant, 3600 kJ kWh^{-1}
c_p	specific heat capacity of the produce [kJ kg^{-1}K^{-1}]
E_e	consumed electricity per month [kWh mo^{-1}]
E_A	activation energy [J mol^{-1}]
k	rate constant [s^{-1}]
k_0	constant [s^{-1}]
M	total mass of all produce that is cooled per month [kg mo^{-1}]
n	reaction's order [-]
R	ideal gas constant, 8.314 J mol^{-1} K^{-1}
T_i	product temperature at the start of the cold chain [K]
T_f	product temperature at the end of the cold chain [K]
T	absolute temperature [K]
t	time [s]

Abbreviations

CFD	computational fluid dynamics
CO_2-eq/kg	carbon dioxide equivalent per kg of fruit
EC	energy coefficient
LCA	life cycle assessment
ReCiPe	method for aggregated life cycle impact assessment (Goedkoep et al., 2013)
VCC	virtual cold chain

5.1 INTRODUCTION

A large share of produced fruit and vegetables are lost between leaving the farm and arriving at the retailer. These postharvest losses in fresh produce supply chains vary from 13% in Europe up to 38% in sub-Saharan Africa (Gustavsson et al., 2011). Proper refrigeration helps to reduce these losses as temperature is the single most important environmental factor affecting the produce deterioration rate and thereby the postharvest life. A decrease in product temperature by 10°C from ambient conditions typically doubles the shelf life (Robertson, 2016; Thompson, 2004). Therefore, a rapid removal of the field heat by cooling after harvest, and the maintenance of optimum cold temperatures throughout the supply chain are essential to preserve fruit quality and minimize losses.

Refrigeration, however, consumes energy, and accounts for 8 % of all electrical energy used in the food industry (Zilio, 2014). With over 400,000 reefer containers and 1’000’000 refrigerated vehicles currently in use (Gac, 2002), the postharvest transport of such refrigerated cargo is responsible for a large share of this energy consumption. With every product that is lost within the supply chain, the corresponding energy used to preserve, and agriculturally produce it, is thereby also lost (FAO, 2011; Gustavsson et al., 2011). The cold chain thus plays an important role in the food-energy-water nexus (Martinez-Hernandez et al., 2017; Owen et al., 2018). Therefore, optimizing postharvest cold chains by prolonging produce shelf life, thereby reducing losses, and lowering energy consumption is essential to reduce the environmental impact. To achieve these goals, new cold chain scenarios (Defraeye et al., 2015) or ventilated package design (Berry et al., 2017; Defraeye et al., 2013a) have recently demonstrated promising potential. However, the currently used methods to evaluate these innovative technologies still suffer from key limitations, which are discussed in the two paragraphs below.

Advanced experiments in refrigerated containers (Jedermann et al., 2014; Moureh et al., 2009) or precooling facilities (Wu et al., 2018) have been used, as well as numerical modeling with computational fluid dynamics (CFD) (Defraeye et al., 2015a; Zhao et al., 2016) . These experimental and computational techniques (Laguerre et al., 2013) enabled to identify and optimize the thermal history of individual products, arranged in larger bulks (e.g. a pallet), and their associated quality evolution. These thermophysical methods provide a very detailed insight into, and understanding of, cooling behaviour in the supply chain. As a novel step in this field, a virtual cold chain (VCC) method was recently developed (Wu et al., 2018; Wu and Defraeye, 2018). Employing the VCC method enables tracking of the thermal history and associated fruit quality of every individual fruit in an entire pallet of packaged fruit throughout the entire postharvest cold chain of interest using CFD. In addition, information on the energy use for ventilation and cooling can also be extracted. These high-resolution numerical or experimental methods, however, lack a quantification of the environmental impact of the different cooling scenarios, supply-chain itineraries and ventilated package types (e.g. cardboard vs. plastic). This is a key bottleneck of such methods, as new cooling strategies can be devised that maintain food quality better, but the data do not enable to quantify how sustainable the new processes are. For that, the entire supply chain needs to be targeted, including differences in travel times, the amount of containers or lorries needed to transport a certain amount of fruit, the food losses, and the used amount of packaging material.

Life cycle assessment (LCA) (Hellweg and Canals, 2014) is capable of providing this information, and is widely used as a decision-support tool by retailers (Stoessel et al., 2012), food companies and policy makers (Hospido et al., 2010; SIK, 2007) to reduce the carbon footprint of their supply chains (Andersson, 2000; Cerutti et al., 2014), including the impact of food losses (Beretta et al., 2017). The recent development of LCA methodologies and dissemination programs by international and local bodies is the basis for LCA’s increased use on agricultural and industrial food products (Roy et al., 2009). In a related context, LCA is also used to evaluate the conversion of food waste into biogas by recycling (Ebner et al., 2014; Jin et al., 2015) or the use of renewable energy in distribution networks of perishables (Burek and Nutter, 2019). LCA enables identification of trade-offs between sourcing regions, transport itineraries, energy technologies or material usage, amongst others (Albrecht et al., 2013; Sanjuan et al., 2005). LCA however relies on inventory databases, such as ecoinvent (Ecoinvent, 2016; WFLDB, 2015), which often only include generic inventory data of postharvest unit operations (precooling, refrigerated container transport or cold storage) (Sanjuán et al., 2014). Dynamic modeling of food products depending on the region, seasonality, food waste rates, or other parameters in the food supply chain is rare, and especially information on the energy consumption is not specific enough (Cuéllar and Webber, 2010), despite the significance of the food system as an energy consumer (Stoessel et al., 2012). For instance, no differentiation in energy use is made between ventilated package designs or container stowing strategies, although these differences have been recently identified to be relevant (Defraeye et al., 2016). As such, the energy and quality gains from better cooling processes and better package systems are rarely explicitly incorporated in LCA (Wikström et al., 2014). In addition, although there are many studies on food waste management (Roy et al., 2009), the avoidable food losses and waste, and the associated embodied energy, are often not accounted for or only covered by approximate assumptions in most LCA studies (Gruber et al., 2014). In a recent combined effort, fruit quality, energy use, and the global warming impact of food cold chains were evaluated together (Gwanpua et al., 2015). However, this method did not provide a sufficient degree of detail to compare either the different package designs or the quality heterogeneity between individual fruits, for example. For retailers or food companies, it would be very useful to have a tool or method that can provide the overall environmental impact of their supply chains, and at the same time information on the temperature-dependent fruit quality evolution, by means of a food quality assessment that is linked to the cooling processes. This could help these stakeholders in the perishables supply chain to choose the most optimal package and cold chain scenario to make their food supply chains more sustainable, and to optimize logistics.

As a pioneering step towards a more holistic evaluation of fresh-produce cold chains, a combination of VCC with LCA is proposed to enrich life cycle assessment with more customized input data from multiphysics modeling. This link between these models provides us with unique information on the temperature-dependent fruit quality reduction of each fruit in a palletized cargo, together with the environmental impact of the complete postharvest part of the supply chain. This holistic method is demonstrated for the case of an overseas citrus cold chain to identify the best-performing and most eco-friendly cold-chain scenario and package.

5.2 MATERIALS AND METHODS

The strategy to combine VCC with LCA is depicted in Figure 5.1. The different methods (VCC and LCA) are detailed below, as well as the way in which they are linked.

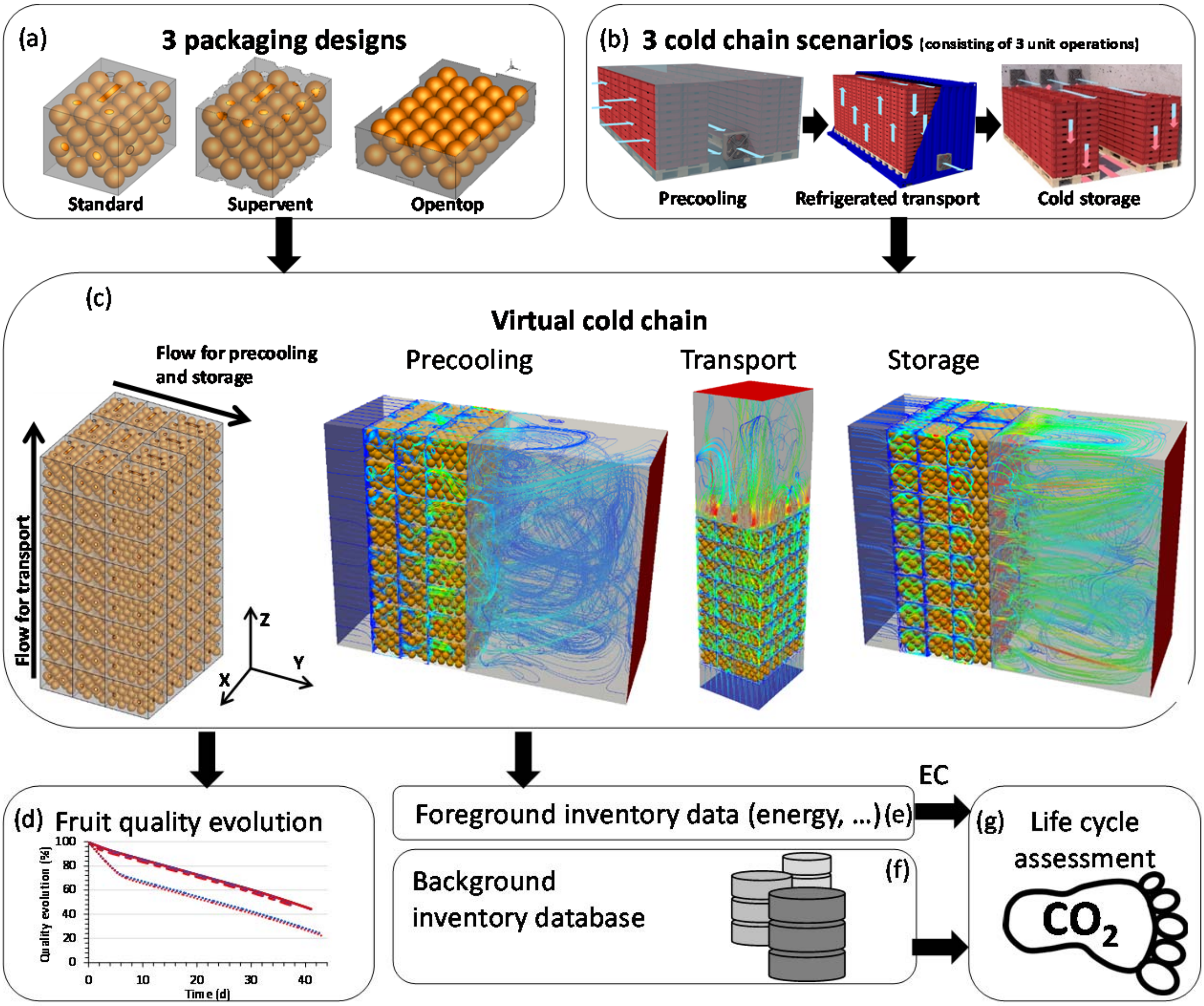


Figure 5.1: Schematic overview of the methodology combining virtual cold chains (VCCs) for different unit operations (precooling, refrigerated transport, cold storage) with life cycle assessment (LCA) to assess the individual fruit quality evolution within a pallet and the environmental impact of different cold chain scenarios and ventilated package designs.

5.2.1 Cold chain scenarios and ventilated packaging

An overseas citrus cold chain is targeted, from South Africa to Switzerland, in particular for orange fruit. Multiple cold chain scenarios and ventilated package designs are evaluated. The three carton box designs (Figure D.1) are Standard, Supervent and Opentop, which are stacked on high-cube pallets (Figure D.2). The targeted cold chains are composed of three refrigerated unit operations: (1) precooling, (2) refrigerated transport, and (3) refrigerated storage (see Figure D.3). By combining these unit operations, we simulate three scenarios of the cold chain for each package design:

- Forced-airflow precooling, where a precooler facility is used to rapidly remove the field heat after packaging and palletization, by forcing cold air horizontally at high airflow rates through the package. This is currently the standard practice in the South African citrus industry.
- Ambient cooling, also called static cooling, where fruits are cooled in a large cold room before shipment. This practice is often employed if the capacity of the precooler facilities is exceeded. The lower airflow rates, however, induce slower fruit cooling.
- Ambient loading, where fruits are loaded into the refrigerated container at the ambient temperature (<22 °C fruit pulp temperature) and are cooled using the container's cooling unit (Defraeye et al., 2016; Defraeye et al., 2015a; Defraeye et al., 2015b). This novel scenario is explored in South Africa as a way to relieve pressure on the precooling facilities as well as for its logistical advantages due to reduced handling.

To serve as a comparative contrast to the South-African situation, the impact of an alternative sourcing region for citrus fruit is also evaluated, namely, fruit coming from Valencia (Spain, Europe).

5.2.2 Coupling VCC and LCA

The VCC and LCA methods (detailed below) are linked to enable a more holistic evaluation of fresh-produce cold chains in terms of the aforementioned package designs (Figure 5.1a) and cold chain scenarios (Figure 5.1b). The following workflow is adopted.

First, the VCC approach is applied to obtain the cooling behaviour and resulting thermal history of every fruit packed inside a pallet of fruit (Figure 5.1c) throughout the complete refrigerated supply chain. From that, the associated quality evolution is extracted for each cold chain (Figure 5.1d).

In a second step, on the basis of the VCC model, the energy efficiencies for cooling orange fruit in a precooling facility, in a refrigerated container during maritime transportation, and in a cold store are estimated for the three different box types, which are required as an input for LCA. For this purpose, the energy coefficient (EC) is used to quantify the energy consumption of cold chain operations (Figure 5.1e). The EC represents the heat that has to be extracted from the fruit (in kJ) per kJ of electricity that is consumed to achieve this goal. It was defined originally for entire cooling facilities (Thompson et al., 2010) and is defined as:

$$EC = \frac{Mc_p\left(T_i - T_f\right)}{E_e c} \tag{1}$$

where M is the total mass of all produce that is cooled per month [kg mo^{-1}], c_p the specific heat capacity of the produce [kJ kg^{-1} K^{-1}], T_i the product temperature at the start of the cold chain [K], T_f the product temperature at the end of the cold chain [K], E_e the consumed electricity per month for operating the facility for fruit cooling [kWh mo^{-1}], and c is 3600 kJ kWh^{-1}. The calculation of the EC, which is based on the VCC model, is detailed in Appendix D. In conventional LCA, the energy use is assumed to increase linearly with time for a specific unit operation (Stoessel et al., 2012), that is, the required power is assumed to be constant. A main merit of combining VCC with LCA is that package-specific ECs could be determined via the VCC method, together with more accurate values for each unit operation.

In a third step, this energy consumption data, via the EC, as well as more detailed package-specific data (dimensions, fruit capacity, material weight) (Figure 5.1f) are fed into the LCA model. LCA is subsequently used to quantify the environmental footprint of the different package designs and cold chain scenarios (Figure 5.1g). By applying this strategy of linking the LCA and VCC methods, a unique insight is provided into the thermophysical behaviour of each single fruit in the cargo, together with a more detailed environmental impact quantification than is currently possible with the conventional LCA.

5.2.3 Virtual cold chain modeling of fruit cooling and quality evolution

The VCC method was presented recently (Wu et al., 2018; Wu and Defraeye, 2018), and only its key features are highlighted. The VCC method evaluates the thermal evolution of a pallet of fruit during convective cooling throughout the cold chain. To this end, each unit operation of each cold chain scenario is calculated sequentially with CFD (computational fluid dynamics, Figure 5.1c). Although these models are in some way a simplified representation of reality, they capture the differences in cooling kinetics for the individual fruit between the different unit operations. In that way, the temperature history of each single fruit inside the pallet is quantified throughout the complete postharvest cold chain. Using the data of the temperature of each fruit, a kinetic rate law model is used to predict the temperature-dependent fruit quality evolution (Figure 5.1d), as detailed below. In that way, heterogeneities in differential cooling behaviour between fruits in the pallet and the resulting quality can be identified.

For the CFD simulations, computational models of a pallet of orange fruit (spheres with diameter 75 mm) and the surrounding air domain are generated for each unit operation. Each single fruit inside the pallet is modeled explicitly. The geometrical details (vent openings) of the ventilated package design are also explicitly included (Figure D.1 and D.2). A pallet contains 5120, 5120 and 3900 fruit for the Standard, Supervent, and Opentop package, respectively. The computational models are meshed with 40 million tetrahedral control volumes for each computational model. The boundary conditions for the airflow rate and delivery air temperature are defined on the basis of commercial practices, and are specified in Table D.1. Precooling is characterized by horizontal flow at high airflow rates, refrigerated transport by vertical flow at moderate airflow rates, and cold storage by horizontal flow at low airflow rates.

The CFD simulations are executed with the software OpenFOAM 2.4.0. Turbulent airflow and heat transport through the ventilated package are solved, as well as heat transport inside the fruit and package. The air and solid domains convectively exchange heat via the boundary layer. To this end, the Reynolds-averaged Navier-Stokes (RANS) equations are solved together with the shear stress k-ω turbulence (SST $k^{-\omega}$) model (Menter, 1994) and wall functions. The current CFD model was validated on multiple occasions by the authors for fruit cooling (Defraeye et al., 2013b, 2013a) for the same turbulence model and a similar geometrical model as used in the present study. All the details of the validation procedures can be found there. A good agreement with experimental data was found.

Fruit quality evolution is modeled by means of a kinetic rate law (Robertson, 2016; Van Boekel, 2008). Such a model quantifies the change of a particular quality attribute A over time, for instance, vitamin content, and is temperature-dependent:

$$\frac{-dA}{dt} = kA^n \tag{2}$$

$$k(T) = k_0 e^{\frac{-E_A}{RT}} \tag{3}$$

where k is the rate constant [s^{-1}], n is the reaction's order (0 in this case, zero order), t is the time [s], k_0 is a constant [s^{-1}], E_A is the activation energy [J mol^{-1}], R is the ideal gas constant (8.314 J mol^{-1} K^{-1}) and T is the temperature (absolute, [K]). To include the dependency of quality decay to the temperature, the rate constant k is made a function of temperature (Eq. (3)), for which typically an Arrhenius relationship is used (Robertson, 2016; Van Boekel, 2008). This temperature is, for example, the core temperature or the volume-averaged fruit temperature. To calculate $k(T)$, k_0 and E_A were calibrated on the basis of quality decay data, and are both assumed to be independent of temperature. In this study, the model was calibrated for A being the overall fruit quality. A quality of 0% implies that the shelf life is completely lost. From literature, we assume that the quality of the orange fruit is completely lost after 56 days of storage at 4 °C (Cantwell, 2001), thus A_{end} (56 d, 4 °C) = 0%, or a shelf life of 56 d. Such data is typically obtained by shelf-life experiments at a certain temperature. For model calibration, information on the temperature dependency of the rate constant is also required. This information is determined via the Q_{10} value:

$$Q_{10} = \frac{k_{T+10}}{k_T} \tag{4}$$

where k_T and k_{T+10} are the rate constants at temperatures T and T+10K. Van't Hoff's rule states that the rate of a biological reaction doubles or triples for every 10°C rise in temperature (Thompson, 2004). As such, the Q_{10} value is about 2-3 for fruit degradation reactions (Robertson, 2016; Thompson, 2004). In this study, a Q_{10} value of 2 was chosen. This implies that an increase in temperature of 10°C doubles the rate constant, so halves the time until the fruit is lost, if stored at a constant temperature. This means that in our study, the citrus fruit can be stored for approximately 28 d at 14 ºC. Note that the model above was explicitly calibrated on the basis of experimental data, so no validation is required in this case.

More details on the CFD simulations and the fruit quality model are specified in Appendix D. Note that the VCC simulation data used in the present publication were presented as a part of a larger simulation study on ventilated package design and cold chain scenarios (Wu et al., 2019), where more details can be found.

5.2.4 Environmental impacts by LCA

The second part of the methodology consists of a life cycle assessment (LCA) of the citrus fruit supply chain and fruit waste treatment, using the software SimaPro 8.3 (PRE, 2017). Life cycle assessment starts from inventory data of specific supply chains, including orange fruit growing, fertilizer, pesticides, machinery inputs, electricity and fuel consumption of the different unit operations, the material consumption for packaging, storage, transport distances and the means of transport, the amount of food waste, and the treatment method of the wasted fruits (in regard to food waste from agricultural production to composting, and from trade and retail to anaerobic digestion). In this study, LCA receives input from the VCC simulations on the energy use of different unit operations and for different packages. The other output of the VCC simulations, namely, the fruit quality loss, was not used in LCA for predicting the resulting amount of food waste at this stage, but is a focus of our future research. Hence, the food waste amounts at different stages in the food supply chain are based on the average estimations by Beretta et al. for Switzerland (Beretta et al., 2017). The datasets used for the background processes of the life-cycle inventory are based on the LCA databases ecoinvent 3.2 ("allocation recycled content") (Ecoinvent, 2016) and the World Food LCA Database 3.0 (WFLDB, 2015). The functional unit of the various cooling scenarios to be compared was defined as 1 kg of orange fruit at the retailer, ready to be sold in Switzerland.

On the basis of the life-cycle inventory data, LCA calculates the climate change impacts with the *global warming potential 100a* method (IPCC, 2013). The impacts are expressed in kilogram CO_2 equivalents. In addition, in appendix D, the aggregated environmental impacts are analyzed with the *ReCiPe* method (Goedkoop et al., 2013). A list of the datasets and their functional units is provided in Table D.5 in appendix D, which also contains information on how energy consumption, electricity generation and food waste are implemented.

5.3 RESULTS AND DISCUSSION

5.3.1 Cooling behaviour of different unit operations and packaging designs

From VCC computations, the cooling of fruit in each unit operation is quantified via the seven-eighths cooling time (SECT) for all package designs. The SECT ($t_{7/8}$) is the time that is needed to reduce the difference between initial-fruit and cooling-air temperature to seven eighths of the initial temperature difference. The SECT is often applied in commercial cooling processes because when it is reached, the fruit is almost at the targeted storage temperature (Brosnan and Sun, 2001). We use the fruit pulp (core) temperature to evaluate the cooling progress by determining the SECT for each individual fruit. We do this because the core (pulp) temperature is the last position in the fruit where the target temperature is reached. As such, this core pulp temperature is often measured in various commercial operations to monitor cooling processes, which is typically performed by placing a point probe in the fruit pulp.

In Figure 5.2a, the average SECT of all fruit inside a pallet is given for all unit operations and package designs, together with the standard deviation. This standard deviation is calculated on the basis of all SECT values of the individual fruit. In Figure 5.2b, the SECT values, averaged over each box in the pallet, are shown for the Supervent package for the three unit operations. Each box is represented by a coloured dot; boxes are depicted in Figure D.2.

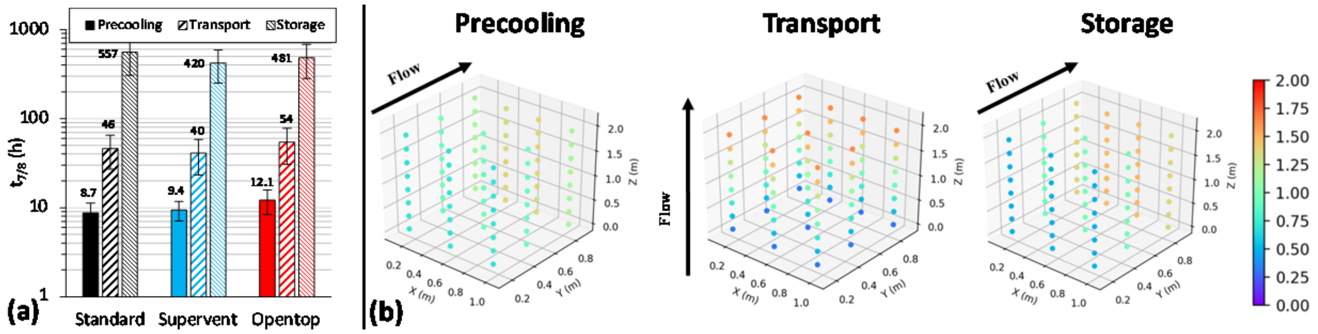


Figure 5.2: (a) Seven-eighths cooling time of the individual fruits for different cold chain unit operations and package designs: average value of an entire pallet (also depicted quantitatively) and standard deviation (logarithmic scale). (b) Seven-eighths cooling time (SECT) for a pallet of Supervent packages for all cooling operations (scaling is done with the total SECT for the entire pallet for that cooling operation, which is SECTavg). Each colored point indicates the SECT/SECTavg, averaged over each single box (Figure adjusted from Wu et al. (2019)).

For precooling, Standard and Supervent packages cool quite similarly. Opentop on the other hand cools slower and in a less uniform way (Figure 5.2). The slower and more heterogeneous cooling of Opentop is intuitively surprising as this package has the highest area of vent openings on its long as well as short side (see Figure D.1 in appendix D), compared to the Standard and the Supervent packages. This finding is attributed to the vent opening configuration, where these are distributed not so homogeneous on both the long and short sides, in comparison to the other two packages. This non-uniform distribution of vent holes introduces preferential pathways. As an example, cold airflow is directed mainly over the fruit that is placed in the top layer, which induces preferential cooling here (Figure D.1). Thus, the fruit at the bottom of the package cools more slowly. Furthermore, the air speeds are lower for Opentop due to its lower density of fruit packing (Wu et al., 2019). During refrigerated transport, the Supervent package outperforms the others. This is mainly due to the optimal vent opening configuration, namely openings located along the edges of the carton. Thus, aligned ventilation channels for cold air are present in the vertical direction along the sides of the package. Since there is also a central vent opening at both the bottom and top surfaces, uniform fruit cooling is achieved. For refrigerated storage, Supervent also performs better than the other cartons. As such, it is, in an overall sense, the carton that provides the most rapid and homogeneous cooling of the fruit.

From Figure 5.2, the spatial non-uniformity of fruit cooling in each pallet is clearly distinguishable for each unit operation. Precooling (meaning high air speeds) clearly provides better cooling uniformity when comparing individual boxes, compared to refrigerated storage (low air speeds). This indicates that the complete pallet is more uniformly cooled at elevated airflow rates. The closer the box is to the inlet, and thus upstream, the faster the cooling is for all carton types. The boxes cool progressively slower with increasing distance from the inlet, i.e. when they are located in more downstream positions in the pallet.

5.3.2 Reduction in fruit quality for various cooling scenarios and package designs

Using the sequential thermal history of the various cooling operations presented, the reduction in fruit quality is determined within the pallet. This is done for the aforementioned postharvest scenarios for each box design. To this end, the volume-averaged fruit pulp temperature within the full pallet is used instead of the single fruit core pulp temperatures, as this gives a better approximation of the general quality evolution. In Figure 5.3a, this volume-averaged (pallet-based) fruit temperature is shown for all package designs to illustrate the temperature history evolution. In Figure 5.3b, the corresponding fruit quality evolution is given.

When comparing the postharvest scenarios, forced-airflow cooling as well as ambient loading exhibit a quite similar reduction in fruit quality. One reason is that citrus fruit is quite resilient and has an inherently long storage life, so that the fruit-quality-decay timescales are much higher than the ones for cooling. Thus, the enhanced quality achieved by a more rapid cooling by using pre-cooling, in comparison to refrigeration inside the container, does not significantly affect the quality reduction of citrus fruit. However, since the postharvest chain with ambient loading has a reduced duration, the final quality is higher compared to the forced-airflow cooling chain. Ambient loading, with its clear logistical advantage, therefore also results in enhanced fruit quality, which also implies less food losses. This possibly can also increase the marketing time window. Ambient cooling, however, results in a larger quality loss in comparison to the two other cold chains. This is related to the long cold storage period at higher fruit temperatures, as a result of which the cooling rates are much lower. As such, this practice is not recommended, but is often the only option due to the limited access or availability to precooling facilities in some fruit supply regions. Ambient cooling will however induce higher quality loss, thus food waste, compared to forced air precooling. This cold chain scenario will also imply a larger economic impact for the retailers, who will have to import a larger amount of fruit to have the same net supply for their customers. However, the quality loss can also remain invisible throughout the cold chain for a resilient species such as orange fruit. This is the case if ambient cooling does not necessarily lead to additional food losses in the cold chain, but just results in a reduced number of shelf life days for the consumer. This invisible quality loss can however lead to increased food waste in households.

The differences in timescales in the cooling process and fruit quality decay also explain the fact that differences between carton designs are rather limited. For all cold chains, Opentop exhibits the lowest quality due to the overall worst cooling behaviour over all unit operations (Figure 5.2). For other fruit species, such as berries, avocado, or mango, which are more sensitive to temperature-driven quality loss, the differences between package designs or cold chain scenarios are expected to be more pronounced.

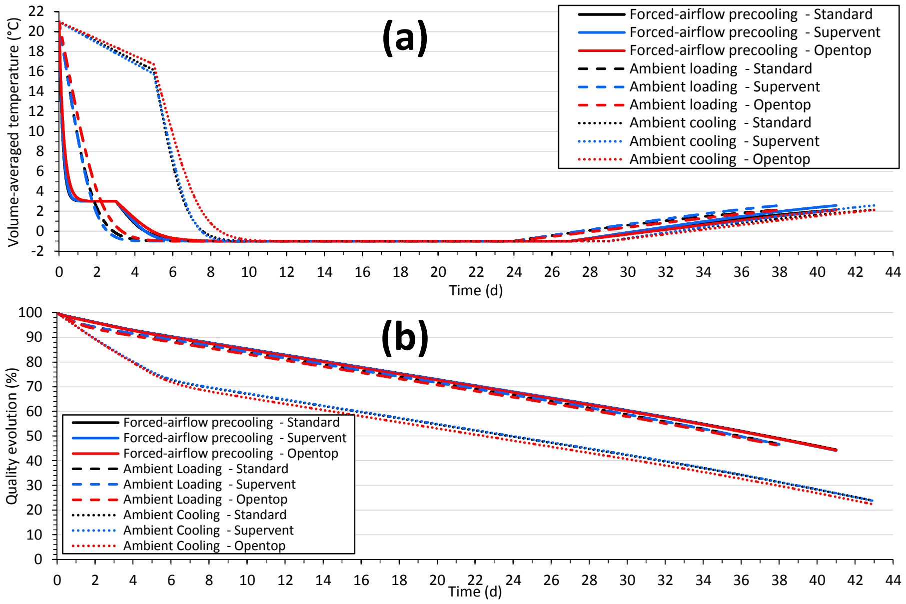


Figure 5.3: (a) Volume-averaged temperature of all palletized fruit as a function of time for various cold chain scenarios and package designs (Figure adjusted from Wu et al. (2019)); (b) corresponding fruit quality evolution in the pallet as a function of time. The remaining overall quality is depicted, where the initial quality was 100% and where the fruit is considered to be lost when the quality level reaches 0%.

5.3.3 Environmental impact of different cold chain scenarios and package designs

Using LCA, the environmental impact is quantified for all three package designs and the three cold chain scenarios. The climate impacts are represented in Figure 5.4 in grams CO_2 equivalent per kg of fruit (IPCC, 2013) and are split up into various processes of the supply chain. For processes that have the same climate impact for each cold chain scenario, no explicit value is quantified in Figure 5.4. As a fourth cold chain scenario, the use of solar energy to precool the fruit is also shown. In Figure 5.5, the differences with the base case (i.e. forced air precooling for the standard package) are quantified for each process in the supply chain to facilitate comparison.

5.3.3.1 Package designs

A comparison of package designs reveals that the Supervent box has the lowest carbon footprint for all cold chain scenarios, although the Standard box follows quite closely. The reasons for this superior performance, compared to the Standard box, are the following:

- For the precooling unit operation, the energy coefficient is higher (EC = 0.41 vs. 0.40 kJ heat removed/kJ of electricity consumed, Table D.2) so that Supervent boxes exhibit a lower carbon footprint (57 instead of 58 g CO_2-eq/kg of fruit).
- For cooling down products in a refrigerated container, the energy coefficient is also higher for Supervent (Table D.2). This cooling down is assumed to occur during lorry transport, whereas fruit are assumed to arrive already cooled in the ship. The differences in energy consumption between the packages, however, originate only during the initial phase of cooling in the container. After the fruit are cooled to the SECT, maintaining a constant interior temperature leads to equal energy consumption for all the packages. The reason is that this energy consumption depends mainly on the heat lost through the container's exterior walls, which does not depend on the package design. As such, the carbon footprints for lorry cooling are very similar (23/72/57 g CO_2-eq/kg for Supervent vs. 23/73/59 g CO_2-eq/kg for Standard for forced-airflow precooling/ambient loading/ambient cooling).

The Opentop package has a much larger environmental impact compared to Standard (and Supervent) packages for the following reasons:

- For the precooling unit operation, the energy coefficient is lower (EC = 0.36 vs. 0.40 kJ heat removed/kJ of electricity consumed) and therefore Opentop boxes exhibit a higher energy consumption for precooling (65 vs. 58 g CO_2-eq/kg).
- For cooling down products in a refrigerated container, which is assumed to happen during lorry transport, the energy coefficient is also lower for Opentop (EC = 0.27 vs. 0.40 kJ heat removed/kJ of electricity consumed).
- For cooling during transport (both ship and lorry), the fruit packing density is lower in Opentop packages (and thus in a pallet), due to the free open space that is present above the fruit in each package. As such, the amount of fruit per pallet is 3900 (60 x 65) instead of 5120 (64 x 80), which is 24% lower. Thus, the environmental impact for cooling is higher as more refrigerated containers (on ships) and lorries are needed to transport the same amount of fruit (205/28 vs. 156/23 g CO_2-eq/kg for ship cooling/lorry cooling).
- For transport, more trucks with Opentop boxes are needed in order to transport the same amount of orange fruit than with standard boxes, leading to a higher carbon footprint (91 vs. 80 g CO_2-eq/kg). For ships, however, we assume that their load factor is limited by weight and not by volume, because of which the same value is used for all packages.
- With respect to the packaging material, Opentop boxes contain 40% less carton and are thus lighter than Standard boxes, per kg of fruit. This is a beneficial effect and actually reduces the carbon footprint of the package part (47 vs. 76 g CO_2-eq/kg) which however is more than offset by the additional cooling and transport energy requirements (see above).

Significant differences between ventilated carton designs are found, with a maximal difference of 63 g CO_2-eq/kg, namely between Supervent and Opentop for the ambient loading scenario. As such, the Supervent package provides a reduction of 10% in the total carbon footprint of the supply chain (relative to that of Opentop), which is substantial.

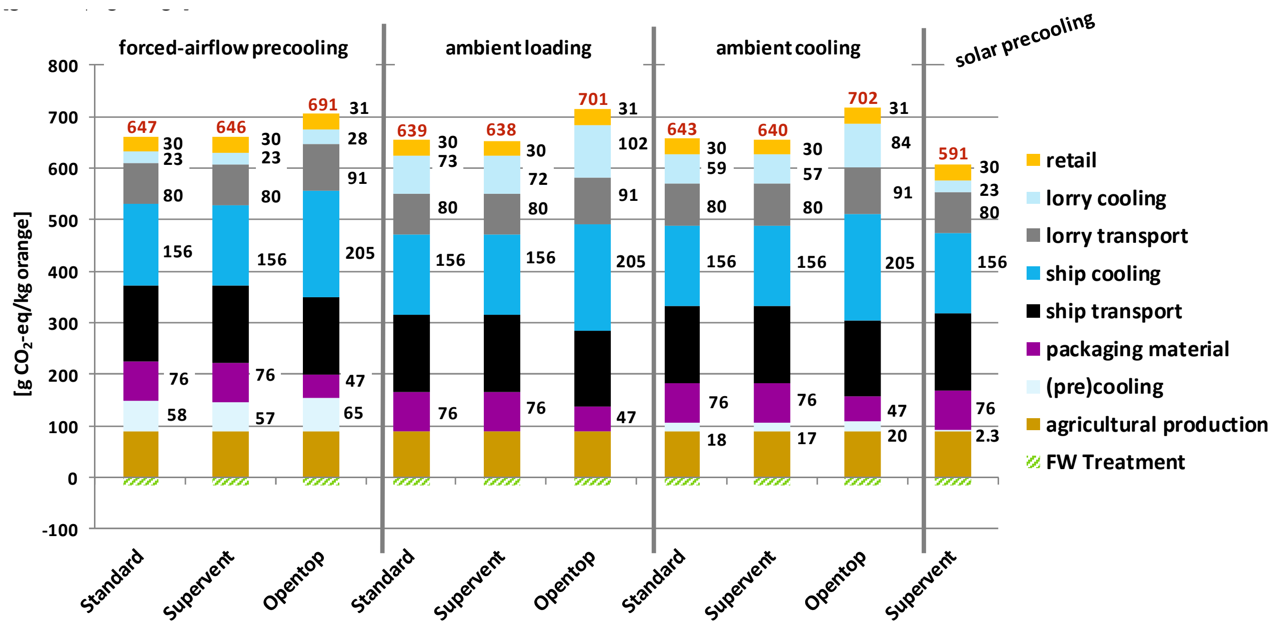
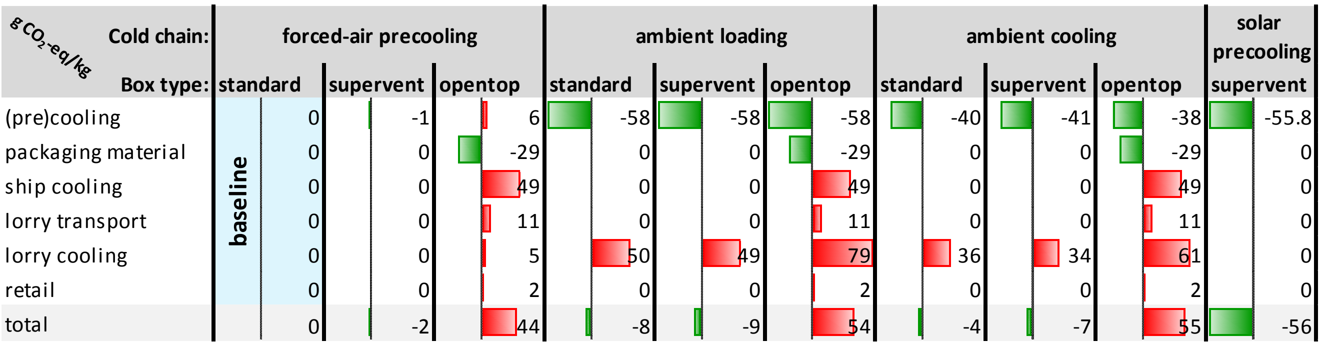


Figure 5.4: The calculated environmental impact (grams CO₂ equivalent per kg of fruit) of all package designs (Standard, Supervent, Opentop) and cold chain scenarios, split up into the different processes of the supply chain and food waste (FW) treatments. The impacts include the present amounts of food waste generated between agricultural production and retail, but exclude household food waste.



$g\ CO_2$-eq/kg Cold chain:	forced-air precooling			ambient loading			ambient cooling			solar precooling
Box type:	standard	supervent	opentop	standard	supervent	opentop	standard	supervent	opentop	supervent
(pre)cooling	0	-1	6	-58	-58	-58	-40	-41	-38	-55.8
packaging material	0	0	-29	0	0	-29	0	0	-29	0
ship cooling	0	0	49	0	0	49	0	0	49	0
lorry transport	0	0	11	0	0	11	0	0	11	0
lorry cooling	0	0	5	50	49	79	36	34	61	0
retail	0	0	2	0	0	2	0	0	2	0
total	0	-2	44	-8	-9	54	-4	-7	55	-56

Figure 5.5: Differences of environmental impact (grams CO₂ equivalent per kg of fruit) of the cold chain and package scenarios with the baseline scenario (forced-air precooling with standard box) for different operations in the supply chain.

5.3.3.2 Cold chain scenarios

When comparing the three cold chain scenarios, ambient loading has the lowest environmental impact, except for Opentop packages. This lower impact is caused by the simple fact that for ambient loading, lorry cooling (during which the fruit are cooled down entirely in the container) caused lower greenhouse gas emissions than precooling plus lorry cooling for the forced-air precooling scenario. The reason is that South Africa's electricity mix, used for the precooling facility, is more carbon intensive than electricity generated for container cooling, which is done with an 18kW diesel-electric generating set (genset) that cools the refrigerated container. The South African electricity mix has a particularly high dependence on coal. The shorter cold chain for ambient loading also contributes to a reduction of the impact, but this effect is much smaller. The higher environmental impact of ambient loading for Opentop packages, however, is due to the lower energy coefficient in the container, compared to the precooling facility.

The environmental performance of ambient cooling lies between the other cold chain scenarios for Standard and Supervent, because the cooling is partly driven by electricity and partly by the diesel-electric generating set as fruit are partially cooled in the cold store and partially in the container. As the fruit are loaded warmer in the refrigerated container (on the lorry) than for forced-air precooling, the lorry cooling also consumes more energy during ambient cooling. However, the quality loss is much higher in the ambient cooling scenario, as identified via the virtual cold chain method (Figure 5.3). Significant differences between cold chain scenarios are found (Figure 5.4 and 5.5), with a maximal difference of 11 g CO_2-eq/kg, namely between forced-air precooling and ambient cooling for the Opentop package. As such, Opentop packaging provide a reduction of 1.6% in the total carbon footprint of the supply chain (relative to that of forced air precooling), which is rather limited.

Figure 5.6 shows the environmental impacts calculated with the aggregated life cycle impact assessment method *ReCiPe*, which considers 17 environmental mechanisms (Goedkoop, 2013). Besides global warming, the method includes environmental mechanisms as water and land use, freshwater eutrophication as well as toxicity, which are relevant mechanisms in most agricultural systems. *ReCiPe* also includes stratospheric ozone depletion, which is relevant in refrigeration systems. For results see Figure D.4, which shows that the general pattern for aggregated *ReCiPe* impacts is the same as for climate change and stratospheric ozone depletion, meaning that our conclusions with respect to packages type and cold chain scenario are valid for different environmental impact mechanisms.

With these results, we have made a step forward compared to the previous state of the art on combining fruit quality, energy use and global warming impact of food cold chains (Gwanpua et al., 2015). The previous study only analyzed the impact category "climate change", but we also show results for "stratospheric ozone depletion" (Figure D.4) and aggregated environmental impacts according to the impact assessment method *ReCiPe*.

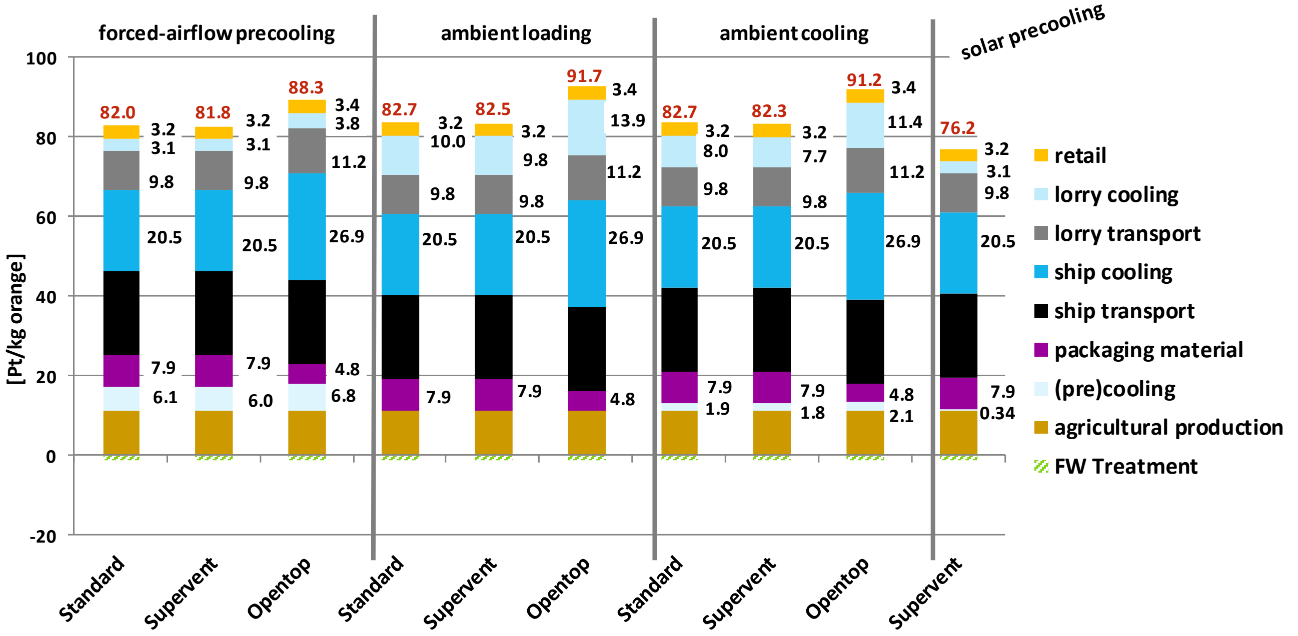


Figure 5.6: Environmental impact (ReCiPe Pt per kg of fruit (Goedkoop et al., 2013)) of all package designs and cold chain scenarios, split up into the different processes of the supply chain

5.3.3.3 *Agricultural production*

The results of Table 4 indicate that the climate impacts of agricultural production account for between 10% and 15% of the climate impacts of the final product. This is not typical for food product LCAs, where agricultural production is the largest contributor to greenhouse gases for many types of products (Notarnicola et al., 2017; Roy et al., 2009). For example, roughly 75% of the impacts of German food consumption are caused by agricultural production and land use changes, whereas the rest is caused by processing, transport, storage, and packaging. However, in the case of fruit production in areas with relatively low fertilizer and pesticide inputs, the impacts of agricultural production are much lower (80 g CO_2-eq/kg of orange from South Africa) than for average products from more intensive crops and animal production (2900 g CO_2-eq/kg average product consumed in Switzerland according to (Beretta et al., 2017)). The impacts of the cold chain from Africa (especially transport and cooling) are much higher than for local products and products that do not need cooling. These results demonstrate that cold chains can be the most important contributor to the climate footprint of food products.

5.3.3.4 Environmental impact of different sourcing regions

The possible climate change impact of different fruit sourcing regions, namely South Africa to Switzerland versus Spain to Switzerland, is compared in Figure 5.7 for the Supervent box. The South African cold chain clearly has a larger environmental impact due to the additional contributions of ship transport and the associated cooling, even though the lorry transport contribution is a little lower. However, the total difference between South Africa and Spain is surprisingly small. This is attributed to the much higher impact of agricultural production in Spain. The contribution of agricultural production in both countries includes carbon footprints associated with fuel consumption of tractors, infrastructure, irrigation, planting, harvesting, etc. In this case, particularly the use of fertilizers and pesticides in Spain (see also Table D.3), as well as the increased irrigation explain the differences. Further verification is needed to identify to what extent these differences are representative for exports from Spain and South Africa to Switzerland, or if they only relate to agricultural practices of domestic production. Nevertheless, it indicates the need for promoting agriculture with a lower environmental impact in this region. Furthermore, there is a need for more detailed and regionalized data on agricultural production of orange fruit in both Spain and South Africa.

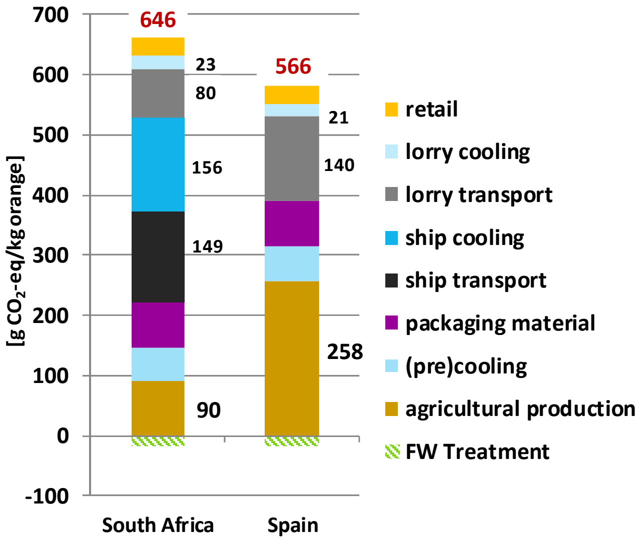


Figure 5.7: Climate impact (grams CO2 equivalent per kg of fruit) of Supervent packages for two different fruit sourcing regions (Spain and South Africa), split up into the different processes of the food supply chain and food waste (FW) treatments.

5.3.4 Optimal combination of packages and cold chain scenario

By combining the information generated from the VCC simulations, on fruit cooling and quality, with that of LCA on environmental impacts, the best combination of package design with the cold chain scenario is identified. Using the present energy mixes, ambient loading of citrus with the Supervent box showed the best performance. Despite its large potential to provide good final fruit quality as well as a low environmental impact, this combination is only explored sporadically in the South African citrus export industry. As ambient loading does not require additional hardware investments, but just altered logistics, it can be implemented very swiftly in existing cold chains. This flexibility makes ambient loading (with Supervent boxes) a very attractive commercial option for the citrus industry.

Since the relatively high environmental impacts of cooling are related to the type of energy used, the use of solar energy to drive precooling is explored for the Supervent box (Figure 5.4) as an extra alternative. The results show that using solar energy provides an extra 55 g CO_2-eq/kg benefit, since the energy needed for precooling becomes almost climate neutral. Forced-airflow precooling also provides slightly better fruit quality than ambient loading (Figure 5.3). The implementation of solar panels to run the precooling facility requires additional hardware investments, but in the long term it can offset investment costs since electricity costs can be saved throughout the years. With this measure, by far the lowest environmental impacts can be achieved, notably even with the lowest fruit quality losses. The differences between forced air precooling with and without solar energy are thus significant (Figure 5.4 and 5.5), namely 55 g CO_2-eq/kg for the Supervent package. As such, a reduction of 8.5% in the total carbon footprint of the supply chain can be achieved (relative to that of forced air precooling).

Finally, one needs to note that currently, the food quality information from the VCC method is not directly applied in the life cycle assessment calculation yet, but the authors are working towards this goal. However, the present results can already be linked to food losses. As an example, one could quantify by how much food losses need to be reduced in a specific cold chain to compensate for the higher climate impacts, as compared to another cold chain. For instance, the food losses in retail for forced-airflow precooling need to be reduced by at least 36% (i.e., 3.2% instead of 5.0% of purchases) for it to have the same carbon footprint as ambient loading. The quality benefits from cooling down the products more quickly at the start of the cold chain by using precooling is unlikely to reduce retail losses by more than 36%. Therefore, ambient loading is probably a more environment friendly option so far. However, if we assume that the differences in the remaining fruit quality for the different cold chains do not influence only retail losses, but also losses at the household level, a reduction by 4-5% of household food losses (24.6% vs. 25.7% of purchases) is enough to compensate for the additional environmental impacts of precooling, compared to direct container loading with a diesel-electric generating set. However, the best overall option is clearly precooling powered by solar energy, since not only environmental impacts, but also quality losses are minimized.

5.4 CONCLUSIONS AND OUTLOOK

The combination of life cycle assessment with virtual cold chains enabled, in a unique way, the identification and quantification of trade-offs between maintaining fruit quality and reducing environmental impact. This is essential information of which importers, exporters, container manufacturers and retailers can benefit, since these stakeholders often have different and conflicting interests. Retailers prefer to receive fruit with a maximal quality and shelf life. Container manufacturers, on the other hand, focus more on making their containers more energy efficient during transit (Lukasse et al., 2011). This can be achieved by reducing internal air circulation, which however could negatively impact fruit quality in some cases. Such trade-offs have not been quantifiable so far by a lack of a more holistic approach combining environmental science with food engineering and mechanical engineering

As an example of a typical trade-off, ambient cooling showed a lower environmental footprint than forced-airflow precooling, but exhibited a much larger quality loss. By relying only on the life cycle assessment results without considering fruit quality, retailers and policy makers would be advised to opt for ambient cooling. This would however have significant impacts on fruit quality losses and the amounts of food waste as well as a reduced shelf life for the consumers. The combination of information of both methods will result in an improved decision making process based on a more holistic view of all the factors relevant to the fruit cold chain. In the same way, this approach enables even more to push promising cold chain protocols forward, for example ambient loading. By quantifying remaining quality as well as energy consumption, different stakeholders can be better convinced to put these strategies into practice.

Apart from identifying trade-offs, our pioneering method enriched life cycle assessment with more customized input data from multiphysics modeling, and at the same time assessed food quality evolution. As illustrated in the present study, the holistic assessment could help different stakeholders in the perishables supply chain to choose the most optimal package and cold chain scenario to make their food supply chains more sustainable, and to optimize logistics. Significant differences between ventilated carton designs (63 g CO_2-eq/kg) and cold chain scenarios (11 g CO_2-eq/kg) were identified, or 10% and 1.6% of the total environmental impact of the supply chain, respectively. If solar electricity is used for precooling, the environmental impact was lowered by 55 g CO_2-eq/kg of fruit (or 8.5%), while still providing similar fruit quality retention of the fruit.

As a future outlook, the virtual cold chain method should be extended to quantify the actual food losses in the cold chain on the basis of the thermal history of the products. The relation between the thermal history and the food quality evolution toward food loss amounts could be determined empirically for this purpose. By using the virtual cold chain-based input of food losses in life cycle assessment, both methods could be coupled more closely to evaluate the overall environmental performance of different cold chains.

Generally, different impact assessment methods in life cycle assessment (climate impacts, acidification, eutrophication, aggregated environmental indicators, etc.) can lead to diverging conclusions, depending on how different impact categories are weighted (Hamilton et al., 2015). We showed additional results of aggregated environmental impacts in appendix D. However, in future studies, different impact categories should be analyzed separately (e.g. eutrophication, water scarcity, land use impacts, aquatic ecotoxicity). Furthermore, continued efforts are required to close the data gaps in life cycle assessment. As illustrated with the comparison of fertilizer and pesticide application in Spain and South Africa (Figure 5.7), agricultural practices can have a large influence on environmental impacts. Individual case studies are therefore not necessarily representative for the comparison between different countries. Larger datasets in various parts of the country are needed that differentiate agricultural production for domestic consumption and for export. Another point would be to evaluate the environmental impacts of reusable plastic boxes instead of recyclable corrugated cardboard boxes. In a recent study (Koskela et al., 2014), it is mentioned that a durable reusable box is often a better choice compared to a recycled box. However, under specific circumstances, a recycled product can also be a good option, if a profitable and effective recycling system is implemented. In their case study, a recyclable corrugated cardboard box system was a more eco-friendly option than a reusable plastic crate system for bread deliveries.

The current study was performed for citrus fruit, which is quite a resilient species with a rather long shelf life. The differences in fruit quality loss between different cold chain scenarios and package designs are expected to become even more pronounced for more perishable species, such as berries or mango fruit. The increasing globalization of supply chains makes interdisciplinary approaches such as the one presented here even more timely.

The methods provided in this paper can also be applied for related application areas, optimizing the logistics of agricultural products and lowering food waste and environmental impacts. A typical example is the use of LCA for evaluating conversion of food waste into biogas by recycling (Ebner et al., 2014; Jin et al., 2015). Here, mechanistic modeling could help optimizing different unit operations, such as the dehydration process for example, and thereby enrich LCA input data. Such work can also be linked to optimization of supply chains for bioenergy feedstock (De Laporte et al., 2016; Sarker et al., 2019). Furthermore, the applied methodology could also be applied for use of renewable energy in distribution networks of perishables (Burek and Nutter, 2019).

5.5 ACKNOWLEDGEMENTS

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CHAPTER 6

CONCLUSIONS

6.1 SYNTHESIS

6.1.1 Relevance of this dissertation for intact, sustainable food systems

Based on recent literature, in section 1.1.1 we demonstrated that food systems are ethically and environmentally important. The general findings are illustrated in Figure 6.1: Food systems depend on the environment, notably on natural resources such as fertile land, water, nutrients, and energy. They also influence the environment by releasing emissions and changing the structure of ecosystems, notably agricultural land. These two relations are illustrated by the red arrows in Figure 6.1, which together represent environmental impacts of food systems. The top of the pyramid illustrates the vital importance of food systems by providing healthy nutrition. Furthermore, in section 1.1.1 we demonstrated the scientific evidence that food systems are not sustainable at present on a global scale, meaning that they partly rely on non-renewable resources, that they use renewable resources at larger rate than the natural regeneration capacity, and that they cause emissions with negative environmental impacts. In the context of this situation, the findings of our dissertation are highly relevant. As illustrated in the red box in Figure 6.1, our results estimate all potentially edible **food waste** (FW) **to be responsible for 25% of the climate impacts of food systems, 27% of water use, 24% of land use, and 23% of the impacts on global biodiversity loss** in Switzerland. The reduction of **FW** is therefore **essential for intact, sustainable food systems**.

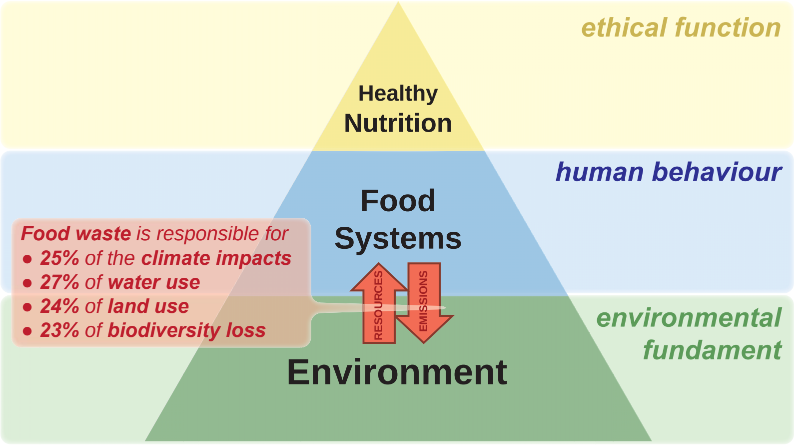

Figure 6.1: Illustration of the key role of food systems to humans, including their vital, ethical function of providing healthy nutrition and their dependency on natural resource availability as an environmental fundament. The red arrows illustrate the environmental impacts of food systems on the environment, including emissions and resource consumption. The contribution of FW to these impacts is indicated in the red box and based on the results from Chapters 2 and 3, which refer to Switzerland.

As a response to the unsustainable present situation of food systems described in Chapter 1.1.1, political commitments towards more sustainable food systems and consumption patterns were released, such as the UN's Sustainable Development Goal 12.3 that calls for halving per-capita retail and consumer FW by 2030. In order to evaluate if political targets are realistic, the results of Chapters 2 and 3 are not sufficient. Using the models developed in these Chapters, we therefore analyzed real case studies implementing measures for FW reduction exemplarily in the food service sector as one of the identified hotspots and then calculated the environmental benefits achieved within these case studies. An extrapolation to the entire food service sector showed, that **the SDG 12.3** is a **challenging** goal, which **can** however **be reached in the food service sector, if innovative measures are implemented** and **if the strategies in food services consider the possibility to reduce FW in other sectors** of the food value chain.

The understanding gained in Chapters 2 and 3 demonstrated that, in some situations, the measures for FW reduction are associated with additional direct environmental impacts of the supply chain. This is for example the case, if better cooling systems are used to increase the products' shelf live and thus reduce their susceptibility to be wasted. In order to identify the environmentally optimal solution, we therefore extended our methodology and coupled the MFA and LCA developed in Chapters 2 and 3 with quality evolution models. This combination offers new possibilities to predict the quality evolution of food products for different supply chain options and, at the same time, to assess the related environmental impacts of the supply chains. With the present model it is possible to **identify cases with trade-offs between quality optimization and reduction of direct supply chain environmental impacts**. In such cases, further model extensions are needed for the identification of the environmentally optimal solution. However, **in other cases** the cold chain option with minimal direct environmental impacts was found to provide the best product quality, implying that **the optimal solution is clear without further assessment**.

In the next sections we explain in more detail, how the **methodologies** developed in this dissertation **complement each other and contribute to the main goal** of providing methods and data to identify FW hotspots in terms of amounts and environmental impacts and to assess reduction measures. We conclude with an overview of the methodological framework developed in this dissertation (Figure 6.6).

6.1.2 Hotspots of quantitative relevance

In the mass flow analysis (MFA) presented in Figure 6.2 we estimate that an average Swiss person consumes roughly 550 kg of food per year, of which 15% is consumed in food services and 0.2% is food donated by charitable organisations. Relative to total available food from domestic production and net imports, **37%** or **325 kg/p/a are wasted** (wet weight). Thereof, 40% is wasted by the consumer in households and food services. Agricultural production and the processing industry contribute 25% to the mass of FW, each. Since the composition of FW differs between flows and since the unit 'wet weight' of FW is not an appropriate indicator for the potential of FW to replace other food (e.g. a kg of whey cannot replace a kg of cheese), the mass-based hotspots are not necessarily reflecting the nutritional and environmental relevance of FW.

We therefore carried out an energy flow analysis (EFA) of the same system, based on the calorific content of each of the 33 modelled food categories. The results are also presented in Figure 6.2 and show that an average Swiss person consumes 2'290 kcal per day. Total FW amounts to **1'170 kcal per day**, which is **34%** of all available food from domestic production and imports. The share of FW from agricultural production is lower (14%) than in terms of mass (25%), mainly because of the relatively high share of vegetables lost in agricultural production, which have a lower-than-average calorific content. The shares of FW from consumers and from the processing industry, however, are larger than in terms of mass. Thus, the energy perspective supports the conclusion by Gustavsson and Cederberg (2011) that most FW of industrialised countries arises at the end of the supply chain even more than the MFA.

The differentiation of food categories presented in appendix C (Fig. C18) shows that the **largest mass of FW** is caused by **fresh vegetables**, **bread and pastries**, and **whey**. In terms of **calories**, however, **breads and pastries**, **vegetal oils and fats**, and **pasta** are the top categories. Whey is not important in terms of energy due to its low calorific content (34kcal/100g); vegetal oils and fats are relevant despite their low amount of FW due to their high calorific content (896 kcal/100g) (Table C3). Thus, wasted oils and fats contain a lot of nutritional energy.

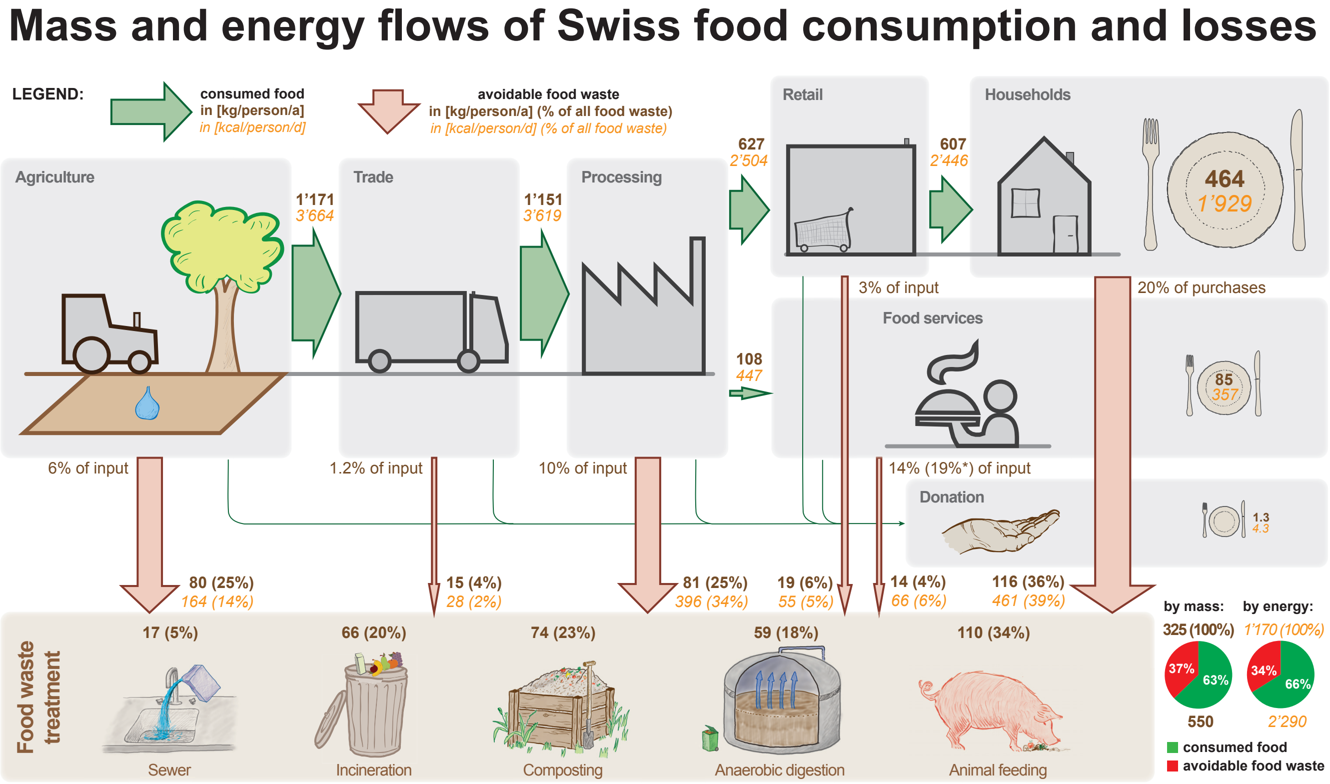

Figure 6.2: Mass and energy flows of consumed food and avoidable FW in the Swiss food value chain, per person. The grey fields represent the stages of the food value chain (agricultural production, trade, processing, retail, households, food services, and food donations). Final consumption is illustrated with plates and includes household consumption, eating in food services, and food donations. The green, horizontal arrows represent regular food flows from one stage of the food value chain to the next. Red, vertical flows represent FW going to FW treatment. The width of the red arrows is proportional to the mass of FW (however, green and red arrows are not proportional). The pictures with brown background represent FW treatment methods (sewage, incineration, composting, anaerobic digestion, animal feeding). Numbers indicated with "% of input" refer to the input into the corresponding stage of the food value chain (e.g. households waste 20% of the food purchases). Percentages in bold refer to total FW amounts and the percentages in the pie charts refer to total, edible food production. Note: The inputs into a stage of the food value chain are larger than the sum of the outputs, since unavoidable FW is not represented. All numbers are based on chapter 2 and relate to Swiss food consumption. For avoidable FW, the result of chapter 4 is shown in parentheses (*) and includes studies from Austria, Germany, Finland, and the UK. Most data is based on the year 2012.

Figure 6.3 shows an extrapolation of the MFA to **Switzerland**. Roughly, 4.4 million tons of food are consumed and **2.6 million tons wasted**. Food donations can save roughly 10'000 t of food, which is a large amount considering that the distribution of this food is mainly based on volunteers. However, compared to total FW it is negligible. **Compared to total retail FW** (153 t), which is qualitatively appropriate for food donations in the majority of cases, **food donations only contribute 6-7%.** Thus, there is a considerable potential to increase food donations.

In 2011 a ban on animal feeding for all FW potentially containing animal proteins was introduced (Zimmerli, 2011). Since then, the amounts of FW used as animal feed have been declining. Therefore, our estimate of one third (~870'000 t) of all FW being used for animal feeding (thereof 88% is from agricultural production and processing) might be too high for the present and future situation. On the other hand, FW going to anaerobic digestion is increasing (Kohler, 2015). The estimated countrywide amounts of roughly 500'000 t of avoidable FW going to anaerobic digestion illustrate that effective FW reduction will considerably affect the need for FW treatment infrastructure. Planning investments in **waste management infrastructure** therefore **needs to be coordinated with national roadmaps to reduce FW**.

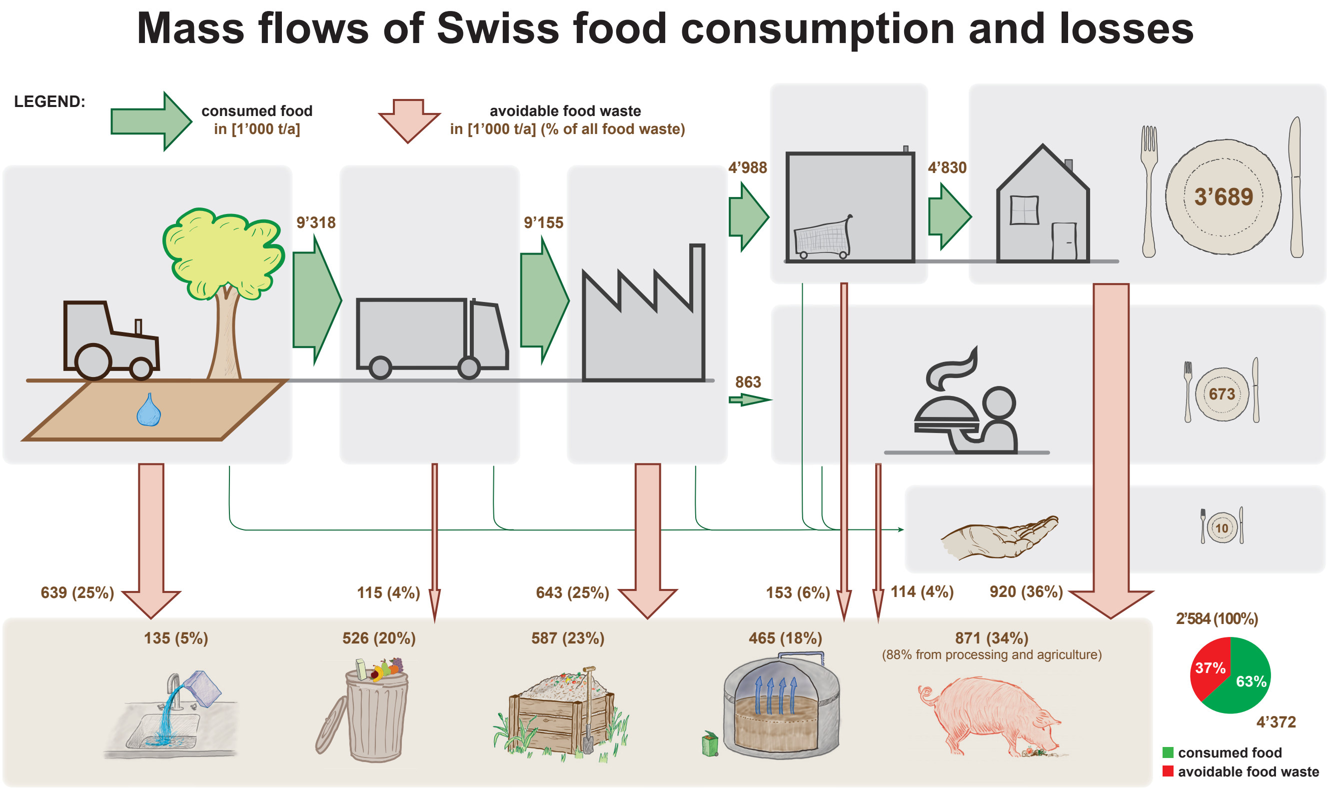

Figure 6.3: Mass flows of consumed food and avoidable FW in the Swiss food value chain in 2012, in 1'000 ton of wet weight per year (for a detailed description see the previous Figure).

As we mentioned earlier, the mass-based hotspots are not necessarily reflecting the environmental relevance of FW. Therefore, in a next step we combined the mass and energy flow analysis with LCA and calculated the environmental impacts of FW.

6.1.3 Hotspots of environmental relevance

In order to couple the MFA with LCA, we collected LCI data concerning most environmentally relevant processes of the food value chain (agricultural production, transport and storage, processing, partly packaging, food preparation) and FW treatment and linked the LCIs with the process-related food and FW flows of the MFA. This approach facilitates the evaluation of LCA results by changing input parameters in the MFA and thus enables the comparison of different scenarios of FW reduction.

Figure 6.4 gives an overview of the climate impacts of the Swiss food value chain, per average Swiss consumer. The 'clouds' next to the stages of the food value chain and the treatment processes show where the greenhouse gases are emitted. We can see that **most of the emissions** are **emitted in agricultural production** (1.6 t CO_2-eq/p/a). Thereof, about 30% (0.5 t CO_2-eq/p/a) are caused by the production of food wasted across the entire food value chain. Shopping, storage, and preparation in households cause 0.2 t CO_2-eq/p/a, of which 13% are due to FW in households. This is lower than the quantitative share of household FW amounts (20% of the purchases; Figure 6.2) because environmentally more relevant food categories (e.g. animal products) are wasted to a lower degree than environmentally less relevant categories (e.g. vegetables, fruits, bread). The results also show that all methods of **FW treatment**, except disposal in the sewage, **lead to net environmental benefits** due to the substitution of useful co-products, i.e. electricity, heat, feed, fertilizer, and peat (Chapter 3.2). Numbers in red refer to the net treatment benefits due to avoidable FW, numbers in green due to unavoidable FW resulting from the supply of consumed food. The benefits from the treatment of avoidable FW, however, are **low** (~50 kg CO_2-eq/p/a) **compared to the impacts of the production and supply of FW** (~500 kg CO_2-eq/p/a). Thus, optimizing the methods of FW treatment in order to reduce environmental impacts is ten times less effective than avoiding FW.

The ‘clouds’ next to the vertical arrows in Figure 6.4 represent the net climate impacts of the corresponding FW flows. **Household FW** is responsible for more than **50% of the climate impacts of all FW**. This is more than in terms of energy (39%) and in terms of mass (36%) (Figure 6.2), mainly because of the accumulation of environmental impacts along the food value chain. Together with food services and retail, they cause roughly 2/3 of the climate impacts of all FW.

The results also show that growing **food which is wasted** in the supply chain of an **average Swiss person** needs more than **9 ha of agricultural land** and **45 m³ of irrigation water per year** (equivalent to the volume of about 450 bathtubs).

In terms of food categories we identified wasted **fresh vegetables**, **whey**, and **beef** to be **hotspots for climate change**. The products with the largest **biodiversity impacts** from land and water use are **cocoa**, **beef**, and **wheat**. The examples of beef and cocoa show that **products with relatively small FW rates are environmentally important** if their per-kg environmental impacts are high. This is based on the assumption that preventing one type of food from being wasted will reduce the production amounts of the same type of food in order to meet the food demand. We consider this a legitimate assumption, since it is probably not realistic that calories are interchangeable independent of the type of food in industrialised countries with high consumer preferences. Focussing FW assessments and measures for FW reduction on environmentally relevant food categories is therefore important.

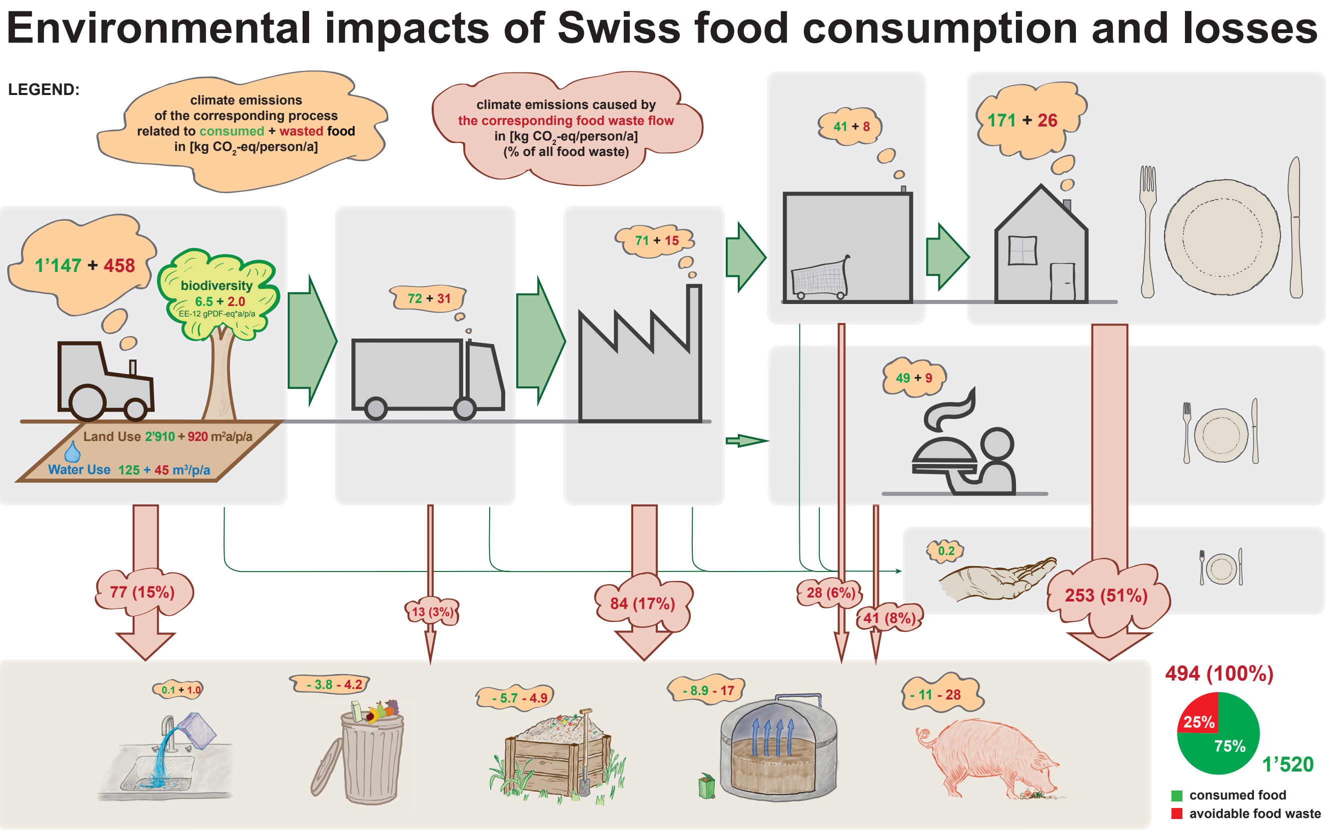

Figure 6.4: Climate impacts of the Swiss food value chain, including credits for substituted products from the treatment of food losses (sewage, incineration, composting, anaerobic digestion, animal feeding). The numbers in the brown trapeze and the tree indicate land, water use, and related biodiversity impacts for total food production, differentiating the impacts allocated to consumed (green) and to wasted food (red). The percentages in the red ‘clouds’ refer to the climate impacts of total FW, the percentages in the pie chart to the climate impacts of consumed *and* wasted food.

Since it is not realistic to entirely avoid FW, in a next step we analysed real case studies implementing measures for FW prevention. We therefore chose the food service sector because, together with the sector of households, it provides the highest average rate of FW (Figure 6.2) and because the Swiss Federal Office for the Environment (FOEN) declared a special interest into case studies in the food service sector, since they intend to start their strategy for FW prevention in this sector (Sanders, 2018). Strategies for FW prevention are probably more effective, if they include various measures, including the improvement of supply chains in order to reduce the products' susceptibility to be wasted. This is particularly important for products with long supply chains. Due to suitable primary data availability for the supply chain of oranges from South Africa and Spain to Switzerland, we chose this supply chain exemplarily and apply a new combination of tools, which includes a product-quality simulation tool and the LCA tool presented in the previous section.

6.1.4 Effective food waste reduction requires a supply chain perspective

By applying the methodology developed earlier in this thesis to case studies of FW reduction, we only demonstrate a few of the possible areas of application. The examples show how the methodology can be utilised to estimate the potential environmental benefits of strategies and scenarios for FW prevention and to assess the environmental benefits achieved in real case studies.

In a first step, we investigated 13 case studies of **food services implementing measures for FW reduction**. We applied our model to the individual case studies in order to assess the environmental benefits achieved within each case study after implementation of the measures. In a next step, we utilised our model to extrapolate FW reduction to the entire food service sector. For the status quo estimation of FW amounts, we included FW measurements from other Western European countries (Austria, Germany, Finland, and the UK) in order to improve data availability for FW quantification. This procedure is based on the assumption that FW rates in food services of Western European countries are in a similar range. According to Henningsson et al. (2004), the quantity of food discarded at the consumption stages of the food value chain increases substantially with growing incomes. However, since the income levels of most Western European countries are at a similar level, we consider our assumption legitimate.

We then calculated a base scenario of FW reduction based on the assumption that all food services in the entire food service sector achieved the same FW reduction as our case studies in their corresponding subsector (hotels, restaurants, business canteens, education, care centres). The results are presented in Figure 6.5 and show that **in-house FW** could be **reduced by 38%** and related **climate impacts by 41%**. Thus, the UN's Sustainable Development Goal (SDG) 12.3 of halving per capita consumer FW by 2030 cannot be reached with the base reduction scenario in the FS sector alone. However, this scenario is mainly based on measures implemented in our case studies in a few months. With a longer implementation period more reduction might be realistic. Furthermore, food services can also influence FW in the supply chain. For example, if they **buy 50% of their vegetables from unmarketable origin** (extended scenario in Figure 6.5), they can **save an additional 32% of food**, compared to present in-house FW. In combination, they can save 70% of their present FW and 58% of the climate impacts. This is more than enough to reach the SDG 12.3 in their sector. The **political target** of halving per-capita FW in the food service sector by 2030 is thus **challenging, but realistic**.

The **progressive restaurant** "Mein Küchenchef", illustrated in the top bar of Figure 6.5, indicates that with a progressive, long-term approach more reduction is realistic. This restaurant, including its supply chain, causes **90% less FW per meal** than average food services and **86% lower climate impacts**. However, more case studies in different subsectors are needed to assess the realistic long-term potential of the whole food service sector.

The environmental assessment of individual case studies of FW reduction shows that the composition of FW savings substantially influences environmental benefits. In some cases, a reduction of FW can even lead to an increase in environmental impacts, if more environmentally relevant food categories are wasted after implementation (for example dessert containing cocoa). The results show that not only food categories are relevant (e.g. beef), but also individual ingredients (e.g. vanilla).

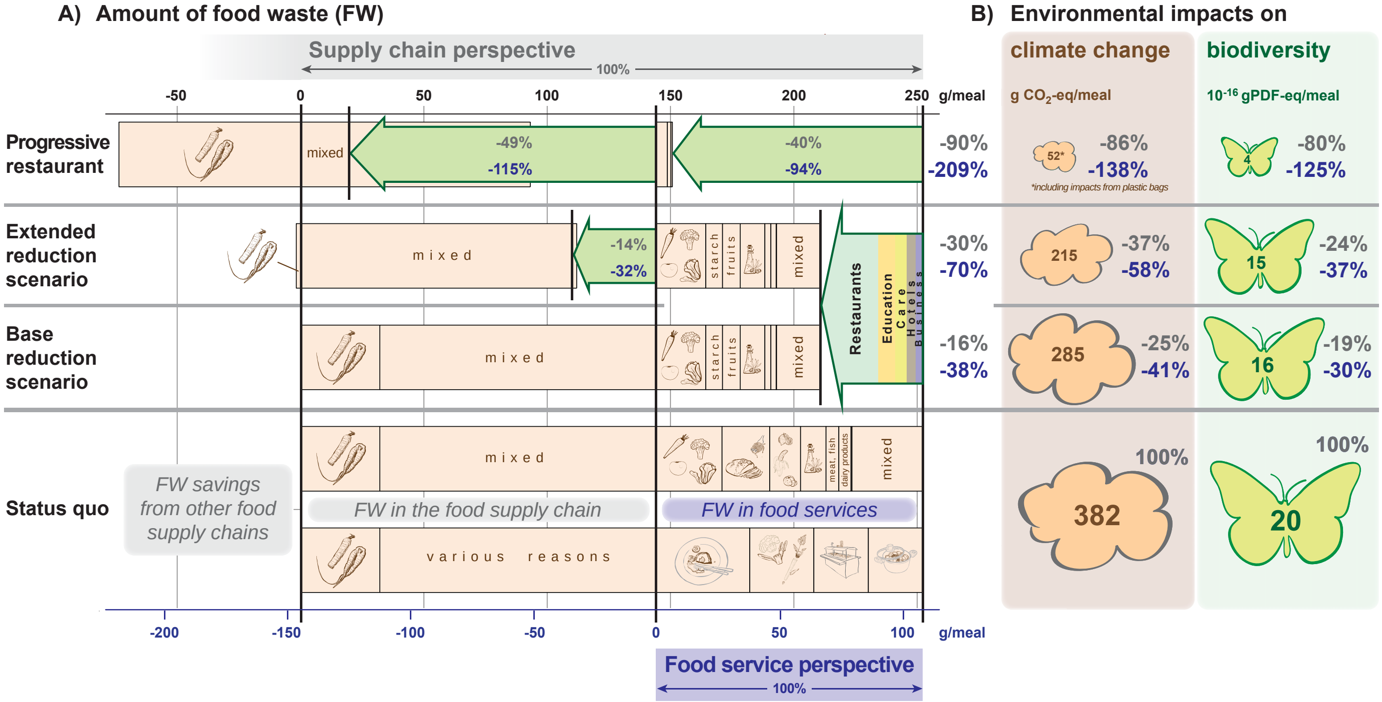

Figure 6.5: Overview of FW amounts and environmental impacts in the Swiss food service sector and potential for reduction in a food service perspective (FW in food services is defined as reference of 100%, blue font) and in a supply chain perspective (FW across the entire supply chain is defined as 100%, grey font). The bottom bar illustrates the reasons for status quo FW (from left to right: *non-marketable or non-standard vegetables, plate waste from the guests, edible trim waste from preparation, buffet surplus, overproduction in the kitchen*) and the second bar from the bottom differentiates status quo FW by food category (*vegetables, bread and starch, fruits, oil, meat and fish, dairy products*, and *mixed*). The other bars show FW amounts in the base and the extended reduction scenario and in a progressive restaurant specialised on FW minimization. The large arrow of FW reduction in the base scenario shows the contribution of individual subsectors.

We learned from the case studies in food services that FW in one stage of the food value chain (e.g. vegetables sorted out in agricultural production) is influenced by other stages of the food value chain (e.g. cosmetic standards required by food services) in many cases. It is therefore important to better understand interrelations between quality evolution (e.g. based on the cooling history), quality requirements (e.g. cosmetic standards for fruits), and FW amounts. Thus, in a next step we extended our model in order to evaluate entire supply chains and compare different supply chain options in terms of FW and environmental impacts. The new model includes a tool simulating the product's quality based on its cooling history. Therewith, it was possible to identify **trade-offs between** reducing the **process-related environmental impacts** (e.g. less energy-intensive cooling methods) **and** the **temperature-dependent quality evolution of the product**. As mentioned earlier, we applied the model to the case of oranges from South Africa. In this case, cooling down the product more quickly by forced-air precooling, compared to container loading at ambient temperature, is related with additional climate impacts, which however might be compensated by the reduced susceptibility of the oranges to be wasted later in the supply chain. If household FW can be reduced by at least 4-5% (24.6% FW instead of 25.7% of the purchases) due to the better quality from quick cool-down, the related climate benefits exceed the additional impacts of the precooling facility compared to direct container loading. It is probable that the qualitative advantage of precooled oranges leads to more than 4-5% reduction of FW in households and that precooling is consequently an environmentally better option than ambient loading. However, this result should be verified by determining the relation between thermal history, food quality evolution, and FW amounts empirically.

Furthermore, we found out that the **environmentally optimal solution depends on the location** (e.g. electricity mix) **and the technology** (e.g. type of energy used for cooling, mode of transport, type of packaging). This finding supports the importance of regionalised assessments. In the case of oranges from South Africa, the optimal of the investigated solutions is ‘forced-air precooling’ powered by solar energy and using ‘supervent’ boxes, which provide better air-flow conditions and a higher load capacity per container than ‘open top’ and ‘standard’ boxes.

This example shows that improving quality and reducing environmental impacts can represent a trade-off or a synergy, depending on the circumstances. In the case of ‘solar precooling’, the environmentally most favourable option is clear, since it also provides the best fruit quality. However, in the case of ‘precooling with the South African electricity mix’ versus ‘container loading at ambient temperature’ the case is not clear. In order to decide whether the FW reduction due to the improved quality associated with precooling compensates the additional environmental impacts of the precooling cold chain, the relation between thermal history and FW amounts needs to be assessed empirically. The supply chain option associated with lower FW rates is not necessarily the environmentally best option. Thus, **FW reduction** is not always environmentally favourable and needs the **consideration of all environmental impacts across the entire food value chain.**

Figure 6.5 shows how all these findings contribute to a meaningful picture of the environmental impacts of FW at country scale. The **three perspectives** of the **MFA, EFA,** and **LCA complement each other** and **represent a comprehensive basis for scenario modelling**. In Chapter 2 we integrated background data (FW rates, food consumption data, and nutritional values) into the MFA and EFA for the case of Swiss food consumption. The main results are illustrated in the red box and include hotspots of quantitative relevance. Chapter 3 builds on Chapter 2 by coupling LCA with MFA in order to calculate input-dependent LCAs of the entire Swiss food consumption. The EFA was utilised in the LCA for the allocation of environmental impacts to consumed and wasted food. The LCA was based on a large collection of LCI background data. The results include the identification of hotspots of environmental relevance in the Swiss food system. In Chapters 4 and 5 we modelled scenarios of FW reduction by applying the model developed in the previous Chapters to specific case studies. In Chapter 4, further background data concerning FW rates in food services was fed into the MFA (blue box at the bottom of Figure 6.5). The output includes an extrapolation of status quo FW and different FW reduction scenarios in the entire food service sector and an evaluation of the potential environmental benefits. While Chapter 4 focusses on one stage of the food value chain including all food categories, Chapter 5 relates to the entire food supply chain of one single product (orange). Additionally to background data used in Chapter 2, specific parameters were used in order to characterise different cold chain options. The evaluation of the cold chains was extended by integrating a quality evolution model (blue box next to the top of the pyramid in Figure 6.5).

Thus, we developed a framework (illustrated as a pyramid in Figure 6.5) to assess the quantitative and environmental relevance of FW of food systems based on status quo background data. The framework provides vast possibilities for scenario modelling by changing any of the input parameters. The framework can be combined with product-quality simulation in order to evaluate different supply chains, which is particularly useful for products that are susceptible to be wasted. The results of Chapters 2 and 3 are more generic results referring to the entire Swiss food system, while the results of Chapters 4 and 5 are specific results for individual case studies providing a higher level of detail. The combination demonstrates the strength of the developed framework by unifying wide system boundaries, which are important to identify hotspot areas of action in large food systems, and a high level of detail, which is important to support the design and implementation of practicable measures for FW reduction.

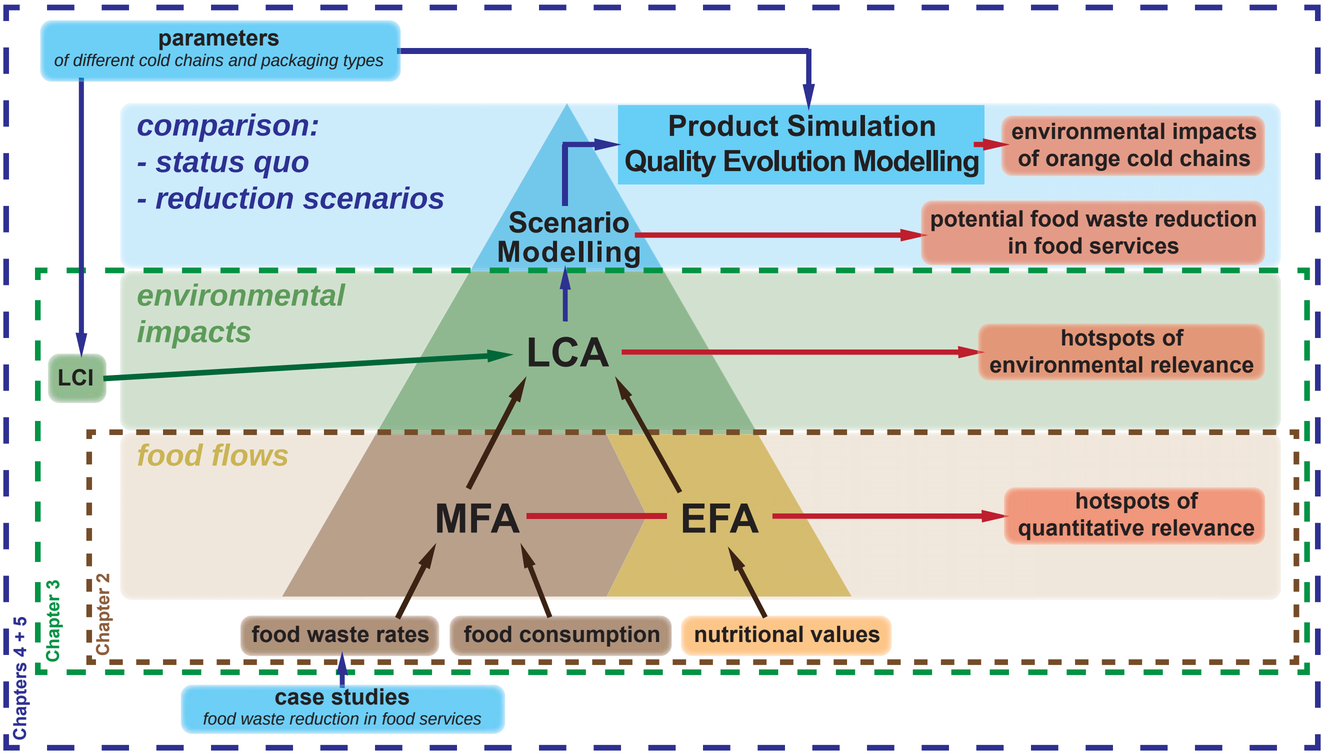

Figure 6.6: "Synthesis Pyramid", illustrating how the methodologies utilised in this study (mass flow analysis MFA, energy flow analysis EFA, life cycle assessment LCA, and quality evolution modelling) are interconnected. The elements of the pyramid and the blue rectangle on top of the pyramid ('Product Simulation') show the foreground models developed in this project. The pyramid visualises how the models build on each other. The boxes outside of the grey dotted line show background data used for the different models. The arrows illustrate the flows of information and the red boxes the main results. The brown, green, and blue dotted lines illustrate the system boundaries of the Chapters 2-5 (Chapter 4 and 5 build on Chapter 3, which builds on Chapter 2).

6.1.5 Scientific relevance

The combination of mass, energy flow analysis (MFA, EFA), and life cycle assessment (LCA) was found to be an appropriate combination of assessment tools in order to calculate the environmental impacts of FW and the environmental benefits of FW reduction scenarios. The combination of the tools provides many advantages over their isolated application:

The MFA represents a comprehensive overview of the assessed food system. By directly coupling MFA with life cycle inventories the **generation of input-dependent LCAs** is facilitated and allows for calculating different scenarios while taking the composition and treatment of FW into account. The integration of EFA into the allocation of environmental impacts to consumed and wasted food is important for an **appropriate representation of heterogeneous food categories** (e.g. environmental impacts allocated to butter and buttermilk). Furthermore, the combination of tools **creates transparency** by showing results at all levels of the supply chain, for individual as well as aggregated food categories, and in terms of mass, energy, and different environmental impacts. An additional strength of the developed methodology is the **regionalised assessment** of land use, water use, and biodiversity loss taking the origin of food imports into account. This is important, since the majority of land and water impacts on biodiversity (between 59% for land use and 99.9% for biodiversity loss due to water use) take place in the foreign supply chains of food imports to Switzerland. In addition to that, the combination of LCA with quality evolution modelling of the assessed food products enables to **identify trade-offs between FW reduction and the reduction of direct environmental impacts of cold chains** in order to improve the environmental performance of supply chains. The developed methodological framework comprises all food supply chains related to Swiss food consumption. The results are thus **comparable between net-exporting and net-importing countries** by applying the same methodology. We therefore suggest using this or a similar, consistent methodology for future assessments of FW in order to generate reliable and comparable results.

Taking these advantages of our methodological approach into account, we created a **unique framework with both a wide system boundary** (food consumption of a country including its entire supply chain and FW treatment) **and a high level of detail** (notably by differentiating between 33 food categories, 6 individual stages of the food value chain, 5 methods of FW treatment, and avoidable versus unavoidable FW). This combination of large system boundaries and a high level of detail, which can be further developed in future, is important to narrow down hotspots of environmental relevant FW flows enough to deduce precise fields of action for FW prevention and to identify relevant stakeholders for the design and implementation of effective FW prevention measures. The MFA is needed to multiply per-kg environmental impacts by the amount of food consumed and wasted. The EFA is needed to **allocate environmental impacts to consumed and wasted food** within each food category. Economic allocation would not be appropriate in this case, because FW does not have market prices reflecting its potential (nutritional) value for consumers. By including the method of **system expansion** into the LCA we take into account that FW reduction implies less useful outputs from FW treatment. They are thus replaced by other products (e.g. peat, fertilizer). With this procedure, we apply a different allocation method for the foreground processes (product substitution by system expansion) compared to the background processes (cut-off). Since the background processes remain constant in the scenarios of FW reduction, this has no influence on the relative results between the scenarios. It however makes the results more comparable to most other studies in the field, which are based on the cut-off system model in the majority of cases.

In order to apply the framework applied in this thesis to an entire country, we had to include an **extraordinary large data collection**. It includes FW rates at different stages of the food value chain and for different food categories and treatment methods, statistical data on food consumption and regionalised imports, and nutritional values for food categories encompassing the entire Swiss food basket. Data also include life cycle inventories for most environmentally relevant processes of the food value chain and FW treatment, and quantitative data from FW measurements in specific case studies of FW reduction combined with qualitative data about the factors that influence FW amounts and reductions.

In order to collect data on FW amounts, the **wet weight** (fresh substance) is the most **appropriate** parameter **for measuring** FW. Other parameters are more difficult to measure (e.g. dry weight or calorific contents) or less insightful (e.g. disposal costs). **FW rates** can be assessed in defined parts of the food system (e.g. in a single bakery) and **combined with FW rates in other subsystems** in order to model the entire food value chain. Total amounts of FW can be calculated by multiplying FW rates by the amount of food produced, purchased, or consumed. The **calorific content** of FW is more appropriate than the wet weight as a **proxy for the nutritional value of food**. The MFA, however, represents an appropriate basis to calculate an EFA, provided that food categories are differentiated. Thus, MFA and EFA are complementary tools to optimally quantify food and FW flows in food systems.

The **differentiation between detailed food categories** is important for the quantification of environmental benefits from specific scenarios of FW prevention. We demonstrated in case studies that the composition of FW substantially influences the environmental benefits of FW prevention.

We conclude that the combination of MFA, EFA, and LCA turned out to be a suitable and **comprehensive framework to calculate environmental impacts of FW**: it differentiates food categories, applies energy allocation of environmental impacts to consumed and wasted products within food categories, and integrates system expansion to take useful outputs from FW treatment into account**.** Furthermore, the developed combination of MAF, EFA, and LCA might also be scientifically relevant to **assess other supply chains**, e.g. the pet food and the feed industry. The combination of MFA and LCA on a national level can be used to analyse environmental impacts of supply chains in other areas of consumption (e.g. indoor plants, clothing, etc.). It thus helps to improve the systems by reducing losses along the supply chains, improving the methods of waste treatment, and increasing the reuse and recycling rates. Haupt et al. (2018) propose a similar framework combining a detailed MFA with LCA in a modular approach in order to assess complete waste management systems based on actual waste flows.

6.1.6 Practical relevance

The scientific findings of this thesis about FW amounts and environmental impacts and about the reduction potential achievable with measures for FW reduction across the entire life cycle are practically relevant in order to

- **monitor** the effect of measures for FW reduction and improve strategies
- **prioritize** measures for FW reduction according to their potential environmental benefits
- **generate credibility** about the importance and **raise awareness** about the effectivity of FW reduction.

The combination of MFA with LCA is a comprehensive approach for monitoring environmental impacts of FW since data from FW monitoring can directly serve as input into the MFA. The identification of 'hotspot' food categories and stages of the food value chain is useful for the prioritisation of measures and the improvement of strategies for FW reduction. The reduction scenarios in food services and the orange cold chain indicate how exemplary measures for FW reduction contribute to reach FW reduction targets such as the Sustainable Development Goal 12.3.

Furthermore, we identified end consumers to be the main contributors to environmental impacts of FW. These and other results can be used to raise awareness about the importance of FW reduction. In order to have a practical impact, these findings should be **communicated to individual target groups**, notably in schools and professional education, in consumer campaigns and the media, in consultancy of the food industry, and in political discourses. The results of our model are particularly useful for communication since mass is a well understandable indicator by laypersons. The energy based results are more insightful regarding the nutritional value of FW and relevant for laypersons as well as other target groups such as nutritionists. The LCA results are important to define the potential contribution of FW reduction to reach environmental goals, e.g. political emission targets. They are also important for communication, considering the growing public awareness about environmental problems. The environmental results provided in this thesis can be communicated in a well understandable way to the public. Land use can for instance be visualised by the agricultural area needed to produce a country's FW; climate impacts can be translated into the equivalent number of average car emissions.

We learned from the assessed case studies that effective reduction of FW-related environmental impacts benefits from a supply chain perspective of individual actors (e.g. food services using products which otherwise would have been wasted in agricultural production). In addition to that, it also benefits from the collaboration between actors in the food value chain. **In the case of the assessed orange cold chain**, if producers try to reduce the environmental impacts of their processes only, they may opt for 'ambient loading' due to lower energy consumption than 'forced-air precooling'. However, in this case only an **integral environmental assessment across the entire food value chain** including the scenario-specific FW rates **reveals the environmentally most favourable solution**. These findings are related to the investigated case studies and are not generalizable to all products and supply chains. An integral assessment of the entire food value chain might be particularly important to reduce FW of perishable products such as berries (in analogy to the orange case study) and for products that are subject to sorting based on cosmetic standards such as carrots and potatoes (in analogy to the progressive restaurant using non-marketable products). For other products it might be sufficient to implement isolated measures for FW prevention, e.g. for vegetal oils and sugar that are storable for longer periods without cooling. However, most food and FW flows consist of several products including at least some perishable or cooled products or products sorted by aesthetical norms. Thus, a **collaboration between actors in the food value chain is probably important for effective FW reduction in most cases**. For isolated supply chains of storable products that are not susceptible to be wasted, an integral assessment and quality simulation might be irrelevant for FW prevention.

Even though there is a large space for further research about the topic of FW, we would like to conclude that this study provides a **thorough knowledge base** that helps policymakers to understand the importance of FW prevention and to develop effective strategies to reduce the environmental impacts of FW and to make our food system sustainable. It shows that **'business as usual' is not a sustainable option** and that **political targets**, e.g. the Resource Efficiency Roadmap defined by the EC in 2011 and the Sustainable Development Goals released by the UN in 2016, are **challenging, but realistic, if all actors of the food value chain**

are involved and effective and innovative strategies for FW reduction implemented. It also shows that quantitative reduction targets may lead to variable environmental benefits, whereas **environmental targets** provide better incentives to prioritize the reduction of environmentally relevant food categories.

6.2 CRITICAL APPRAISAL AND OUTLOOK

FW is a relatively new research field. Even though in the last few years the number of studies in this field has rapidly increased, the state of knowledge about FW amounts and environmental impacts is still based on a small data basis with large uncertainties. This study also provides several uncertainties and limitations. In the next sections we discuss uncertainties and compare our results with available literature. In section 6.2.3 discuss further limitations and deduce opportunities for future research.

6.2.1 Discussion of uncertainties

The uncertainty of FW rates was assessed **for each product category** and **each stage of the food value chain** with a **pedigree assessment** according to Frischknecht et al. (2007). The results are presented in Appendix B, Tables B9 and B10. The highest uncertainties (pedigree score 1.6-2) are related to losses in agricultural production of canned fruits and cereals, in postharvest handling and trade of sugar and eggs, and in the processing of eggs. The average FW rates of all food categories reach pedigree scores between 1.2 and 1.4 for agricultural production, trade, and processing and 1.1-1.2 for retail, food services, and households. The **uncertainty of the LCI** was assessed extensively **for the stage of agricultural production**, which is environmentally most relevant, in Chapter C.11 and presented in Tables C34 and C35 in Appendix C. The largest uncertainties are found in the production of berries and rice with pedigree scores between 2 and 3. For the average of all food categories a score of 1.36 was found. The pedigree assessment includes reliability, completeness, sample size, geographical, temporal, and technological correlation.

Since we did not quantify uncertainties related to the LCI of other processes than agricultural production and related to food consumption and since no error propagation assessment was performed, we could not define a range of uncertainty for our results. The main reason was the **difficulty of quantifying all sources of uncertainty**, e.g. related to the boundary between edible and inedible FW, to the uncertainty of assumptions regarding product substitution, or to the uncertainty of the detailed composition of FW within the 33 food categories assessed in this study. In the next section we therefore show an in-depth comparison of our results with available literature.

6.2.2 Comparison with literature

The comparison of our results with literature (see also Table C29) shows that **final food intake** is consistent with data from nutritional studies (+-4%). Average **FW rates in agricultural production** lie between assessments for Europe and Norway (Gustavsson and Cederberg, 2011, Hanssen and Møller, 2013). FW rates **in retail** are consistent to studies in Norway (13% and 5% deviation) (Hanssen and Møller, 2013, Hamilton et al., 2015). FW rates **in wholesale (trade)** were estimated 4.8x higher than in Hanssen and Møller (2013)'s study for Norway. However, the absolute numbers are low in both studies (0.26% of input versus 1.2% in our study) and therefore not sensitive for total FW amounts. The difference is probably due to sorting, which takes place at different stages of the food value chain and which might be attributed more to the stages *agricultural production* and *processing* in their study. FW rates **in the processing industry** are 3 times higher than in Hamilton et al. (2015). However, the difference can be explained by different system boundaries (cereals are not included in their analysis) and methodologies (they quantify dry matter contents). We based FW rates **in households** on Quested et al. (2013), who includes the largest compositional analysis of household FW which we could find in literature, and combined them with surveys and diaries in order to cover all disposal routes. We then adopted their FW rates to the Swiss food basket. The results are 1.8-2.5x higher than in the studies by Hanssen and Møller (2013) and Hanssen et al. (2016) from Norway. However, the first study used web-based consumer self-reporting, which is known to lead to under-reporting compared to compositional analyses (Stuart, 2009, Quested et al., 2011), the latter study did not include possibly avoidable FW and FW disposed of in the sewer and fed to animals. Compared to Rosenbauer (2011)'s estimation for Germany our results are 13-54% higher, which can again be explained by under-reporting since they used online diaries. Compared to Kranert et al. (2012), another study from Germany, our estimation is 1.9-2.5x higher, which might partly be explained by home composting, pet feeding, and disposal in the sewer, which are not included in their study. Schneider et al. (2012) report 2-4x lower FW amounts from households in Austria. Different food classification and uncertainties in their surveys estimating FW amounts in home composting, pet feeding, and disposal in the sewer can only partly explain the large difference. FW **in the food service sector** was underestimated in our first publications presented in Chapters 2 and 3 (14% of food input). However, the final results presented in Chapter 4 and included in Figure 6.2 (18% of food input) include most recent literature and are based on measurements in 1'042 food service locations in Switzerland, Germany, Austria, Finland, and the UK. The average estimates from individual studies reach from 64 g/meal to 137 g/meal (Figure 4.6).

Gustavsson and Cederberg (2011) estimated avoidable FW relative to agricultural production, excluding inedible parts, at roughly 1/3 in Europe. This is consistent with our estimation of 34% in terms of calories (Figure 6.2).

The **total carbon footprint of food consumption** in Switzerland is 4% lower than in Jungbluth et al. (2011) and the per-capita footprint 33% lower than in Germany. The latter deviation might be explained by the electricity mix, which is more carbon intensive in Germany than in Switzerland. The **per-capita climate impacts of FW** is within the range reported by Schott and Cánovas (2015) for several countries in Europe and USA, 19% higher than in Eberle and Fels (2015)'s estimation for Germany, and 33% lower than in FAO (2013), relating to Europe. The latter study partly includes environmental impacts of unavoidable FW and excludes benefits from product substitution from FW treatment, which might explain their higher results. Furthermore, in Europe some of the FW is disposed of in landfills, where more greenhouse gases are released.

6.2.3 Limitations and Outlook

In Table 6.1 we give an overview of important limitations and deduce suggestions for future research. The Table includes data limitations, methodological limitations of the applied approaches, limitations related to the selection of methodological approaches, as well as limitations related to the system boundary of this thesis.

Table 6.1: Limitations of this dissertation and suggestions for future studies (outlook). The main limitations are discussed in the text.

LIMITATIONS	OUTLOOK
Data limitations	
...related to food waste quantification	
Uncertainty of FW rates due to	Improve data quality of **FW rates** by
- estimates instead of measurements	- replacing estimations by **measurements**
- small sample size	- extending measurement **periods** and number of **locations** (especially agricultural production, households)
- assumptions based on similar products	- analysing **new products**
- different location or culture	- analysing **new regions, cultures**
- methodology to measure household FW in most countries not complete and reliable (according to Stuart (2009), self-reporting leads to considerable underestimations)	- applying **reliable methodologies for household FW**, combining compositional analyses with diaries, similarly to Quested et al. (2013)
- the simplification that FW rates of partially imported products are equal to domestic production	- differentiate **FW rates depending on the provenience of the products**, especially between regions with different weather, climate, and soil conditions
Edible crops remaining unharvested (e.g. from fruit trees, private gardens, wild berries) are not included in the analysis due to lack of data. However, case studies suggest that there is a considerable potential to save food (Henz, 2016).	Estimate the **quantitative and environmental potential of unharvested crops** in different regions to substitute food imports and develop strategies to harvest, process, and store the products.

Table 6.1 (continuation)

The mass and energy flow analysis only differentiates 33 food categories, which include the entire food basket, but exclude alcoholic beverages and most soft drinks. Beverages which are generally included in the assessment (e.g. dairy drinks, juices, coffee) might not be captured in all measurements since liquids are often disposed of separately to food.	Analyse the FW rates of **more detailed product groups** or **individual products** at each stage of the food value chain. Include **beverages** in future FW measurements, especially beverages with potentially large environmental impacts, e.g. alcoholic beverages. Ensure to take into account all disposal routes.
The boundary between consumption in food services and household consumption is not always clear. Depending on the method of FW quantification, this can implicate inaccuracy, e.g. if household FW measurements only include food physically discarded in the household, but household consumption also includes food consumed on the way.	Quantify average food consumption under different circumstances (e.g. "cook and eat at home", "cook at home and eat out-of-home", "buy from retail and eat on the way", "take-away", "restaurants", "bars"…) and relate FW measurements to the appropriate area of consumption (**consistent system boundary between households and food services**).
Uncertainty how FW is disposed.	Report the **methods of treatment** in all future FW studies.
After the introduction of a ban on animal feeding for all FW potentially containing animal proteins, FW from food services and partly from the processing industry was diverted to other methods of treatment (Zimmerli, 2011). Our estimate was mainly based on Kohler (2015) and should be updated in future studies.	Investigate how much **FW** is **presently used for animal feeding** in Switzerland and in Europe and analyse current trends, since regulations in this field are evolving relatively fast.
…related to LCI	
Availability of product-specific LCIs and the level of detail, reliability, and documentation quality of available data are limited. Agricultural practices can vary largely between farms and regions of a country and can substantially influence the environmental impacts. Individual case studies are therefore not necessarily representative for the average production of a country.	**Extend LCI databases** with reliable **data on food products *and* beverages**, prioritizing environmentally relevant products and including clear, detailed, and well-structured **documentation**, especially regarding system boundaries and functional units. Incorporate large datasets in various parts of a country in order to cover **different agricultural practices**. Consider differences in domestic production and exports.
Missing LCIs about environmental impacts of different types of FW discarded in the sewage (we used a rough estimation based on milk).	Quantify the **environmental impacts of different types of FW discarded in the sewage** and going to wastewater treatment plants.
LCI data to analyse cold chains is mainly based on models rather than empirical evidence (e.g. energy consumption of forced-air cooling in South Africa).	Collect **primary data** relevant for the **LCI of food value chains** (e.g. energy consumption for cooling, transportation routes, food processing).
…related to food waste reduction	
The sample size of the case studies for FW reduction in food services is relatively small due to limited data availability. Food categories are not always differentiated and categorisation is not harmonized. Measurement periods are usually short.	Carry out **FW reduction interventions** and **monitor their effect** over longer time periods, in new locations across all types of food services, and implement new measures for reduction. Adopt **consistent methodologies** with previous studies and **differentiate food categories** in order to improve strategies for prevention and allow environmental assessments of the achieved reductions. If appropriate, use new measurement tools to automatize processes, such as electronic weighing systems to monitor FW in food services including food category differentiation (KITRO, 2018).
Only data from one progressive restaurant was available as a proxy for the long-term potential to reduce FW.	Implement innovative **measures for long-term FW prevention** in case studies in different subsectors and types of food services willing to collaborate over longer periods and monitor the effect.

Table 6.1 (continuation)

Limitations due to methodological implementation	
...related to MFA	
Food classification is static across the entire food value chain. However, in the real food value chain products are combined to new products (e.g. flour, salt, and yeast to bread) or separated into linked co-products (e.g. milk to cheese and whey). Therefore, FW rates in our model often do not relate to a specific product, but to the estimated average of several products containing the same ingredient (e.g. eggs contained in various products). To accurately calculate average FW rates of ingredients, the composition of all compound products and their amounts consumed needs to be known, which is usually not the case and leads to uncertainties.	Develop methods to integrate intersections in the life cycle of products in order to **model linked co-products** and **compound products** (meals, recipes).
The boundary between avoidable and unavoidable FW is not clearly defined.	Analyse parts of food, which are not clearly considered as edible, concerning their nutritional value and their potential to be processed to healthy, marketable food. By (re)defining detailed criteria for the category of possibly avoidable FW (Quested et al., 2013), a **list of edible and possibly edible parts of food** could be defined. This is important to harmonize methodologies between FW studies. Follow the guidelines of the "Food Loss and Waste Accounting and Reporting Standard" (FLW-Protocol, 2011).
Since chapter 2 is a reprint of Beretta et al. (2013), the numbers are not entirely up-to-date and slightly deviate from the updated version of the MFA and EFA used in chapters 3-6 and documented in Appendix B. However, the differences do not influence our conclusions.	
...related to LCA of the food value chain	
Some datasets from other databases than *ecoinvent* are based on different system boundaries (e.g. agricultural equipment and the production of pesticides and manure are not included in the *Agrifootprint* database, which is used for the assessment of some meat products). Data from generic processes in LCA is sometimes based on averages, unrepresentative sampling, or outdated results.	**Harmonize** methodologies of different **LCA databases**.
The environmental impacts of food processing are only assessed for a few products (appendix B). As a simplification, other products are assumed to be processed in the same way.	Model **LCA of food processing** for all environmentally relevant processing methods.
The life cycle impact assessment (LCIA) methods do not include all relevant aspects of agricultural production. Presently available methods with full aggregation do not include biodiversity impacts, soil compaction, erosion, and salinization.	Develop further **LCIA methods for relevant impact categories of agricultural products** (e.g. soil quality, animal welfare) and include indicators for all impact categories into fully aggregating LCIA methods (e.g. **biodiversity impacts** (Chaudhary et al., 2015, Verones et al., 2016), **soil compaction** (Stoessel et al., 2018), **salinization**, etc.).
Allocation of environmental impacts to consumed and wasted food: The calorific content is used as a proxy for the nutritional value of food. However, there are other aspects contributing to the (nutritional) value of food. For example, the potential of saving FW with low calorific content, but large content of micronutrients (e.g. lemon peel) is underestimated with this procedure.	Develop and integrate more differentiated **indicators for the nutritional value** of food and analyse the sensitivity of the results to the choice of the indicator. Deduce methodological suggestions depending on the practicability and data availability of the new indicators and the adequacy of the results.

Table 6.1 (continuation)

...related to LCA of food waste treatment	
The substitution of useful co-products from FW treatment is based on assumptions about the alternative scenario of FW prevention. However, the assumptions might not correspond to the practices in a realistic alternative future scenario (e.g. the composition and origin of the substituted feed, the electricity mix in future).	Analyse **sensitivities**, **economic incentives**, and the **future development** of factors influencing the products and types of energy, which **substitute the present functions of FW treatment**. Identify relevant factors and include them in future studies. Base long-term suggestions on future scenarios in order to avoid development in a wrong direction (e.g. in a country with coal in its energy mix, anaerobic digestion might provide larger environmental benefits than feeding FW to livestock; however, in a future scenario with more renewable energy this might change; projects requiring new infrastructure need long-term planning in order to consider their whole life span).
The environmental benefits of improved soil quality from the application of inorganic matter in compost and digestate is uncertain (Dinkel et al., 2012).	Improve methods to **quantify the effects of compost and digestate on soil quality** and consider realistic substitution scenarios (e.g. when does compost substitute peat?).
...related to food waste reduction	
FW reduction achieved in individual case studies of food services was extrapolated to the entire food service sector based on only 5 subsectors. The large variability of FW amounts and composition between food services of the main subsector, however, suggests that further differentiation of the sector is needed.	Determine which **parameters** are **relevant to define different types of food services**, which are more **homogenous** than the present subsectors in terms of FW amounts, composition, and the most appropriate FW reduction measures. Examples for such parameters are serving systems, preparation methods, customer segments.
Techniques which make over-production conservable for several days in food services are effective measures to reduce FW; however, practicability and additional environmental impacts of the techniques are not entirely considered in extrapolations of FW reduction scenarios.	Analyse the environmental impacts of current **techniques to make over-production conservable** and determine their **practicability**. Develop new, improved techniques, such as sous-vide cooking with a closed-loop recycling system for plastic bags.
The link between quality and FW is not quantified.	Analyse different cold chains of the same product and d**etermine** the **relation between thermal history, food quality evolution, and FW amounts empirically**.
Limitations due to the selection of methods	
Our methodology only included environmental impacts of FW. Social implications, ethical aspects (e.g. animal welfare), and economic consequences were not analysed in this study.	Extend LCA methods and **integrate social, ethical, and economic aspects**. For example, social life cycle assessment (**S-LCA**) is a method to assess social and sociological aspects of products and their actual and potential positive and negative impacts along the life cycle (Norris and Franze, 2013). A framework for integrating **animal welfare** into life cycle sustainability assessment has been developed by Scherer et al. (2018).
The reasons for FW were not analysed. Hotspots of quantitative and environmental relevance were defined by the physical origin of FW. However, the reason why food is wasted might be related to one or several other actors than the actor physically wasting the food (e.g. if farmers sort out vegetables that do not correspond to cosmetic standards).	Identify **reasons of FW** and **relevant actors**, e.g. by surveys and case studies or by changing parameters such as packaging type and size and measuring the effect on FW amounts.
Due to large uncertainties of predicting changes in the consumers' behaviour we did not consider rebound effects of indirect behavioural changes associated with FW reduction, e.g. activities carried out with the money saved from FW prevention.	Analyse the **environmental effect of behavioural changes associated with FW reduction**. A possible methodology was adopted by Martinez-Sanchez et al. (2016).

Table 6.1 (continuation)

Limitations due to the system boundary	
The system boundary is limited to Swiss food consumption, including domestic production and net imports.	Adopt the same methodology of this study to **other countries**.
FW reduction case studies are limited to the sector of food services.	FW reduction case studies are limited to the sector of food services.
The combination of quality assessments with supply chain environmental impacts was only carried out for a specific case study (oranges from South Africa and Spain, packaged in recyclable corrugated cardboard boxes).	Perform further assessments with the coupled methodology of quality simulations and LCA for other types of food than oranges and other packaging types (e.g. reusable plastic containers).
Surplus food consumption due to over-weight and insufficient chewing and related health implications were not included in the system boundaries of this study. Human excretion and related waste water treatment was also neglected.	Assess the potential to reduce food consumption by avoiding **overconsumption and overweight** and by **properly chewing food** in order to optimally digest its nutrients. Consider Ceren et al. (2016) analysing the climate impacts of surplus food consumption.
The potential to use FW as pet food was not considered.	Assess the **potential** to use unavoidable and possibly avoidable food **to replace pet food** and calculate environmental benefits.

Improving input data quality

As we show in Table 6.1, the level of detail of our results and their reliability can largely be improved by feeding our models with more reliable and more differentiated data. The main limitation is **primary data availability**. According to Parfitt et al. (2010), FW estimates used in literature often link back to the same limited primary datasets. It is therefore important to increase efforts for primary data collection, e.g. with support from governments and sustainability funds, and to provide incentives for companies to make their data available for research projects.

Areas of further application

The methodology adopted in this thesis provides many possibilities for further application**.** It can be applied **to other food systems** (e.g. countries) or to **parts of the systems** (e.g. individual stages of the food value chain or individual products). It can also be applied to individual case studies implementing specific measures for FW reduction and then used to learn from the results and improve future FW prevention strategies. The results from the application to case studies can further be used to anticipate the environmental benefits of a potential large scale application (similarly to the scenarios of FW prevention in Chapter 4). There is a large number of possible case studies and scenarios to be assessed with our tools due to the innumerable approaches to reduce FW in supply chains, which include for example:

- Making presently non-marketable food products marketable, either by appropriate marketing strategies or by further processing methods to convert them into new products, for example to convert whey into protein-rich products for sports nutrition (Kopf-Bolanz et al., 2015)
- Improving effective communication between actors of the food value chain in order to quickly react to fluctuating product availability and demand, e.g. by processing surplus perishable products into storable products or by increasing the demand with sales promotion and price reductions (WRAP, 2017)
- Donating surplus food to charitable organizations in order to prevent it from being wasted (in the UK Parfitt and Parry (2016) quantified food redistribution at 0.3-0.8% of total wholesale FW, which is about 2% of the estimated redistribution potential)
- Establishing Foodsharing networks for the redistribution of surplus food (Foodsharing, 2018)

In order to **prioritize the large number of possibilities to reduce supply chain FW** and to quantify the environmental benefits achieved after implementation of measures, the methodology developed in this thesis represents a valuable support. **Evaluating the effect of measures after implementation** and **extrapolating to the implementation of the same measures at a larger scale** is important for the justification to invest effort and money into the implementation of measures at the large scale.

The methodology of this thesis can also be used **in the design phase of new supply chains**, which is important to improve the environmental performance of future supply chains.

Since most of the FW was found to arise in households, FW reduction at this stage of the food value chain is particularly important. There is still little empirical evidence on the effectiveness of measures for FW reduction in households, e.g. by awareness building. However, FW measurements were carried out before and after implementation of an extensive media campaign in the UK. The results showed a reduction of per-capita household FW by 24% between 2007 and 2012 (Quested et al., 2013). Despite continued media campaigns, face-to-face trainings, instore information, improved data labelling, and storage advices to help the public make the most of their food, the UK's goal of a further FW reduction by 5% in households could not be met by 2015. Instead, FW amounts increased by 2% compared to 2012 (statistically not significant). As possible reasons they mention falling food prices and more people living alone (WRAP, 2017). This example shows that **FW reduction at the consumer level needs long-term prevention strategies.** However, in order to **justify long-term investments into such strategies**, information about potential environmental benefits is essential. In this context, the methodologies developed in this thesis might become even more relevant on the long term, notably **for monitoring and constantly providing updated information**. This is important to adapt and improve FW prevention strategies and to communicate environmental consequences to stakeholders and the public.

Further development and extensions

In order to apply the methodology in future, it should be **implemented in an appropriate software** with a user-friendly input data interface in order to integrate the large amounts of data needed for the calculation of specific scenarios. Furthermore, it should directly be linked to LCI databases such as *ecoinvent* in order to always guarantee updated LCA results.

In addition to that, the methodology developed in this thesis provides many **possibilities for further extensions**. Food classification in our model is static across the entire food value chain. However, in real food value chains products are combined to new products (e.g. flour, salt, and yeast to bread) or separated into linked co-products (e.g. milk to cheese and whey). Therefore, FW rates in our model often do not relate to a specific product, but to the estimated average of several products containing the same ingredient (e.g. eggs contained in various products). To accurately calculate average FW rates of ingredients, the composition of all compound products and their amounts consumed needs to be known, which is usually not the case and leads to uncertainties. A new **framework to model co-products and compound products** is particularly important, if detailed food categories are differentiated and compound dishes analysed based on their composition (recipe). Furthermore, the extension of the EFA with **nutritional indicators** (e.g. including proteins, vitamins, minerals) can provide useful applications in the food industry in order to identify nutritionally valuable FW flows and use them for valorisation. The LCA of **FW treatment** can be improved by **differentiating the composition of FW** and by **empirically supporting the substitution assumptions**, e.g. for the use of compost and digestate from FW. A combination with the LCA model EASTECH (www.easetech.dk) might provide synergies for composition-dependent LCA of FW treatment processes. For the substitution of useful co-products from FW treatment, a consequential approach might be appropriate, since a reduction of avoidable FW marginally reduces total compost and digestate availability. Furthermore, the LCAs of food products can be further developed into dynamic LCAs taking **regional** as well as **seasonal variations** (especially for products from greenhouses) into account. The applied LCIA methodologies do not consider **all impact categories relevant in agricultural production** (e.g. soil compaction, salinization, erosion). For some impact categories, new approaches have recently been developed, e.g. for soil compaction by Stoessel et al. (2018). These impacts can be integrated in future versions of our methodology.

Coupling quality evolution modelling empirically with FW rates opens innumerable possibilities to optimise the environmental performance of supply chains. This might be **particularly relevant for easily perishable products**, where parameters such as temperature, pressure, percussion, and vibration during transport might largely affect the products' susceptibility to be wasted. For other products with a generally long shelf live, such as sugar and rice, this approach might be irrelevant.

Methodological system boundaries exclude aspects potentially relevant to reduce environmental and other negative impacts caused by FW. For instance, we did not consider **additional food consumption due to overeating**, even though it provides a potential to reduce environmental impacts from food production while the reduction of overweight has a positive health effect (Ceren et al., 2016). Furthermore, we did not consider **rebound effects**, e.g. if consumers spend the money saved from buying less surplus food on other activities with adverse environmental effects (Martinez-Sanchez et al., 2016). This is especially relevant for consumer communication and awareness raising, since rebound effects will likely depend on the consumers' motivation to reduce FW.

The case studies of FW reduction in food services showed that **FW is often caused by a sequence of reasons**, e.g. if high customer expectations combined with high standards of their competitors urge restaurants to fill up their buffets and offer the entire variety of dishes until to the end of the service (KITRO, 2018). With our methodology we only analysed the physical origin of FW, but not the reasons leading to the wastage. Nevertheless, our case studies in food services demonstrated that FW at the agricultural level can be reduced, if food services use non-standard products that otherwise would have been wasted (Mein_Küchenchef, 2018). Other case studies confirm the importance of involving all relevant actors of the food value chain. For instance, non-standard products could be saved if retailers reduce the cosmetic norms *and* consumers learn that the products' nutritional quality and taste are not negatively influenced by cosmetic characteristics such as the form of vegetables (Stuart, 2009). The reasons for FW are assessed in a growing number of studies, the majority of them focussing on specific stages of the food value chain, e.g. households (Quested et al., 2013, Schanes et al., 2018). Some studies analyse correlations between FW amounts and other parameters such as per-capita GDP (Xue et al., 2017). The **combination of our methodology with studies analysing the factors contributing to FW** will provide **useful insights for the identification, design and implementation of effective FW prevention strategies**.

The exclusion of ethical, social, and economic impacts is one of the major limitations of this thesis. However, several approaches are available that can be integrated into our methodology in future projects. For **ethical aspects**, a framework for integrating **animal welfare** into LCA has been recently developed by Scherer et al. (2018). **Social life cycle assessment** (**S-LCA**) is an option to assess social and sociological aspects of products and their actual and potential positive and negative impacts along the life cycle (Norris and Franze, 2013). A study by the FAO introduced a methodology that enables a **full-cost accounting (FCA)** of FW. According to their study, "The FCA framework incorporates several elements: market-based valuation of the **direct financial costs**, non-market valuation of **lost ecosystems goods and services**, and **well-being valuation** to assess the social costs associated with natural resource degradation" (FAO, 2014b). Based on this report, FAO also assessed societal costs and benefits of a number of case studies for FW reduction (e.g. improved carrot sorting in Switzerland) (FAO, 2014a). The possibility to integrate ethical, social, and economic aspects into the methodology applied in this thesis demonstrates the **large potential to extend our methodology into a powerful model for integral FW assessments**. The growing number of methodological approaches, integrating new relevant impacts of food systems on human well-being and future generations, reinforces the likelihood of our methodology to be further developed.

As a conclusion, the methodology adopted in this dissertation represents a **solid basis to model** the environmental impacts of **specific scenarios** for FW prevention, which is of growing importance to meet sustainability goals. The methodology is open for further developments and extensions in order to **learn from implemented strategies** for FW reduction, **improve future strategies**, support the **design of more sustainable supply chains**, and combine FW prevention with other measures towards more sustainable food systems.

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APPENDICES

APPENDIX A

SUPPORTING INFORMATION

QUANTIFYING FOOD LOSSES AND THE POTENTIAL FOR REDUCTION IN SWITZERLAND

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SUMMARY

This supplementary material in appendix A contains information on the methodology, data sources, and assumptions of the mass and energy flow analysis of food consumption and waste in Switzerland, presented in chapter 2.

Section A.1 describes all sources of primary data (firms, associations, public institutions). Section A.2 explains how the share of food consumption in households and in the food service sector was estimated for Switzerland, section A.3 how food consumption was calculated for each food category. The next section explains how food loss rates were estimated in each food category (the general methodology applied for all food categories is explained in chapters 2.2.6.1-2.2.6.6).

Data reliability was assessed in section A.5, including tabulations of the pedigree results for all stages of the food value chain and for all products. The last section A.6 contains tabulations of all food waste rates, differentiating food categories, stages of the food value chain, avoidability, and reasons for the food to be wasted.

A.1 FIRMS THAT PROVIDED DATA

Table A.1 contains a list of the firms within the Swiss food supply chain that provided quantitative and qualitative data about their food losses.

Table A.1: Overview of the firms that provided data for the mass and energy flow analysis.

FIRMS (31)	
Agricultural producers (5)	
• Producer of meat, cereals, and vegetables for processing: Rüchihof, Möhlin (IP, Integrated Production[1]).	
• Producers of vegetables (fresh and for processing) and potatoes: Raihof, Möhlin; Huber Gemüsebau, Steinmaur (IP).	
• Producer of fruits and vegetables, own farm shop: Eulenhof, Möhlin (organic).	
• Producer of milk, cereals, and vegetables for processing: Tannenhof, Möhlin (IP).	
Food trading and logistics industry (5)	(± 800 million CHF)
• Fruit logistics centre: Tobi Seeobst, Bischofszell.	
• Supplier of food service settings: HOWEG transGourmet Schweiz AG, Winterthur.	
• Fruit and vegetable logistics centre: ZEMAG (Zürcher Engros Markthalle), Zurich.	
• Fruit and vegetable logistics centre: Coop, Q-Kontrolle DS Nord, Möhlin.	
• Producer and trader of vegetables: Huber Gemüsebau, Steinmaur.	
Food processing industry (6)	
• Company for vegetable processing	(± 12 000 t of vegetables/year)
• Producers of fresh and dried pasta (2)	(± 22 000 t of pasta/year)
• Major bakery	(± 114 000 t of baked goods/year)
• Slaughterhouse	(± 680 000 slaughterings/year)
• Dairy	(± 3 000 t of milk/year)
Food service settings (2; data from 201 settings**)**	(± 300 million CHF)
• Major catering outlet running more than 300 restaurants and bars: SV-Group, Dübendorf.	
• Gourmet restaurant: Stucki, Basel.	
Retailers (4)	(± 30 billion CHF)
• Supermarkets and discounters (3)	
• Wholefood shop	
Bakeries (5; data from 29 branches**)**	(± 30 million CHF)
• Major bakery with centralized production	(±25 million CHF)
• Wholemeal bakery: Furter, Aarau.	
• Aukofer, Möhlin.	
• Stocker's Back & Snackhaus, Zeiningen.	
• Büeler, Möhlin.	
Food banks (4)	
• Tischlein deck dich	
• Caritas Luzern	
• Schweizer Tafeln	
• Partage	
ASSOCIATIONS (10)	
• Swiss Farmer's Union (SBV), Brugg	
• Swissfruit, Zug (Union of the Swiss Fruit Producers)	
• Swissveg, Bern (Union of the Swiss Vegetable Producers)	
• Schweizerische Zentralstelle für Gemüsebau und Spezialkulturen SZG, Koppigen	
• Swissbaker, Bern (Association of Swiss bakery and sweetmeat shop operators)	
• Swisscofel, Bern (Swiss association of fruit, vegetable and potato trade)	
• Gastrosuisse, Zürich	
• Proviande, Bern (Association of the Swiss meat industry)	
• Ausbildungszentrum für die Schweizer Fleischwirtschaft ABZ, Spiez (Training centre of the Swiss meat industry)	
• Aviforum, Zollikofen (Centre of competence for the Swiss poultry industry)	
PUBLIC INSTITUTIONS (3)	
• Swiss Federal Statistical Office (BFS, FSO)	
• Federal Office for Agriculture (BLW, FOAG)	
• Federal veterinary office (BVET, FVO)	

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[1] Integrated production (IP) is a Swiss standard for farming with reduced inputs of pesticides, manure, water, and energy and keeping livestock in a near-natural environment.

A.2 HOME CONSUMPTION VERSUS CONSUMPTION IN THE FOOD SERVICE INDUSTRY

In order to calculate the contribution of losses from the food service industry, from retail, and from households to the losses over the whole food supply chain, the share of the food consumed in Swiss food service settings relative to the overall food consumption must be known. The food costs of the average food consumed in Swiss service outlets per household was deduced from the average expenses of a Swiss household in food service settings and the average share of the food costs relative to the total income of Swiss food service settings. However, food service settings can generally buy their food for cheaper prices than private households (assumed volume discount of 5%; Stucki, 2011). To be comparable with food expenses of households, the real food costs of the service outlets were converted into the hypothetical costs, if they had to buy the same food at retail prices. Then, the converted food costs of the food service industry were compared with the food expenses of private households (Table A.2).

Description of values		Data source
Expenses in service settings in 2008 per average Swiss household per month	335.45 CHF	*Gastrosuisse, 2011*
Share of food costs (including drinks) of total income in an average service setting	30.5 %	*Gastrosuisse, 2011*
➔ Food costs in 2008	102.3 CHF	
Mean retail price of food / mean purchase price for service settings	105%	*Stucki, 2011*
➔ Hypothetical retail price of the food consumed in service settings in 2008	107.40 CHF	
Household expenses for food	600 CHF	*BFS, 2008*
➔ Total expenses for food	707.40 CHF	

Table A.2: Calculation of the share of the food consumed in Swiss food service settings relative to the overall food consumption (explanations

A.3 DERIVATION OF CONSUMPTION IN EACH FOOD CATEGORY

Consumption refers to the retail and catering trade level, i.e. the quantity the private households and the catering companies purchase, including the losses occurring in home consumption and catering. Data mainly originate from the Swiss Farmer's Union (SBV, 2009)[2]. Fresh fruits were separated into apples, berries and other fresh fruits, because apples are the fruit with the highest per capita consumption and because berries, in general, have the tendency to be more perishable. The consumption of canned fruits, unluckily, only refers to the imports. Due to lack of data, canned fruits produced in Switzerland were classified as fresh fruits (SBV, 2009). For the consumption of vegetables it was assumed, that fresh and storable vegetables are produced and consumed in the same proportions (3/4 fresh, 1/4 storable; SZG, 2011). Frozen vegetables are classified as processed. The consumption of bread and pastries was defined as consumption of dry flour and was thus reduced by 20% compared to the consumption of fresh products. 10% is the average content of other ingredients than flour, which are modelled in separate food categories (butter, sugar, eggs, oil…). Another 10% is the average content of water in the baked goods (BLW, 2010, Monaco, 2011). The latter does not influence the energy balance. The consumption of pasta refers to the flour (other ingredients modelled in other food categories), assuming all durum wheat to be used for pasta production. The category of cheese, per definition, contains curd and 3% of the produced whey, the category of butter 13% of the produced buttermilk (SBV, 2011). The other dairy products were attributed to the category of milk. Other drinks were not included in this analysis, except fruit juice, that was modelled in the categories *apples* and *fresh fruits*. Meat was differentiated into the categories "pork", "poultry", and "beef". Meat from dairy livestock was modelled separately in the diary category and meat from laying hens in the egg category, because diary and egg production would not be possible without the corresponding meat losses. Other meat types (horse, lamb…) were attributed to the category of beef.

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[2] The consumption of cereals is based on the market report for cereals (BLW, 2010), the consumption of pasta based on the Swiss Union of Pasta Producers (NZZ-Online, 2009).

A.4 DERIVATION OF FOOD LOSSES IN EACH FOOD CATEGORY

The general methods applied to all food categories are explained in the sections 2.2.6.1 - 2.2.6.6 of the paper. In this section, only the loss entries derived specifically for individual food categories are described. This is mainly the case for the losses in agricultural and animal production, processing, and postharvest handling and trade. The percentages refer to mass, if not indicated differently. An overview of all the loss entries is displayed in the tables A.11 and A.12.

A.4.1 Fruit Losses

According to a major fruit trading company, 56% of all cherries and 50% of all plums and apples are declassified and used for processing. Based on this information, the average declassification rate of the category "fresh fruits" was estimated at 54%. 6% of all berries were estimated to be sorted out due to unsatisfied quality standards; another 6% is lost because of mismatch between offer and demand. The amount of fresh fruits and apples from trees and shrubs that are not harvested due to missing demand or inadequate organisation were ignored because of lack of data. We estimated that 2.5% of the apples, 7.5 % of the berries, and 6% of the remaining fresh fruits get lost in the technical or manual harvest processes (Eulenhof, 2011, Tobi, 2011).

Declassified apples are mainly processed to apple juice. Dried fruits, pies and other products are of minor quantitative relevance (SBV, 2009). For simplification, in our model all the declassified apples are processed to apple juice. In this process, an estimated 30% of the mass of the apples results as side products that are fed to livestock. In the processing of other fruits, 38% result as side products[3]. About 25% were estimated to be fed to livestock[4] (Eulenhof, 2011; SBV, 2011; Schweizerischer Obstverband, 2011b; Tobi, 2011). Processing losses of berries were ignored[5].

The losses of unprocessed fruits in trade were estimated as follows: 1.1% for apples, 1.55% for berries, 2.3% for other fresh fruits (Tobi, 2011). The losses of fruit juices in households and food service settings were assumed to be equal to the household losses of soft drinks, i.e. 7% according to defra (2010).

A.4.2 Losses of canned fruits

In this category, only canned fruits from imports were modelled (the amount of canned fruits produced in Switzerland is unknown). We estimated that 1.5% of the canned fruits are discarded because of inedible quality and 5% are lost on the field in the harvest process (Eulenhof, 2011, Tobi, 2011). According to the statistics of the Swiss Farmer's Union, imported canned fruits have an average energy content of 172 kcal/100g, whereas the corresponding fresh fruits contain 70 kcal/100g. Assuming the by-products of fruit processing to have an energy content of 15 kcal/100g, it was estimated that 60% of the mass is lost in processing (SBV, 2009, SBV, 2011).

A.4.3 Potato Losses

The technically caused losses of harvest were estimated 2.5%, the rotten, unpalatable potatoes sorted out in trade 3% (Raihof, 2011). Regarding the *avoidable* losses, an estimated 161,300 t of fresh potatoes (corresponds to 29.7% of the production) were fed to livestock in the years 2008-2010 (Spycher and Chaubert, 2011). In Europe, 7.2% of the agricultural production of roots and tubers is lost in trade (Gustavsson et al., 2011). Subtracting this from Spycher's amount of the totally fed potatoes, the remaining 22.5% were assumed to be the relative losses fed to livestock in agricultural production. From the processing industry, an additional 21,500 t of potatoes (corresponds to 6.1% of the input) were fed to livestock (Spycher and Chaubert, 2011). The total avoidable losses over the whole food supply chain were consistent with Gustavsson et al. (2011) (54% versus 52% of the agricultural production).

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[3] For fresh fruits excluding apples, the average mass loss in processing was assumed to be 36%, for apples 29% (Tobi, 2011; SBV, 2011; Swissfruit, 2011). An additional 0.8% of the apples and 2% of the fresh fruits are sorted out because of inedible quality (Tobi, 2011). The average energy content of fresh fruits and apples is 52 kcal/100g, the content of apple juice 43 kcal/100g, and for the other processed products 60 kcal/100g (SBV, 2011;Yazio.de, 2011).

[4] According to SBV (2009) 200 TJ of side products from the fruit juice industry were fed to livestock in 2007. This corresponds to all the side products of apple juice production plus 25% of the side products of processing other fresh fruits.

[5] On one hand, processing of berries causes losses. On the other hand, the resulting products are less perishable and thus less susceptible to spoilage. Which effect is more dominant, is unknown.

A.4.4 Vegetable Losses

The vegetables remaining on the field because of inedible quality at the time of harvest were not defined as loss (see section 2.2.4 in the main paper). The technically caused losses are very variable depending on the harvest method, the type of vegetable and weather conditions. In average, they were estimated at 3-10% (Eulenhof, 2011) and classified as *unavoidable*.

Gustavsson et al. (2011) estimates the avoidable vegetable and fruit losses in agricultural production in Europe at 20%. The allocation between fresh, storable and processed vegetables was based on the following estimations according to a farmer's interview: The losses of edible products due to unsatisfied quality standards are the highest for storable vegetables (10-20%). Based on experience, they are lower for fresh vegetables and for vegetables destined for processing (2-12%). Additionally, 15-25% of the fresh vegetables are not harvested because of a mismatch between offer and demand; the growth rate of these vegetables during the harvest period is very variable and hardly predictable; on the other hand, demand is too inelastic to adapt to these changes (Eulenhof, 2011). Assuming an average Swiss consumption rate of 60% fresh, 20% storable and 20% processed vegetables (SBV, 2009, SZG, 2011), the estimations of Eulenhof yielded 20.3% of average, avoidable vegetable losses. Assuming the amounts of fruit and vegetable losses to be similar, Eulenhof's values for Switzerland are consistent with Gustavsson's values for Europe[6].

The avoidable losses of fruits and vegetables in postharvest handling and trade were estimated at 5% for Europe (Gustavsson et al., 2011). Eulenhof estimated the storage losses of storable vegetables at 8-12% (Eulenhof, 2011); a major food trading company estimated the storage losses of fresh fruits and vegetables 0.2-0.4% (Freiburghaus, 2011). Assuming again a consumption ratio of 20% storable, 20% processed, and 60% fresh vegetables and assuming the losses in vegetables and fruits to be similar, the average storage losses of vegetables are 2.2%. Assuming that the 5% losses described by Gustavsson are higher than 2.2%, because they also include the losses of quality sorting, the latter contribute 2.8% of the losses of all vegetables. Since quality sorting does not concern processed vegetables, the percentage for fresh and storable vegetables is 3.5%[7].

The losses in processing were divided into minimal, *unavoidable* losses of inedible parts and into *avoidable* losses due to high quality standards. Souci et al. (2008) provides values for the typical yield of single vegetables. The typical mass yield for the consumption of the 20 most consumed vegetables in Switzerland was calculated[8], resulting in 84%. Thus, 16% is lost. However, the unavoidable vegetable losses in households are identified as 5.5% by Quested and Johnson (2009). Based on the mentioned data, the inedible parts of vegetables were estimated between 6 and 16%, 11% being the most probable value. A major vegetable processing company, producing peas, beans and spinach, estimated its losses at 15-20% (Ditzler, 2011). Thus, the *avoidable* losses are between 0 and 14%. Gustavsson et al. (2009) estimate the *avoidable* losses in fruit and vegetable processing at about 10%[9]. The average of the two estimates is 8.5 (5-12)%.

The calorific content is related to the edible parts of the vegetables. The inedible parts were assumed to have the same calorific content as the edible parts.

A.4.5 Losses in the pasta production chain

In the category of pasta, only the wheat of the pasta was modelled. The other ingredients are part of other food categories.

We assumed that the technical losses of harvest and the storage losses in the trade industry are equal for bread wheat and for durum wheat, namely 10% (Eulenhof, 2011, Rüchihof, 2011) and 1% (SBV, 2009), respectively. In the process of flour milling from

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[6] 27%*60% + 15%*20% + 7%*20% = 20.6%; Gustavsson estimates the *avoidable* losses of fruits and vegetables in agriculture at 20% in Europe.

[7] 2.8% / 80% = 3.5%; 80% is the consumption of fresh and storable vegetables relative to the overall vegetable consumption (SBV, 2009).

[8] The 21 most consumed vegetables in Switzerland contribute 65% of the total vegetable consumption by mass (Eichholzer and Camenzind-Frey, 2005).

[9] Gustavsson et al. (2009) estimates the avoidable losses in processing for fruits and vegetables at 2%. Assuming the losses to be equal for fruits and for vegetables and assuming that only 20% of the vegetables are processed (SBV, 2009), the loss rate for the vegetables that are processed is 10%.

durum wheat, 16% of the initial mass result as bran and 18% as second flour, both fed to livestock (Spycher and Chaubert, 2011)[10]. Bran, a by-product of milling with high nutritional value, was classified as *possibly avoidable* food loss.

The losses in pasta manufacture are very variable, depending on the specific product. Generally, we distinguished four main types of pasta: fresh, canned, frozen, and dried pasta. Fresh, canned, and frozen pasta include products with additional ingredients and fillings (ravioli, tortelloni, lasagne…). These products are usually associated with sophisticated production processes causing more food losses, compared to pure pasta (noodles, gnocchi…). Data from a major producer of fresh pasta was used to estimate the production losses of fresh, canned and frozen pasta, assuming that its product range is representative for the Swiss consumption of these products. To estimate the production losses of dried pasta, data from a major bakery and pasta producer was available.

However, the *possibly avoidable* and the *unavoidable*, technically caused losses were not measured separately. Based on rough estimate of a production manager, it was assumed that half of these losses are *possibly avoidable* (e.g. ravioli produced in the period of changing from cheese to spinach filling on the same production line).

The losses during storage and trade, in contrast, are dependent on the life span of the products. Fresh pasta generally expires after around a month, while canned, frozen, and dried pasta have life spans of one and more years. The losses of fresh pasta in trade and storage were estimated between 1 and 2%, caused by the ambitious demand of supermarkets to satisfy the hardly predictable demand for a wide range of products all the time. The losses for canned, frozen and dried pasta were guessed at 0-1% (estimations from 2 major Swiss producers of pasta).

For the calculation of the overall pasta losses, it was assumed that the average Swiss pasta consumption is composed by 25% of fresh pasta, 25% of canned and frozen pasta and 50% of dried pasta (estimation based on the interview with a production manager in the pasta industry). An overview is displayed in Table A.3.

Table A.3: Derivation of the losses in pasta production. The numbers in italic are measurements; the other values are estimations from experts working in the pasta production industry.

	Fresh pasta	Canned & frozen pasta	Dried pasta	Derived values for Swiss consumption
Assumption for the consumed quantities	1/4	1/4	1/2	100%
Losses during production (II, III)	*9.5 (8-11)%*	9.5 (8-11)%	*1.6 (1.5-1.7)%*	5.6 (4.8-6.4)%
Damaged package (III)	1.5 (1-2)%	0.5 (0-1)%	0.5 (0-1)%	0.8 (0.3-1.3)%
Products stored for too long (I)	1.5 (1-2)%	0.5 (0-1)%	0.5 (0-1)%	0.8 (0.3-1.3)%
Donations (I)	0.4 (0.3-0.5)%	0.05%	0.05%	0.14 (0.1-0.18)%
> TOTAL avoidable (I):				0.94 (0.4-1.48)%
> TOTAL possibly avoidable & unavoidable (II-III):				6.4 (5.1-7.7)%
References: two major Swiss producers of fresh and dried pasta				

A.4.6 Losses in cereal production and processing

Eulenhof (2011) and Rüchihof (2011) estimate the technical harvest losses of bread wheat at 5-15%. The losses in trade are 0.5-1.5% (SBV, 2009). In the process of flour milling from bread wheat, 6.6% of the initial mass result as bran and 15% as second flour, both fed to livestock (Spycher and Chaubert, 2011)[11]. Bran, a by-product of milling with high nutritional value, was classified as *possibly avoidable* food loss. The losses due to quality standards are very variable, especially due to different weather conditions. In the year 2000, 22.8% were sorted out and fed to animals (BLW, 2000). However, data is not available at the same level of detail for the

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[10] These values are also consistent with SBV (1983) (average yield in flour milling of Triticum durum: 64%).

[11] These values are also consistent with SBV (1983) (average yield in flour milling of bread wheat: 76%).

years after 2000. Therefore, the estimation used in this paper is uncertain. The production losses in bakeries were estimated at 2% by Monaco (2011) and at 4% by another, major bakery (1% of them being avoidable, e.g. by optimal staff instructions).

A.4.7 Losses in rice production and processing

Since no data about the losses in agriculture and trade was available for rice, the same values as for other cereals were modelled (10% technical losses of harvest and 1% loss in trade). The losses in rice processing, according to Spycher et al. (2011) amount to 19.6% (8.6% of broken rice, 2.4% of unripe rice, 8.6% of other processing losses that are fed to livestock as second flour). Broken rice was qualified as *possibly avoidable*, the other losses as *unavoidable*.

A.4.8 Losses in maize production and processing

Due to missing data for agriculture and trade, the same values as for other cereals were modelled (10% technical losses of harvest and 1% loss in trade). After Spycher et al. (2011) 46.5% by mass results as by-product of corn processing and is fed to livestock (data from 2005-2008). This is consistent with the mean yield in the processing of corn to corn meal of 55% (SBV, 1983). Assuming that 14% of the corn goes to consumers and food service settings as unprocessed corncob, 6%[12] are *unavoidable* losses of corn in catering companies and private households. In the processing industry, 39%[13] of the total corn are lost and fed to livestock. This allocation is uncertain, but does neither influence the total losses over the entire food supply chain nor the allocation of the *avoidable* losses at each stage of the food chain and is therefore of little relevance.

A.4.9 Losses of sugar

The agricultural losses of sugar beets and the losses in further treatment of sugar to sweet products were ignored due to lack of data. The processing losses in this analysis only refer to sugar manufacture. The yield of sugar manufacture comes to 17% relative to mass (SBV, 2009). Considering the energy content of sugar beet (85 kcal/100g), of sugar (401 kcal/100g), and of the various by-products, a calorific yield of 80% was calculated (Arrigo et al., 1999, Yazio.de, 2011).

The losses in retail and consumption only refer to the sugar as a part of the various products containing sugar. The other ingredients were modelled in other food categories. The losses in retail were based on the average losses of desserts, cakes, pies, sweet cookies, sweet roulades and chocolate, the losses in households were based on cakes and desserts.

A.4.10 Losses of oils and fats

The *avoidable* losses in agriculture (10%), trade (1%), and processing (8%) were taken from Gustavsson et al. (2011) analysing oilseeds and pulses in Europe. *Unavoidable* losses were ignored due to lack of data.

A.4.11 Dairy losses

According to the Swiss supply statistics of milk, 16% of the produced milk was fed to livestock in 2007 (SBV, 2009). The analysis of a milk producer showed that less than 1% of the produced milk is consumed for the uprising of milk cows (Tannenhof, 2011). Hence, most of the milk fed to livestock is not required part of the milk production system, but is rather used for meat production. It could be avoided by replacing milk with vegetarian forage, but this could have an impact on the productivity of meat production and on meat quality. For this reason, here it is classified as *unavoidable*. In a scenario, where reducing meat consumption is regarded as an option to reduce waste, it would have to be classified as *avoidable*.

According to Tannenhof (2011) about 1% of the milk is lost due to illnesses of the cows. The losses in trade were estimated at 0.5% (Gustavsson et al., 2011).

The Swiss milk statistics revealed an average yield of cheese of 12.3% by mass in 2009. Assuming an energy content of 59 kcal/100g for raw milk and 271 kcal/100g for cheese, the calorific yield amounts to 69% (SBV, 2009, SBV, 2011). In the case of butter, the yields are 7.5% by mass (BFS, 2010). In the model, we assumed that 13% of the mass of the processed raw milk for

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[12] 45% x 14% = 6%

[13] 45% x (100% - 14%) = 39%

butter is used as skimmed milk with a calorific content of 33 kcal/100g, and 3% of the mass of the processed row milk for cheese is used as whey with a calorific content of 21 kcal/100g for further food and drink processing (SBV, 2011). However, the utilisation rates of skimmed milk and whey are rough estimates.

One of the main uncertainties ignored in this analysis is the politically induced over-production of milk due to milk quotes.

Milk production is a co-product of meat production. The losses related to the meat available from diary livestock were incorporated in the analysis, assuming the same losses as modelled for beef. It was assumed that all the meat from outgoing dairy cows and from calves (after feeding them up for 4-4.5 months with milk) is used (Tannenhof, 2011).

A.4.12 Losses in egg production

The analysis of eggs presents two difficulties. First, the meat of the laying hens is a by-product of egg production whose losses should be considered, too. Second, eggs are processed to innumerable different products. The different methods of processing are related to variable losses; the different products are variable in their perishability (uncooked pastries are highly perishable, whereas dried pasta is storable for years). In this analysis, eggs and meat from laying hens were modelled as co-products. The losses in retail and consumption only refer to the eggs as a part of the various products containing eggs. The other ingredients were modelled in other food categories.

The losses due to poultry illness were assumed to be equal to livestock illness (1%). In addition to that, the slaughtering waste of the laying hens used for meat production and the waste of the discarded laying hens was considered. According to the president of Gallocircle, 60% of the laying hens are not converted into meat due to lacking demand (Ferrara, 2011). For the remaining 40%, the slaughtering waste (inedible parts) was estimated at 44% of the weight of the entire animals (Aviforum, 2011). Based on data about the animal by-products (Arrigo et al., 1999, SFF, 2008), the average calorific content of the entire laying hens was roughly estimated at 105 kcal/100g. The surplus cockerels could either be used as eggs, if it were possible to define their sex in advance without destroying the eggs (this technology is currently under research; Ferrara, 2011), or they could be grown up for meat production. Since their characteristics are inferior to broilers regarding meat production, this is not economic. In this analysis, the losses were quantified in relation to the alternative scenario of using the eggs. It was assumed that each laying hen lays 316 eggs (Aviforum, 2011). Thus, the losses come to 0.32%[14]. These losses were classified as *avoidable*.

For lack of data, the egg losses in trade and processing were assumed to be equal to the dairy losses after Gustavsson et al. (2011) (0.5% in trade and 1.2% in processing) and the losses in poultry equal to the average meat losses after Gustavsson (0.7% in trade and 5% in processing). Eggs incorporated in mixed products were modelled as fresh eggs.

A.4.13 Losses in the meat chain

Based on estimations of a milk and beef producer, the meat losses due to illness of livestock come to 4% (Tannenhof, 2011). This estimate was also used for pork and poultry production. The slaughtering waste of pork and beef is based on measurements and qualified estimations of a major slaughterhouse (SBA, 2011) and on data from literature (SFF, 2008), the slaughtering waste of poultry is based on qualified estimations of the aviforum (Aviforum, 2011). The total losses of slaughtering were estimated as follows: 35% for broilers, 27.5% for pork and 53% for cattle. The detailed numbers are displayed in Table A.12. The major source of error is located in the estimation of the calorific content of the various animal by-products. Based on data from “Flows of the biogenic goods in Switzerland” (Baum et al., 2008), from the teaching material for butchers (SFF, 2008) and on nutritional tables (Arrigo et al., 1999), the following average calorific contents of the entire animal bodies were determined: 113 kcal/100g for broilers, 200 kcal/100g for pork and 123 kcal/100g for cattle.

For the losses in post-harvest handling and trade and in processing, the values from Gustavsson et al. (2011), related to the average meat losses in Europe, were adopted (0.7% in trade and 5% in processing).

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[14] 1 / 316 = 0.32%

A.4.14 Fish Losses

The losses in fisheries are very variable between different fisheries, locations and fish species. Gustavsson et al. (2011) estimate the average *avoidable* European losses of fishes and shellfishes at 9.4%. In a report of the "Scientific, Technic and Economic Committee for Fisheries" of the European Commission they guess that 40-60% of all the fishes harvested by European fleets are discarded in the water because of high quality standards and because some species are less profitable (Stuart, 2009). Based on this, the *possibly avoidable* losses were estimated between 9 and 60%, with the highest probability at 35%. The *unavoidable* losses in fisheries and processing are not included. Only the inedible parts removed in households and food service settings were modelled. Therefore, the modelled amount of fish caught at the beginning of the food supply chain only refers to the parts of the fish that are sold at the retail level.

In Europe, the *avoidable* losses of seafood and fishes account for 0.5% in trade and for 6% in processing (Gustavsson et al., 2011).

A.4.15 Bread and pastry losses in supermarkets and bakeries

The losses were estimated according to measurements and estimations of 5 bakeries. A city bakery with between 20 and 30 branches estimated its losses at 8%, 1.6% of them being reused and 0.4% being donated. The remaining 6% are fed to livestock. A small, independent city bakery has measured its bread losses. 4.7% of the produced products are fed to livestock. An additional 2% are reused and donated. A village bakery with 3 branches estimated its losses between 3 and 7%, another innovative, smaller village bakery between 3 and 6%. An old, traditional bakery with a narrow range of steady customers has kept its original philosophy not to overproduce and to accept the shelves being usually quite empty in the late afternoon. Most unsold products are consumed by the staff or reused. They roughly estimated the losses fed to animals at 1% of the volume of sales. This bakery was not included in the calculation of the average bakery losses because it probably is a rare, unrepresentative case for nowadays. Nevertheless, it shows that minimal losses are realistic.

From the mean losses of the other four bakeries (6%, 4.7%, 5%, 4.5%), an average of 5 % was calculated. A confidence interval was defined, based on the lowest (3%) and the highest value (7%) in the village bakeries (Aukofer, 2011, Büeler, 2011, Monaco, 2011, Stocker, 2011).

A.4.16 Losses in the food service industry

The derivation of the unavoidable and of the avoidable kitchen and plate waste, for all food categories, is described in section 2.2.6.4 of the paper. The allocation for individual food categories, for plate waste, is mainly based on the composition of 1,504 canteen guest's plate waste[15]. The relative composition of the unavoidable losses was assumed to be equal to the unavoidable losses in households, the relative composition of the avoidable kitchen waste equal to the avoidable losses in households. The numbers are shown in Table A.4.

Table A.4: Losses in the food service sector in individual food categories (% of weight). The total losses for all food categories are based on literature (Andrini and Bauen, 2005, Baier and Reinhard, 2007) and on measurements (Stucki, 2011, SV_Group, 2011, ETH-Mensa, 2012). The relative composition of plate waste is based on the measurements in a canteen; the composition of kitchen waste was assumed to be equal to household losses.

Food category		Losses in the food service industry		
		unavoidable (III)	(possibly) avoidable (I-II)	
			kitchen waste	plate waste
1	Apples	7.1%	15.6%	2.5%
2	Other fresh fruits	32.2%	9.5%	2.4%
3	Berries	3.2%	11.7%	0.5%
4	Canned fruits	0.0%	6.9%	4.0%
5	Potatoes	14.5%	15.1%	1.0%
6	Fresh vegetables	14.5%	16.5%	3.2%
7	Storable vegetables	14.5%	13.4%	3.2%
8	Processed vegetables	0.0%	6.1%	3.2%
9	Breads and pastries	0.0%	16.9%	3.4%
10	Pasta	0.0%	13.9%	4.7%
11	Rice	0.0%	13.9%	4.8%
12	Maize	11.3%	12.1%	7.5%
13	Sugar	0.0%	5.2%	8.1%
14	Oils and fats	1.8%	6.8%	9.9%
15	Milk/other dairy products	0.0%	3.9%	1.2%
16	Cheese	4.8%	6.1%	1.2%
17	Butter	0.0%	3.5%	1.2%
18	Eggs	29.0%	3.9%	3.3%
19	Pork	8.0%	7.3%	3.0%
20	Poultry	40.2%	7.1%	3.0%
21	Beef and other meat / offal	8.0%	5.1%	4.3%
22	Fish	13.8%	5.9%	2.6%
1-22	All categories	**8.1%**	**8.9%**	**2.9%**

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[15] The analysis was undertaken the 20th of April 2012 during lunch in the *ETH-Mensa Polyterrasse* in Zurich (ETH-Mensa, 2011). The plate waste of 1'504 guests was sorted into 18 food categories and weighted. The percentage of food waste relative to the average portions served was calculated for each food category individually. The losses of berries were assumed to be equal to other fresh fruits, the losses of poultry equal to pork. The losses of butter, cheese, and milk were estimated from the losses of a milk sauce with cheese and of cheese cake, the losses of eggs from pasta and cakes with eggs as important ingredients, the losses of apple from apple puree, the losses of maize from polenta, and the losses from oils and fats from salad sauce. The losses of sugar and bread were based on the analysis of 49 guests' left-overs in the gourmet restaurant *Stucki* in Basel the 16th of February 2011 (Stucki, 2011). The losses of sugar are estimated from the average desert left-overs, the losses of bread from the left-overs on the guest's tables, excluding bread that was untouched.

A.4.17 Household losses

Data about household losses was taken from the two English studies Quested and Johnson (2009) and defra (2010). Quested provides data for avoidable, possibly avoidable and unavoidable food waste, but only within 15 food categories. Defra, on the other hand, provides data within 39 food categories, but only for the avoidable losses. Therefore, the numbers from Quested were used within six of the food categories analysed in this paper. In the remaining categories, numbers from defra were used for the avoidable food losses. The corresponding *possibly avoidable* and *unavoidable* losses, in most cases, were calculated, assuming the same proportions between *avoidable*, *possibly avoidable* and *unavoidable* as in Quested for the most similar food categories, respectively. Table A.5 shows the values used in this analysis. For meat, apples, vegetables, potatoes, maize, and berries the *unavoidable* losses are based on Souci et al. (2008) and SBV (2011). The *possibly avoidable* losses of maize were assumed to be equal to rice; of storage vegetables equal to fresh vegetables; of potatoes and apples they were derived from SBV (2011). The *avoidable* losses of storage vegetables were assumed to be equal to processed vegetables.

The total losses over all food categories are similar to Quested's values for all food categories excluding drinks (21.3% of the food purchased). The slight deviation can be explained by the differences between the Swiss and the UK food basket.

Table A.5: Household losses, based on data from UK (% of weight). The numbers in italic are from the sources listed on the right (Quested and Johnson, 2009, defra, 2010). The other numbers were derived from data in defra (2010), Quested and Johnson (2009), Souci et al. (2008), and SBV (2011), based on specific assumptions and calculations (section A.4.17).

Food category		Household losses			
		unavoidable	possibly avoidable	avoidable	source
Fruits					
1	Apples	**4.4%**	**12.0%**	***24.0%***	defra
2	Other fresh fruits	***20.0%***	***3.0%***	***19.0%***	Quested
3	Berries	**2.0%**	**3.0%**	**24.0%**	
4	Canned fruits	***0.0%***	***0.0%***	***15.8%***	Quested
Vegetables					
5	Potatoes	**9.0%**	**17.5%**	***17.4%***	defra
6	Fresh vegetables	**9.0%**	**17.0%**	***21.0%***	Quested
7	Storable vegetables	**9.0%**	**17.0%**	**14.0%**	
8	Processed vegetables	***0.0%***	***0.0%***	***14.0%***	Quested
Corn					
9	Breads and pastries	***0.0%***	***6.0%***	***33.0%***	Quested, defra
10	Pasta	***0.0%***	**3.0%**	***29.0%***	Quested, defra
11	Rice	***0.0%***	**3.0%**	**29.0%**	Quested, defra
12	Maize	**7.0%**	**3.0%**	**14.0%**	
Sugar					
13	Sugar	***0.0%***	***0.0%***	***12.0%***	Quested
Oils and fats					
14	Oils and fats	***1.1%***	***11.9%***	***3.7%***	Quested
Diary					
15	Milk/other dairy products	***0.0%***	***0.0%***	***9.0%***	Quested, defra
16	Cheese	**3.0%**	***0.0%***	***14.0%***	Quested, defra
17	Butter	***0.0%***	***0.0%***	***8.0%***	Quested, defra
Eggs					
18	Eggs	**18.0%**	***0.0%***	***9.0%***	Quested, defra
Meat					
19	Pork	**5.0%**	**3.7%**	***13.1%***	defra
20	Poultry	**25.0%**	**3.7%**	***12.8%***	defra
21	Beef and other meat / offal	**5.0%**	**2.6%**	***9.1%***	defra
Fish					
22	Fish	**8.6%**	**3.0%**	***10.5%***	defra
All categories		**3.6**	**6.2**	**15.6**	

A.4.18 Food donations

In Switzerland most donations are organised by the following four institutions (estimated amounts of donated food in 2009 in brackets): Tischlein deck dich (2'100 t), Schweizer Tafel (2'800 t), Partage (1'148 t) and Caritas. Caritas runs shops, where disadvantaged people can buy food at reduced prices. Some of the products are unmarketable, but most of them are regular products, purchased at reduced prices in special arrangements with the food industry. Caritas does not analyse how much of the volume of sales constitutes of unmarketable products that would otherwise result as losses. A rough estimate by one of the institute leaders stated 1'000 t per year (Caritas-Luzern, 2011). In addition to these institutionalised donations, locally organised donations were estimated at 1'000 t per year, based on example cases (e.g. bakeries offering their surplus food to old people's homes and to com-panies for their staff).

Around 8'000 t of food were donated in 2009. In the same year, the Swiss food consumption amounted to 5'400'000 t (SBV, 2009). Consequently, food donations accounted for 0.15% of the food consumed at the retail level[16]. However, the unsold food that could be used for donation, on one hand, and the demand for donated food, on the other hand, both bear a high potential (Tdd, 2011).

A.4.19 Assumptions for "best available technology" and "reasonable costs"

In this paper, the losses quantified as *avoidable* relate to a scenario of optimal distribution and processing adopting current best available technology and avoiding unreasonable extra costs. However, the definition of "best available technology" and "reasonable extra costs" is sometimes difficult and subjective. Table A.6 shows losses assumed to be *unavoidable* without technology improvement beyond current best available standard and without unreasonable extra costs.

Table A.6: Estimation of losses that are not avoidable without further technology innovation and without unreasonable extra costs (a complete list of all loss entries is displayed in Tables A.11 and A.12; the corresponding references can be found in Tables A.9 and A.10).

Losses related to…	Food Category	Assumed Losses (related to weight)
Manual harvesting	Apples	2.5 (0.8-4.2)%
	Berries	7.5 (5-10)%
Technical harvesting	Potatoes	2.5 (1-4)%
	Vegetables	5 (3-10)%
	Bread wheat, Rice, Maize	10 (5-15)%
Storage problems	Wheat	1 (0.5-1.5)%
	Milk	0.5 (0.3-0.7)%
Method of processing	Bread baking	2 (1.5-2.5)%

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[16] Consumption at the retail level refers to consumption of both private households and the food service industry, including the losses at their level of the food supply chain.

A.5 ASSESSMENT OF DATA RELIABILITY

Table A.7 shows the pedigree matrix used for the assessment of data reliability, which is illustrated in Tables A.9 and A.10. A pedigree score was attributed to each data source for the five indicators *reliability, completeness, temporal, geographical, further technological correlation* and for *sample size*. Where several references were used for the same estimate, the pedigree scores for *completeness* and *sample size* were attributed to all the references together.

Table A.7: Pedigree matrix (modified from Frischknecht et al., 2007). *Verified data* refers to data published in official statistics and public documents or to data verified by on-site check, cross check or mass/energy balance. *Sample size* refers to the number of firms, to the number of food service outlets, of households, and to the number of retailer cooperatives from which loss data is available, respectively. *Technological correlation* considers, if data derives from the enterprises and the processes which cause the corresponding food losses and if the losses refer to the food category under study (material). The market considered for the assessment of *completeness*, in this analysis, refers to Switzerland.

Pedigree score	1	2	3	4	5 (default)
Reliability	Verified data based on measurements	Verified data partly based on assum-ptions ***or*** non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered ***or*** >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered ***or*** some sites but from shorter periods	Representativeness unknown or data from a small number of sites ***and*** from shorter periods
Temporal correlation	2009-2011	2007-2008	2002-2006	1995-2001	Before 1995
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included, or from smaller area included in the area under study	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown ***or*** distinctly different area (North America in-stead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Origin of data: - enterprises - processes - materials -> all 3 of them correspond to study	Origin of data: - enterprises - processes - materials -> 2 of them corres-pond to study	Origin of data: - enterprises - processes - materials -> 1 of them corresponds to study	Origin of data: - enterprises - processes - materials -> 1 of them related to study	Data from different technology
Sample size	> 100	> 20	> 10	> 2	unknown

The uncertainty estimations (SD_{g95}) in Tables A.9 and A.10 were calculated with the formula (1) and (2) (modified from Frischknecht et al., 2007):

$$U_{1\text{-}4,a} = [\ln(U_{1,a})]^2 + [\ln(U_{2,a})]^2 + [\ln(U_{3,a})]^2 + [\ln(U_{4,a})]^2 \tag{1}$$

with:

$U_{1,a}$: uncertainty factor of reliability of reference a

$U_{2,a}$: uncertainty factor of temporal correlation of reference a

$U_{2,b}$: uncertainty factor of temporal correlation of reference b

…

$$SD_{g95} = \exp^{\sqrt{[\ln(U_{1-4})]^2 + [\ln(U_5)]^2 + [\ln(U_6)]^2 + [\ln(U_7)]^2}} \tag{2}$$

with:

SD_{g95} : uncertainty estimation (square of the geometric standard deviation, 95% interval)

$U_{1\text{-}4}$: average of $U_{1\text{-}4,a}$, $U_{1\text{-}4,b}$,...

The uncertainty factors applied for a specific pedigree score are shown in Table A.8.

Table A.8: Uncertainty factors, applied together with the pedigree matrix (modified from Frischknecht et al., 2007).

	Pedigree Score				
Indicator	**1**	**2**	**3**	**4**	**5**
U_1 Reliability	1	1.05	1.10	1.20	1.5
U_2 Temporal correlation	1	1.03	1.10	1.20	1.5
U_3 Geographical correlation	1	1.01	1.02	1.05	1.1
U_4 Further technological correlation	1	1.10	1.20	1.50	2.0
U_5 Completeness	1	1.02	1.05	1.10	1.2
U_6 Sample size	1	1.02	1.05	1.10	1.2
U_7 Basic uncertainty	1.05				

Table A.9: Uncertainty estimation for the losses of vegetarian products according to the pedigree matrix used in Frischknecht et al. (2007).

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Food category Fruits 1 Apples Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↗		1.29	3	5
Reference 1	Tobi Seeobst	2	1	3	1		
Reference 2	Eulenhof	2	1	4	2		
Reference 3		(without unharvested losses)					
Postharvest handling and trade			↗		1.22	3	4
Reference 1	Tobi Seeobst	2	1	3	1		
Reference 2	Freiburghaus, ZEMAG	2	1	3	3		
Reference 3							
Reference 4							
Processing industry			↗		1.40	4	5
Reference 1	Tobi Seeobst, SBV	2	1	4	3		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.29	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	2	3		
Reference 3	Discounter[1]	1	1	2	3		
Reference 4	Wholefood shop[1]	2	1	3	3		
Private households			↑		1.17	3	1
Reference 1	Quested, defra, Souci	5	2	3	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.31		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Fruits 2 Fresh fruits Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↗		1.37	4	5
Reference 1	Tobi Seeobst	2	1	4	3		
Reference 2	Eulenhof	2	1	4	2		
Reference 3		(without unharvested losses)					
Postharvest handling and trade			↗		1.25	3	4
Reference 1	Tobi Seeobst	2	1	4	2		
Reference 2	Freiburghaus, ZEMAG	3	3	3	2		
Reference 3							
Reference 4							
Processing industry			↗		1.40	4	5
Reference 1	Tobi Seeobst	2	1	4	3		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.31		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Fruits 3 Berries Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↗		1.37	4	5
Reference 1	Tobi Seeobst	2	1	4	3		
Reference 2	Eulenhof	2	1	4	2		
Reference 3		(without unharvested losses)					
Postharvest handling and trade			↗		1.34	4	5
Reference 1	Tobi Seeobst	2	1	4	2		
Reference 2							
Reference 3							
Reference 4							
Processing industry							
Reference 1							
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.17	3	1
Reference 1	Quested,defra, Souci	5	2	3	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.32		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Fruits 4 Canned fruits Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↓		1.64	4	5
Reference 1	Eulenhof	2	1	4	4		
Reference 2							
Reference 3		(without unharvested losses)					
Postharvest handling and trade							
Reference 1							
Reference 2							
Reference 3							
Reference 4							
Processing industry			↗		1.29	4	4
Reference 1	SBV (2009)	2	1	3	3		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↓		1.64		
Total (Ø of whole food chain)			↗		1.36		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Vegetables 5 Patatoes Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↑		1.17	3	2
Reference 1	SBV (2009)	1	2	2	1		
Reference 2	Raihof	2	1	4	1		
Reference 3							
Postharvest handling and trade			↗		1.31	3	5
Reference 1	Raihof	2	1	4	1		
Reference 2							
Reference 3							
Reference 4							
Processing industry							
Reference 1							
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↗		1.24	3	1
Reference 1	Quested,defra, Souci	5	2	4	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.29		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Vegetables 6 Fresh vegetables Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↘		1.57	4	4
Reference 1	Eulenhof	2	1	5	3		
Reference 2	Gustavasson	2	2	2	4		
Reference 3							
Postharvest handling and trade			↗		1.21	3	2
Reference 1	Eulenhof	2	1	4	2		
Reference 2	Freiburghaus	1	1	3	2		
Reference 3	Gustavasson	2	2	2	3		
Reference 4							
Processing industry							
Reference 1							
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↘		1.57		
Total (Ø of whole food chain)			↗		1.33		

Legend:

Uncertainty Estimation:
↑ → **1.0 - 1.2**
↗ → **1.2 - 1.4**
↘ → **1.4 - 1.6**
↓ → **> 1.6**

a) Geographical correlation
b) Temporal Correlation
c) Reliability
d) Further technological correlation
e) Completeness
f) Sample Size

1 The two supermarkets and the discounter had a total volume of sales of 47,000 Bn. Fr in 2010. The wholefood shop is an independent, smaller shop in a major town.

2 Data derives from a Swiss industrial bakery with an output of about 100,000 t/a.

3 Data derives from a bakery with centralised production and 20-30 branches located in the centre and in the surroundings of a major Swiss town.

4 Data derives from a producer of fresh pasta with an output of 5-10,000 t/a and from a producer of dried pasta with an output of 20-30,000 t/a.

Table A.10: Uncertainty estimation for the losses of animal products, the losses used for feeding, and for donations, according to the pedigree matrix used in Frischknecht et al. (2007).

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Food category Diary 15 Milk and other diary prod. Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↑		1.16	2	2
Reference 1	SBV (2009)	1	2	2	1		
Reference 2	Tannenhof	2	1	4	1		
Reference 3							
Postharvest handling and trade			↑		1.15	3	3
Reference 1	Gustavasson	2	2	2	2		
Reference 2							
Reference 3							
Reference 4							
Processing industry	No Data						
Reference 1							
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.24		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Diary 16 Cheese Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↑		1.16	2	2
Reference 1	SBV (2009)	1	2	2	1		
Reference 2	Tannenhof	2	1	4	1		
Reference 3							
Postharvest handling and trade			↑		1.15	3	3
Reference 1	Gustavasson	2	2	2	2		
Reference 2							
Reference 3							
Reference 4							
Processing industry			↑		1.13	2	2
Reference 1	SBV (2009)	1	2	2	2		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.22		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Diary 17 Butter Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↑		1.16	2	2
Reference 1	SBV (2009)	1	2	2	1		
Reference 2	Tannenhof	2	1	4	1		
Reference 3							
Postharvest handling and trade			↑		1.15	3	3
Reference 1	Gustavasson	2	2	2	2		
Reference 2							
Reference 3							
Reference 4							
Processing industry			↑		1.12	2	2
Reference 1	BFS (2010)	1	1	2	2		
Reference 2	Neff	2	1	3	1		
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↘		1.52		
Total (Ø of whole food chain)			↗		1.22		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Eggs 18 Eggs Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↘		1.53	3	3
Reference 1	Tannenhof	2	1	4	5		
Reference 2	Ferrara	1	1	3	1		
Reference 3	Aviforum	2	1	2	1		
Postharvest handling and trade			↓		2.02	4	3
Reference 1	Gustavasson	1	2	2	5		
Reference 2							
Reference 3							
Reference 4							
Processing industry			↓		2.02	4	3
Reference 1	Gustavasson	2	2	2	5		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.13	3	1
Reference 1	Quested,defra, Souci	5	2	1	1		
Total (MAX of whole food chain)			↓		2.02		
Total (Ø of whole food chain)			↘		1.58		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Meat 19 Porc Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↘		1.55	3	3
Reference 1	SBA	2	1	2	1		
Reference 2	Arrigo	1	4	2	3		
Reference 3	SFF	1	2	2	5		
Postharvest handling and trade			↗		1.23	3	3
Reference 1	Gustavasson	2	2	2	3		
Reference 2							
Reference 3							
Reference 4							
Processing industry			↗		1.23	3	3
Reference 1	Gustavasson	2	2	2	3		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.17	3	1
Reference 1	Quested,defra, Souci	5	2	3	1		
Total (MAX of whole food chain)			↘		1.55		
Total (Ø of whole food chain)			↗		1.32		

Pedigree scores and uncertainty estimation for total losses (avoidable & unavoidable)	Meat 20 Poultry Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↘		1.55	3	3
Reference 1	Aviforum	2	1	2	1		
Reference 2	Arrigo	1	4	2	3		
Reference 3	SFF	1	2	2	5		
Postharvest handling and trade			↗		1.23	3	3
Reference 1	Gustavasson	2	2	2	3		
Reference 2							
Reference 3							
Reference 4							
Processing industry			↗		1.23	3	3
Reference 1	Gustavasson	2	2	2	3		
Reference 2							
Reference 3							
Catering trade			↘		1.52	2	1
Reference 1	SV Group	1	1	1	4		
Reference 2	Baier et al.	2	2	3	4		
Reference 3	Andrini et al.	2	3	3	4		
Reference 4	Stucki	2	1	1	4		
Retail trade			↗		1.22	3	5
Reference 1	Supermarket 1[1]	1	1	1	1		
Reference 2	Supermarket 2[1]	1	1	1	1		
Reference 3	Discounter[1]	1	1	1	1		
Reference 4	Wholefood shop[1]	2	1	3	1		
Private households			↑		1.17	3	1
Reference 1	Quested,defra, Souci	5	2	3	1		
Total (MAX of whole food chain)			↘		1.55		
Total (Ø of whole food chain)			↗		1.32		

Legend:

Uncertainty Estimation:
↑ → **1.0 - 1.2**
↗ → **1.2 - 1.4**
↘ → **1.4 - 1.6**
↓ → **> 1.6**

a) Geographical correlation
b) Temporal Correlation
c) Reliability
d) Further technological correlation
e) Completeness
f) Sample Size

1 The two supermarkets and the discounter had a total volume of sales 47,000 Bn. Fr in 2010. The wholefood shop is an independent, smaller shop a major town.

Amount of losses used for feeding	a)	b)	c)	d)	e)	f)
		↗		1.22	3	3
Spycher et al. (2011)	1	1	4	1		
SBV (2009)	2	1	2	1		

Donations	a)	b)	c)	d)	e)	f)
		↑		1.17	3	3
Tischlein deck dich (2011)	2	1	3	1		
Schweizer Tafel (2011)	2	1	3	1		
CARITAS (2011)	2	1	4	1		
Partage (2011)	2	1	3	3		

7 Storable vegetables

Reference	a)	b)	c)	d)	e)	f)
		↘		1.57	4	4
Eulenhof	2	1	5	3		
Gustavasson	2	2	2	4		
		↗		1.21	3	2
Eulenhof	2	1	4	2		
Freiburghaus	1	1	3	2		
Gustavasson	2	2	2	3		
Huber	2	1	4	1		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↘		1.57		
		↗		1.34		

8 Processed vegetables

Reference	a)	b)	c)	d)	e)	f)
		↘		1.57	4	4
Eulenhof	2	1	5	3		
Gustavasson	2	2	2	4		
		↗		1.25	4	3
Gustavasson	2	2	2	3		
		↗		1.27	3	5
Ditzler	1	1	3	2		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.13	3	1
Quested,defra, Souci	5	2	1	1		
		↘		1.57		
		↗		1.33		

Cereals

9 Bread Wheat (Breads and pastries)

Reference	a)	b)	c)	d)	e)	f)
		↓		1.64	4	5
Eulenhof	2	1	4	4		
		↑		1.17	3	2
SBV (2009)	1	2	3	2		
		↘		1.41	5	5
Major bakery[2]	1	1	2	1		
Furter	2	1	2	1		
BLW (2000)	2	4	4	3		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↑		1.17	3	2
Centralised bakery[3]	2	1	3	1		
Furter	2	1	2	1		
Auki	2	1	4	1		
Stocker	2	1	4	1		
		↑		1.13	3	1
Quested,defra, Souci	5	2	1	1		
		↓		1.64		
		↗		1.34		

10 Durum Wheat (Pasta)

Reference	a)	b)	c)	d)	e)	f)
		↓		1.64	4	5
Eulenhof	3	1	4	4		
		↗		1.25	3	2
SBV (2009)	3	2	3	3		
		↑		1.20	3	4
Pasta producer 1[4]	2	1	3	2		
Pasta producer 2[4]	2	1	3	2		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↓		1.64		
		↗		1.33		

11 Rice

Reference	a)	b)	c)	d)	e)	f)
		↓		1.64	4	5
Eulenhof	3	1	4	4		
		↘		1.53	3	2
SBV (2009)	3	2	3	4		
		↗		1.24	2	5
Spycher et al.	1	1	3	1		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↓		1.64		
		↗		1.38		

12 Corn

Reference	a)	b)	c)	d)	e)	f)
		↓		1.64	4	5
Eulenhof	2	1	4	4		
		↘		1.53	3	2
SBV (2009)	2	2	3	4		
		↘		1.40	2	4
Spycher et al.	1	1	3	1		
SBV (1983)	1	5	4	1		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↓		1.64		
		↘		1.41		

Sugar

13 Sugar

Reference	a)	b)	c)	d)	e)	f)
No Data						
		↓		2.01	3	3
Gustavasson	1	2	2	5		
		↑		1.17	3	3
Schweizerzucker	1	1	2	1		
Spycher	1	1	4	1		
SBV (2009)	1	2	3	2		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.13	3	1
Quested,defra, Souci	5	2	1	1		
		↓		2.01		
		↘		1.41		

Oils and fats

14 Oils and fats

Reference	a)	b)	c)	d)	e)	f)
		↗		1.25	3	3
Gustavasson	2	2	3	3		
		↗		1.23	3	3
Gustavasson	1	2	2	3		
		↗		1.23	3	3
Gustavasson	2	2	2	3		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.13	3	1
Quested,defra, Souci	5	2	1	1		
		↘		1.52		
		↗		1.26		

21 Beef

Reference	a)	b)	c)	d)	e)	f)
		↘		1.55	3	3
SBA	2	1	2	1		
Arrigo	1	4	2	3		
SFF	1	2	2	5		
		↗		1.23	3	3
Gustavasson	2	2	2	3		
		↗		1.23	3	3
Gustavasson	2	2	2	3		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	1	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↘		1.55		
		↗		1.32		

Fish

22 Fish

Reference	a)	b)	c)	d)	e)	f)
		↘		1.54	4	3
Gustavsson	1	2	5	2		
Stuart	1	2	5	2		
		↗		1.24	4	3
Gustavsson	1	2	4	1		
		↗		1.24	4	3
Gustavsson	1	2	4	1		
		↘		1.52	2	1
SV Group	1	1	1	4		
Baier et al.	2	2	3	4		
Andrini et al.	2	3	3	4		
Stucki	2	1	1	4		
		↗		1.22	3	5
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	2	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.17	3	1
Quested,defra, Souci	5	2	3	1		
		↘		1.54		
		↗		1.32		

All Food Categories

Reference	a)	b)	c)	d)	e)	f)
		↗		1.39		
	(Average of all food categories)					
		↗		1.27		
	(Average of all food categories)					
		↗		1.23		
	(Average of all food categories)					
		↑		1.12	3	1
SV Group	1	1	1	1		
Baier et al.	2	2	3	1		
Andrini et al.	2	3	3	1		
Stucki	2	1	1	1		
		↑		1.11	3	3
Supermarket 1[1]	1	1	1	1		
Supermarket 2[1]	1	1	2	1		
Discounter[1]	1	1	1	1		
Wholefood shop[1]	2	1	3	1		
		↑		1.13	3	1
Quested,defra, Souci	5	2	1	1		
		↗		1.39		
		↗		1.21		

A.6 MASS AND ENERGY BALANCE

The energy balance in Figure A.1 shows that from the net output of the stages agricultural and animal production (50'833 TJ), including slaughtering waste and postharvest losses, around 52% is finally ingested, while around a quarter is (theoretically) avoidable food waste. In terms of mass, only 36% of the production is in-gested. The difference can be explained by the relatively low calorific content of many unavoidable losses (e.g. bones, whey, by-products of sugar manufacture). Total avoidable food waste corresponds to 50% of the ingested food in terms of energy. From this, nearly half is in perfect quality and discarded because of inefficient delivery from producer to consumer.

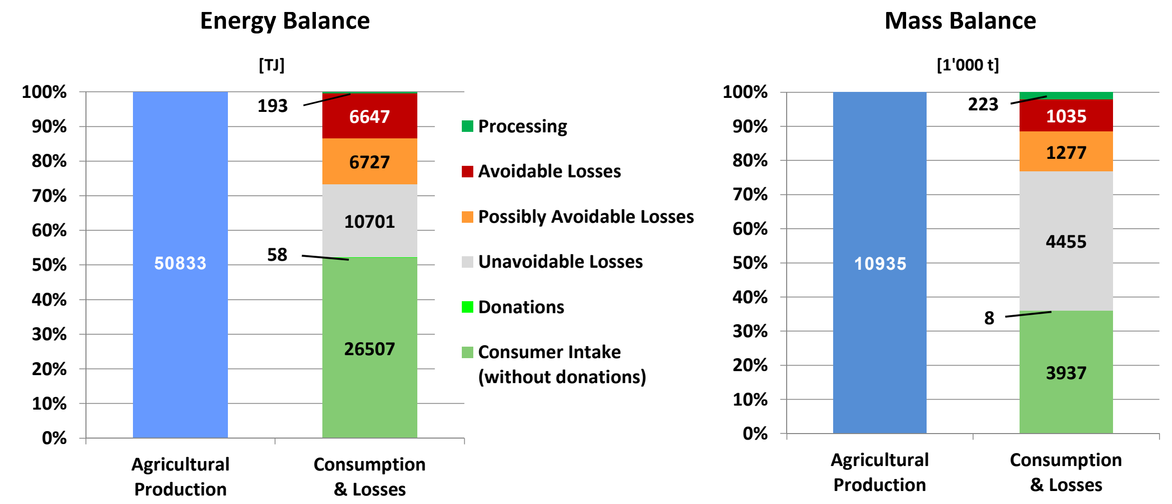

Figure A.1: Energy and mass balance of the food produced to meet the Swiss food demand. The blue columns show the net output agricultural and animal production, including slaughtering waste and inedible parts that are removed later in the production chain. In the right columns, food consumption and food losses are displayed. Avoidable losses refer to inefficient distribution (mainly spoilage), possibly avoidable losses to unsatisfied quality standards. The category "non-food use" refers to losses used for manufacture of non-food products (e.g. cosmetics, leather, fertilizer).

Table A.11: Overview of the food loss records across the food value chain for plant products.

					Apple									
Product category					Fruits									
Product group					Apple									
Initial products	a) one initial product ->				Apple									
	b) two correlated products ->									Apples for processing				
Final products					Dessert apples					Apple juice				
Household consumption (relative to total consumption)					85%	->	85%			85%	->	85%		
Consumption in food service and catering (relative to total consumption)					15%	->	15%			15%	->	15%		
					% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]
Sector	**Reference**	**Process**		**Reason for losses**	**REF**	**Ø**	**min**	**max**		**REF**	**Ø**	**min**	**max**	
total production at the beginning of the food chain					100%				52					
Agriculture, plant products					100%	**53%**	36%	69%						
	Edible crop yield at harvest time	Harvest		Illness *(inedible at harvest time)*	100%									
				Weather	100%									
				Basic food sorting	100%									
			III	Technical harvesting	100%									
			III	Manual harvesting	100%	**2.5%**	0.8%	4.2%						
					100%									
			II	Quality sorting	100%	**30.0%**	20.0%	40.0%						
			II	Quality sorting	100%	**20.0%**	15.0%	25.0%						
			II	Quality sorting	100%									
						??								
			I	Insufficient demand	100%									
		Storage	III	Basic food sorting	100%									
			I	Stored for too long	100%									
		TOTAL			100%	**52.5%**	35.8%	69.2%						
Trade					48%	**1.1%**	0.7%	1.5%		50%				
	Food purchased	Trade 1	III	Basic food sorting	48%	**0.8%**	0.6%	1.0%		50%				
			III	Transport	48%					50%				
			III	Storage problems	48%					50%				
			II	Quality sorting	48%					50%				
			II	Quality sorting	48%					50%				
			I	Stored for too long	48%	**0.3%**	0.1%	0.5%		50%				
		TOTAL			48%	**1.1%**	0.7%	1.5%		50%				
Processing					47%					50%	**29.8%**	25.5%	35.0%	
	Food purchased	Processing 1	III	Basic food sorting	47%					50%	**0.8%**	0.5%	1.0%	
			III	Transport	47%					50%				
			III	Storage problems	47%					50%				
			III	Failure	47%					50%				
			III	Method of processing	47%					50%	**29.0%**	25.0%	34.0%	75
			III	Method of processing	47%					50%				
			III	Method of processing	47%					50%				
			II	Quality sorting	47%					50%				
			II	Quality sorting	47%					50%				
			I	Stored for too long	47%					50%				
			I	Stored for too long	47%					50%				
			I	Change in the production line	47%					50%				
			I	Change in the production line	47%					50%				
		TOTAL			47%					50%	**29.8%**	25.5%	35.0%	
Processing					47%					35%				
	Food purchased	Processing 2	III	Basic food sorting	47%					35%				
			III	Method of processing	47%					35%				
			I	Method of processing	47%					35%				
			II	Quality sorting	47%					35%				
			I	Stored for too long	47%					35%				
			I	Stored for too long	47%					35%				
			I	Change in the production line	47%					35%				
		TOTAL			47%					35%				
Trade					47%					35%				
	Food purchased	Trade 2	III	Basic food sorting	47%					35%				
			III	Transport	47%					35%				
			III	Storage problems	47%					35%				
			II	Quality sorting	47%					35%				
			I	Stored for too long	47%					35%				
		TOTAL			47%					35%				
Food service					7%	**25.2%**	32.2%	21.1%		5%	**7.0%**	5.0%	9.8%	
	Food purchased	Preparation	III	Inedible parts	7%	**7.1%**	9.9%	5.1%	52	5%				
			III	Inedible parts	7%					5%				
			III	Failure	7%					5%				
			II	Quality sorting	7%	**13.6%**	19.0%	9.7%		5%				
			I	Over-production	7%					5%				
			I	Stored for too long	7%	**2.0%**	1.4%	2.8%		5%	**3.5%**	2.5%	4.9%	43
		Serving	I	Plate waste	7%	**2.5%**	1.8%	3.5%		5%	**3.5%**	2.5%	4.9%	43
		TOTAL			7%	**25.2%**	32.2%	21.1%		5%	**7.0%**	5.0%	9.8%	
Retail					40%	**3.2%**	2.7%	3.6%		30%	**1.0%**	0.7%	1.3%	
	Food purchased	Sale	III	Transport	40%					30%				
			III	Storage conditions	40%					30%				
			I	Too long on the reatil shelves	40%	**1.5%**	1.3%	1.7%		30%	**1.0%**	0.7%	1.3%	43
			I	Too long on the reatil shelves	40%	**0.2%**	0.1%	0.2%		30%				
			I	Too long on the reatil shelves	40%	**1.5%**	1.3%	1.7%		30%				
			I	Too long on the reatil shelves	40%					30%				
		TOTAL			40%	**3.2%**	2.7%	3.6%		30%	**1.0%**	0.7%	1.3%	
Households					39%	**40.4%**	30.0%	50.8%		29%	**7.0%**	5.0%	9.0%	
	Food purchased	Preparation	III	Inedible parts (apple cores, meat bones...)	39%	**4.4%**	4.0%	4.8%	52	29%				
		Preference	II	Taste preferences	39%	**12.0%**	8.0%	16.0%	63	29%				
		Planning	I	Storage conditions	39%					29%				
			I	Purchased / cooked too much	39%	**12.0%**	9.0%	15.0%		29%	**7.0%**	5.0%	9.0%	43
			I	Purchased / cooked too much	39%	**12.0%**	9.0%	15.0%		29%				
			I	Purchased / cooked too much	39%					29%				
		TOTAL			39%	**40.4%**	30.0%	50.8%		29%	**7.0%**	5.0%	9.0%	
Consumption at the retail and food service level					**46%**					**35%**				
Final consumption (intake)					**28%**				51	**32%**				43

					Fresh fruits									
Product category					Fruits									
Product group					Fruits									
Initial products	a) one initial product ->				Fresh fruits									
	b) two correlated products ->									Fruits for processing				
Final products					Dessert fruits					Fruit juice, other processed fruits				
Household consumption (relative to total consumption)					85%	->	85%			85%	->	85%		
Consumption in food service and catering (relative to total consumption)					15%	->	15%			15%	->	15%		
					% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]
Sector	**Reference**	**Process**		**Reason for losses**	**REF**	**Ø**	**min**	**max**		**REF**	**Ø**	**min**	**max**	
total production at the beginning of the food chain					100%				52					
Agriculture, plant products					100%	**60%**	41%	77%						
	Edible crop yield at harvest time	Harvest		Illness *(inedible at harvest time)*	100%									
				Weather	100%									
				Basic food sorting	100%									
			III	Technical harvesting	100%	**6.0%**	2.0%	8.0%						
			III	Manual harvesting	100%									
					100%									
			II	Quality sorting	100%	**32.0%**	22.0%	42.0%						
			II	Quality sorting	100%	**22.0%**	17.0%	27.0%						
			II	Quality sorting	100%									
						??								
			I	Insufficient demand	100%									
		Storage	III	Basic food sorting	100%									
			I	Stored for too long	100%									
		TOTAL			100%	**60.0%**	41.0%	77.0%						
Trade					40%	**2.3%**	1.1%	3.5%		54%				
	Food purchased	Trade 1	III	Basic food sorting	40%	**2.0%**	1.0%	3.0%		54%				
			III	Transport	40%					54%				
			III	Storage problems	40%					54%				
			II	Quality sorting	40%					54%				
			II	Quality sorting	40%					54%				
			I	Stored for too long	40%	**0.3%**	0.1%	0.5%		54%				
		TOTAL			40%	**2.3%**	1.1%	3.5%		54%				
Processing					39%					54%	**38.0%**	26.0%	50.0%	
	Food purchased	Processing 1	III	Basic food sorting	39%					54%	**2.0%**	1.0%	3.0%	
			III	Transport	39%					54%				
			III	Storage problems	39%					54%				
			III	Failure	39%					54%				
			III	Method of processing	39%					54%	**9.0%**	5.0%	13.0%	39
			III	Method of processing	39%					54%	**27.0%**	20.0%	34.0%	39
			III	Method of processing	39%					54%				
			II	Quality sorting	39%					54%				
			II	Quality sorting	39%					54%				
			I	Stored for too long	39%					54%				
			I	Stored for too long	39%					54%				
			I	Change in the production line	39%					54%				
			I	Change in the production line	39%					54%				
		TOTAL			39%					54%	**38.0%**	26.0%	50.0%	
Processing					39%					33%				
	Food purchased	Processing 2	III	Basic food sorting	39%					33%				
			III	Method of processing	39%					33%				
			I	Method of processing	39%					33%				
			II	Quality sorting	39%					33%				
			I	Stored for too long	39%					33%				
			I	Stored for too long	39%					33%				
			I	Change in the production line	39%					33%				
		TOTAL			39%					33%				
Trade					39%					33%				
	Food purchased	Trade 2	III	Basic food sorting	39%					33%				
			III	Transport	39%					33%				
			III	Storage problems	39%					33%				
			II	Quality sorting	39%					33%				
			I	Stored for too long	39%					33%				
		TOTAL			39%					33%				
Food service					6%	**44.2%**	58.8%	34.6%		5%	**7.0%**	5.0%	9.8%	
	Food purchased	Preparation	III	Inedible parts	6%	**32.2%**	45.1%	23.0%		5%				
			III	Inedible parts	6%					5%				
			III	Failure	6%					5%				
			II	Quality sorting	6%	**7.5%**	10.5%	5.4%		5%				
			I	Over-production	6%					5%				
			I	Stored for too long	6%	**2.0%**	1.4%	2.8%		5%	**3.5%**	2.5%	4.9%	60
		Serving	I	Plate waste	6%	**2.4%**	1.7%	3.4%		5%	**3.5%**	2.5%	4.9%	60
		TOTAL			6%	**44.2%**	58.8%	34.6%		5%	**7.0%**	5.0%	9.8%	
Retail					33%	**5.6%**	4.9%	6.2%		28%	**0.8%**	0.4%	1.2%	
	Food purchased	Sale	III	Transport	33%					28%				
			III	Storage conditions	33%					28%				
			I	Too long on the reatil shelves	33%	**2.7%**	2.4%	3.0%		28%	**0.8%**	0.4%	1.2%	60
			I	Too long on the reatil shelves	33%	**0.2%**	0.1%	0.2%		28%				
			I	Too long on the reatil shelves	33%	**2.7%**	2.4%	3.0%		28%				
			I	Too long on the reatil shelves	33%					28%				
		TOTAL			33%	**5.6%**	4.9%	6.2%		28%	**0.8%**	0.4%	1.2%	
Households					31%	**46.0%**	35.0%	59.0%		28%	**7.0%**	5.0%	9.0%	
	Food purchased	Preparation	III	Inedible parts (apple cores, meat bones...)	31%	**3.0%**	4.0%	7.0%		28%				
		Preference	II	Taste preferences	31%	**20.0%**	16.0%	24.0%		28%				
		Planning	I	Storage conditions	31%					28%				
			I	Purchased / cooked too much	31%	**9.0%**	8.0%	15.0%		28%	**7.0%**	5.0%	9.0%	60
			I	Purchased / cooked too much	31%	**10.0%**	7.0%	13.0%		28%				
			I	Purchased / cooked too much	31%					28%				
		TOTAL			31%	**46.0%**	35.0%	59.0%		28%	**7.0%**	5.0%	9.0%	
Consumption at the retail and food service level					**37%**					**33%**				
Final consumption (intake)					**20%**				52	**31%**				60

					Berries					Canned fruits					Potatoes				
Product category					Fruits					Fruits					Vegetables				
Product group					Berries					Canned fruits					Potatoes				
Initial products	a) one initial product ->				Berries					Fresh fruits					Potatoes				
	b) two correlated products ->																		
Final products					Berries					Canned fruits					Potatoes				
Household consumption (relative to total consumption)					85%	->	85%			85%	->	85%			85%	->	85%		
Consumption in food service and catering (relative to total consumption)					15%	->	15%			15%	->	15%			15%	->	15%		
					% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]
Sector	**Reference**	**Process**		**Reason for losses**	**REF**	**Ø**	**min**	**max**		**REF**	**Ø**	**min**	**max**		**REF**	**Ø**	**min**	**max**	
total production at the beginning of the food chain					100%				43	100%				70	100%				77
Agriculture, plant products					100%	**20%**	10%	29%		100%	**5%**	1%	9%		100%	**25%**	19%	31%	
	Edible crop yield at harvest time	Harvest		Illness *(inedible at harvest time)*	100%					100%					100%				
				Weather	100%					100%					100%				
				Basic food sorting	100%	**6.0%**	2.0%	10.0%		100%					100%	**7.5%**	5.0%	10.0%	
			III	Technical harvesting	100%					100%					100%	**2.5%**	1.0%	4.0%	
			III	Manual harvesting	100%	**7.5%**	5.0%	10.0%		100%	**5.0%**	1.0%	9.0%		100%				
					100%					100%					100%				
			II	Quality sorting	100%	**6.0%**	3.0%	9.0%		100%					100%	**22.5%**	18.0%	27.0%	
			II	Quality sorting	100%					100%					100%				
			II	Quality sorting	100%					100%					100%				
											??								
			I	Insufficient demand	100%	**6.0%**	2.0%	10.0%		100%					100%				
		Storage	III	Basic food sorting	100%					100%					100%				
			I	Stored for too long	100%					100%					100%				
		TOTAL			100%	**19.5%**	10.0%	29.0%		100%	**5.0%**	1.0%	9.0%		100%	**25.0%**	19.0%	31.0%	
Trade					81%	**1.6%**	0.6%	2.5%		95%					75%	**12.6%**	14.4%	11.9%	
	Food purchased	Trade 1	III	Basic food sorting	81%	**1.3%**	0.5%	2.0%		95%					75%	**3.0%**	1.0%	5.0%	
			III	Transport	81%					95%					75%				
			III	Storage problems	81%					95%					75%				
			II	Quality sorting	81%					95%					75%	**9.6%**	13.4%	6.9%	
			II	Quality sorting	81%					95%					75%				
			I	Stored for too long	81%	**0.3%**	0.1%	0.5%		95%					75%				
		TOTAL			81%	**1.6%**	0.6%	2.5%		95%					75%	**12.6%**	14.4%	11.9%	
Processing					79%					95%	**61.5%**	31.0%	92.0%		66%	**6.1%**	8.5%	4.4%	
	Food purchased	Processing 1	III	Basic food sorting	79%					95%	**1.5%**	1.0%	2.0%		66%				
			III	Transport	79%					95%					66%				
			III	Storage problems	79%					95%					66%				
			III	Failure	79%					95%					66%				
			III	Method of processing	79%					95%	**60.0%**	30.0%	90.0%	15	66%				
			III	Method of processing	79%					95%					66%				
			III	Method of processing	79%					95%					66%				
			II	Quality sorting	79%					95%					66%	**6.1%**	8.5%	4.4%	
			II	Quality sorting	79%					95%					66%				
			I	Stored for too long	79%					95%					66%				
			I	Stored for too long	79%					95%					66%				
			I	Change in the production line	79%					95%					66%				
			I	Change in the production line	79%					95%					66%				
		TOTAL			79%					95%	**61.5%**	31.0%	92.0%		66%	**6.1%**	8.5%	4.4%	
Processing					79%					37%					62%				
	Food purchased	Processing 2	III	Basic food sorting	79%					37%					62%				
			III	Method of processing	79%					37%					62%				
			I	Method of processing	79%					37%					62%				
			II	Quality sorting	79%					37%					62%				
			I	Stored for too long	79%					37%					62%				
			I	Stored for too long	79%					37%					62%				
			I	Change in the production line	79%					37%					62%				
		TOTAL			79%					37%					62%				
Trade					79%					37%					62%				
	Food purchased	Trade 2	III	Basic food sorting	79%					37%					62%				
			III	Transport	79%					37%					62%				
			III	Storage problems	79%					37%					62%				
			II	Quality sorting	79%					37%					62%				
			I	Stored for too long	79%					37%					62%				
		TOTAL			79%					37%					62%				
Food service					12%	**15.4%**	11.0%	21.6%		6%	**10.8%**	7.7%	15.1%		9%	**30.6%**	21.9%	42.9%	
	Food purchased	Preparation	III	Inedible parts	12%	**3.2%**	2.3%	4.5%		6%					9%	**14.5%**	10.4%	20.3%	
			III	Inedible parts	12%					6%					9%				
			III	Failure	12%					6%					9%				
			II	Quality sorting	12%	**5.7%**	4.1%	8.0%		6%	**4.8%**	3.5%	6.8%		9%	**9.1%**	6.5%	12.8%	
			I	Over-production	12%					6%					9%	**4.0%**	2.9%	5.6%	
			I	Stored for too long	12%	**6.0%**	4.3%	8.4%		6%	**2.0%**	1.4%	2.8%		9%	**2.0%**	1.4%	2.8%	
		Serving	I	Plate waste	12%	**0.5%**	0.4%	0.7%		6%	**4.0%**	2.8%	5.6%		9%	**1.0%**	0.7%	1.4%	
		TOTAL			12%	**15.4%**	11.0%	21.6%		6%	**10.8%**	7.7%	15.1%		9%	**30.6%**	21.9%	42.9%	
Retail					67%	**7.8%**	6.3%	9.0%		31%	**0.4%**	0.3%	0.6%		52%	**2.8%**	2.3%	3.2%	
	Food purchased	Sale	III	Transport	67%					31%					52%				
			III	Storage conditions	67%					31%					52%				
			I	Too long on the reatil shelves	67%	**3.8%**	3.1%	4.4%		31%	**0.0%**		0.0%		52%	**1.3%**	1.1%	1.5%	
			I	Too long on the reatil shelves	67%	**0.2%**	0.1%	0.2%		31%	**0.1%**	0.1%	0.2%		52%	**0.2%**	0.1%	0.2%	
			I	Too long on the reatil shelves	67%	**3.8%**	3.1%	4.4%		31%	**0.3%**	0.2%	0.4%		52%	**1.3%**	1.1%	1.5%	
			I	Too long on the reatil shelves	67%					31%					52%				
		TOTAL			67%	**7.8%**	6.3%	9.0%		31%	**0.4%**	0.3%	0.6%		52%	**2.8%**	2.3%	3.2%	
Households					62%	**29.0%**	19.5%	38.5%		31%	**15.8%**	12.8%	18.8%		51%	**44.0%**	34.5%	53.5%	
	Food purchased	Preparation	III	Inedible parts (apple cores, meat bones...)	62%	**2.0%**	1.5%	2.5%		31%					51%	**9.0%**	7.0%	11.0%	
		Preference	II	Taste preferences	62%	**3.0%**	2.0%	4.0%		31%					51%	**17.5%**	14.0%	21.0%	
		Planning	I	Storage conditions	62%					31%					51%				
			I	Purchased / cooked too much	62%	**12.0%**	8.0%	16.0%		31%	**15.8%**	12.8%	18.8%		51%	**9.0%**	7.0%	11.0%	
			I	Purchased / cooked too much	62%	**12.0%**	8.0%	16.0%		31%					51%	**8.5%**	6.5%	10.5%	
			I	Purchased / cooked too much	62%					31%					51%				
		TOTAL			62%	**29.0%**	19.5%	38.5%		31%	**15.8%**	12.8%	18.8%		51%	**44.0%**	34.5%	53.5%	
Consumption at the retail and food service level					**74%**					**36%**					**60%**				
Final consumption (intake)					**54%**				43	**31%**				172	**35%**				77

Annotation: In some cases, food loss entries with the same reason are split into subentries within several cells, because, in the model, the individual subentries are attributed to different ways of recovery or dispoasal (animal feed, compost, AD...).

Storable vegetables

Vegetables
Vegetables
Storable vegetables

Storable vegetables
89% -> 89%
11% -> 11%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				37
100%	**20%**	13%	30%	
100%				
100%	**12.5%**	10.0%	15.0%	
100%				
100%	**5.0%**	3.0%	10.0%	
100%				
100%				
100%	**12.5%**	8.0%	17.0%	
100%	**2.5%**	2.0%	3.0%	
100%				
100%				
100%				
100%				
100%	**20.0%**	13.0%	30.0%	
80%	**13.6%**	9.0%	16.1%	
80%				
80%				
80%				
80%	**3.5%**	1.0%	4.0%	
80%	**0.1%**	0.0%	0.1%	
80%	**10.0%**	8.0%	12.0%	
80%	**13.6%**	9.0%	16.1%	
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
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69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
69%				
8%	**31.1%**	22.2%	43.5%	
8%	**14.5%**	10.4%	20.3%	
8%				
8%				
8%	**8.4%**	6.0%	11.8%	
8%	**3.0%**	2.1%	4.2%	
8%	**2.0%**	1.4%	2.8%	
8%	**3.2%**	2.3%	4.4%	
8%	**31.1%**	22.2%	43.5%	
61%	**9.6%**	5.5%	13.6%	
61%				
61%				
61%	**4.7%**	2.7%	6.7%	
61%	**0.2%**	0.1%	0.2%	
61%	**4.7%**	2.7%	6.7%	
61%				
61%	**9.6%**	5.5%	13.6%	
56%	**40.0%**	29.0%	50.0%	
56%	**9.0%**	5.0%	12.0%	
56%	**17.0%**	13.0%	21.0%	
56%				
56%	**7.0%**	5.5%	8.5%	
56%	**7.0%**	5.5%	8.5%	
56%				
56%	**40.0%**	29.0%	50.0%	
63%				
39%				37

Processed vegetables

Vegetables
Vegetables
Fresh vegetables for processing

Processed vegetables
70% -> 70%
30% -> 30%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				36
100%	**12%**	5%	22%	
100%				
100%	**12.5%**	10.0%	15.0%	
100%				
100%	**5.0%**	3.0%	10.0%	
100%				
100%				
100%	**5.0%**	1.0%	9.0%	
100%	**2.0%**	1.0%	3.0%	
100%				
100%				
100%				
100%				
100%	**12.0%**	5.0%	22.0%	
88%	**0.3%**	0.2%	0.4%	
88%				
88%				
88%				
88%				
88%				
88%	**0.3%**	0.2%	0.4%	
88%	**0.3%**	0.2%	0.4%	
88%	**19.5%**	11.0%	28.0%	
88%				
88%				
88%				
88%				
88%	**6.0%**	3.0%	9.0%	
88%	**5.0%**	3.0%	7.0%	
88%				
88%	**8.5%**	5.0%	12.0%	
88%				
88%				
88%				
88%				
88%				
88%	**19.5%**	11.0%	28.0%	
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
71%				
21%	**9.2%**	6.6%	12.9%	
21%				
21%				
21%				
21%	**1.1%**	0.8%	1.5%	
21%	**3.0%**	2.1%	4.2%	
21%	**2.0%**	1.4%	2.8%	
21%	**3.2%**	2.3%	4.4%	
21%	**9.2%**	6.6%	12.9%	
49%	**0.2%**	0.1%	0.3%	
49%				
49%				
49%	**0.1%**	0.0%	0.1%	
49%	**0.0%**	0.0%	0.0%	
49%	**0.1%**	0.0%	0.1%	
49%				
49%	**0.2%**	0.1%	0.3%	
49%	**14.0%**	8.0%	20.0%	
49%				
49%				
49%				
49%	**7.0%**	4.0%	10.0%	
49%	**7.0%**	4.0%	10.0%	
49%				
49%	**14.0%**	8.0%	20.0%	
71%				
62%				36

Bread Wheat

Cereals
Bread wheat
Bread wheat

Cereals in breads and pastries
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				330
100%	**10%**	5%	15%	
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**10.0%**	5.0%	15.0%	
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
89%	**44.0%**	34.1%	50.1%	
89%				
89%				
89%				
89%				
89%				
89%	**17.0%**	13.0%	17.0%	290
89%				
89%	**20.0%**	16.0%	25.0%	
89%	**7.0%**	5.1%	8.1%	170
89%				
89%				
89%				
89%				
89%	**44.0%**	34.1%	50.1%	
50%	**3.0%**	2.0%	4.0%	
50%				
50%	**2.0%**	1.5%	2.5%	360
50%	**1.0%**	0.5%	1.5%	360
50%				
50%				
50%				
50%				
50%	**3.0%**	2.0%	4.0%	
48%				
48%				
48%				
48%				
48%				
48%				
48%				
7%	**20.3%**	14.5%	28.5%	
7%				
7%				
7%	**0.5%**	0.4%	0.7%	360
7%				
7%	**1.0%**	0.7%	1.4%	360
7%	**15.4%**	11.0%	21.6%	360
7%	**3.4%**	2.5%	4.8%	360
7%	**20.3%**	14.5%	28.5%	
41%	**5.1%**	3.0%	7.2%	
41%				
41%				
41%	**1.5%**	1.0%	2.0%	360
41%	**0.7%**	0.3%	1.1%	360
41%	**3.7%**	2.3%	5.1%	360
41%	**0.7%**	0.4%	1.0%	360
41%	**5.1%**	3.0%	7.2%	
39%	**39.0%**	29.0%	49.0%	
39%				
39%	**6.0%**	3.0%	9.0%	360
39%				
39%	**16.0%**	12.0%	20.0%	360
39%	**17.0%**	14.0%	20.0%	360
39%				
39%	**39.0%**	29.0%	49.0%	
46%				
30%				360

Durum Wheat (Pasta)

Cereals
Durum wheat
Durum wheat

Wheat in pasta
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				344
100%	**10%**	2%	18%	
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%	**10.0%**	2.0%	18.0%	
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**10.0%**	2.0%	18.0%	
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
89%	**34.0%**	28.0%	38.0%	
89%				
89%				
89%				
89%				
89%				
89%	**18.0%**	15.0%	19.0%	344
89%				
89%	**16.0%**	13.0%	19.0%	275
89%				
89%				
89%				
89%				
89%				
89%	**34.0%**	28.0%	38.0%	
59%	**7.3%**	5.5%	9.2%	
59%				
59%	**3.2%**	2.5%	3.9%	
59%				
59%	**1.2%**	1.0%	1.4%	
59%	**0.8%**	0.3%	1.3%	
59%	**0.1%**	0.1%	0.2%	
59%	**2.0%**	1.6%	2.4%	
59%	**7.3%**	5.5%	9.2%	
54%				
54%				
54%				
54%				
54%				
54%				
54%				
8%	**18.5%**	13.3%	25.9%	
8%				
8%				
8%	**0.5%**	0.4%	0.6%	
8%				
8%	**11.4%**	8.1%	15.9%	
8%	**2.0%**	1.4%	2.8%	
8%	**4.7%**	3.3%	6.5%	
8%	**18.5%**	13.3%	25.9%	
46%	**0.5%**	0.4%	0.6%	
46%				
46%				
46%	**0.2%**	0.1%	0.2%	
46%	**0.1%**	0.1%	0.2%	
46%	**0.2%**	0.2%	0.3%	
46%				
46%	**0.5%**	0.4%	0.6%	
46%	**32.0%**	25.0%	39.0%	
46%				
46%	**3.0%**	2.0%	4.0%	
46%				
46%	**14.0%**	11.0%	17.0%	
46%	**15.0%**	12.0%	18.0%	
46%				
46%	**32.0%**	25.0%	39.0%	
54%				
38%				370

Rice

Cereals
Rice
Rice

Rice
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				358
100%	**10%**	2%	18%	
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%	**10.0%**	2.0%	18.0%	
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**10.0%**	2.0%	18.0%	
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
89%	**19.6%**	16.0%	23.2%	
89%				
89%				
89%				
89%				
89%	**8.6%**	7.0%	10.2%	
89%	**2.4%**	2.0%	2.8%	
89%				
89%	**8.6%**	7.0%	10.2%	
89%				
89%				
89%				
89%				
89%				
89%	**19.6%**	16.0%	23.2%	
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
72%				
11%	**18.6%**	13.7%	24.3%	
11%				
11%				
11%	**0.5%**	0.4%	0.6%	
11%				
11%	**11.4%**	8.5%	14.2%	
11%	**2.0%**	1.4%	2.8%	
11%	**4.8%**	3.4%	6.7%	
11%	**18.6%**	13.7%	24.3%	
61%	**0.3%**	0.2%	0.4%	
61%				
61%				
61%	**0.1%**	0.1%	0.1%	
61%	**0.1%**	0.1%	0.2%	
61%	**0.1%**	0.1%	0.1%	
61%				
61%	**0.3%**	0.2%	0.4%	
61%	**32.0%**	25.0%	39.0%	
61%				
61%	**3.0%**	2.0%	4.0%	
61%				
61%	**14.0%**	11.0%	17.0%	
61%	**15.0%**	12.0%	18.0%	
61%				
61%	**32.0%**	25.0%	39.0%	
71%				
50%				358

Maize

Cereals
Maize
Maize

Maize
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				366
100%	**10%**	5%	15%	
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%	**10.0%**	5.0%	15.0%	
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**10.0%**	5.0%	15.0%	
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
90%				
90%				
90%				
90%	**1.0%**	0.5%	1.5%	
89%	**39.0%**	35.0%	43.0%	
89%				
89%				
89%				
89%				
89%	**39.0%**	35.0%	43.0%	
89%				
89%				
89%				
89%				
89%				
89%				
89%				
89%				
89%	**39.0%**	35.0%	43.0%	
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
54%				
8%	**30.9%**	21.9%	40.9%	
8%	**11.3%**	7.9%	14.7%	
8%				
8%	**1.0%**	0.8%	1.3%	
8%				
8%	**9.1%**	6.8%	11.4%	
8%	**2.0%**	1.0%	3.0%	
8%	**7.5%**	5.4%	10.5%	
8%	**30.9%**	21.9%	40.9%	
46%	**0.3%**	0.2%	0.4%	
46%				
46%				
46%	**0.1%**	0.1%	0.1%	
46%	**0.1%**	0.1%	0.2%	
46%	**0.1%**	0.1%	0.1%	
46%				
46%	**0.3%**	0.2%	0.4%	
46%	**24.0%**	16.8%	31.2%	
46%	**7.0%**	4.9%	9.1%	
46%	**3.0%**	2.1%	3.9%	
46%				
46%	**4.0%**	2.8%	5.2%	
46%	**10.0%**	7.0%	13.0%	
46%				
46%	**24.0%**	16.8%	31.2%	
54%				
41%				366

Sugar

Sweet products
Sugar
Sugar beets

Sugar in sweet products
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				85
100%				
100%	**?**			
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**83.0%**	74.5%	91.5%	
100%				
100%				
100%	**10.0%**	9.0%	11.0%	10
100%	**45.0%**	40.0%	50.0%	10
100%	**25.0%**	23.0%	27.0%	42
100%	**3.0%**	2.5%	3.5%	44
100%				
100%				
100%				
100%				
100%				
100%				
100%				
100%	**83.0%**	74.5%	91.5%	
17%				
17%				
17%				
17%				
17%				
17%				
17%				
17%				
17%				
17%	**0.5%**	0.3%	0.8%	
17%				
17%				
17%				
17%	**0.1%**	0.1%	0.2%	401
17%	**0.4%**	0.2%	0.6%	401
17%	**0.5%**	0.3%	0.8%	
3%	**13.3%**	10.0%	16.6%	
3%				
3%				
3%	**0.5%**	0.4%	0.6%	401
3%				
3%	**2.3%**	1.7%	2.9%	401
3%	**2.4%**	1.8%	3.0%	401
3%	**8.1%**	6.1%	10.1%	401
3%	**13.3%**	10.0%	16.6%	
14%	**3.3%**	2.5%	4.1%	
14%				
14%				
14%	**1.2%**	0.9%	1.5%	401
14%	**0.1%**	0.1%	0.2%	401
14%	**2.0%**	1.5%	2.5%	401
14%				
14%	**3.3%**	2.5%	4.1%	
14%	**12.0%**	8.4%	15.6%	
14%				
14%				
14%				
14%	**8.0%**	5.6%	10.4%	401
14%	**4.0%**	2.8%	5.2%	401
14%				
14%	**12.0%**	8.4%	15.6%	
16%				
14%				401

Oils and fats

Oils and fats
Oils and fats
Oils and fats

Oils and fats
85% -> 85%
15% -> 15%

	% (by mass)			[kcal/100g]
REF	Ø	min	max	
100%				634
100%	**6%**	4%	8%	
100%				
100%				
100%				
100%				
100%				
100%				
100%	**4.2%**	2.9%	5.5%	
100%				
100%				
100%				
100%				
100%	**1.8%**	1.3%	2.3%	
100%	**6.0%**	4.2%	7.8%	
94%	**0.6%**	0.3%	0.9%	
94%				
94%				
94%				
94%				
94%				
94%	**0.6%**	0.3%	0.9%	
94%	**0.6%**	0.3%	0.9%	
93%	**61.6%**	46.2%	77.0%	
93%				
93%				
93%				
93%				
93%				
93%	**56.6%**	42.5%	70.8%	449
93%				
93%	**2.5%**	1.9%	3.1%	
93%				
93%	**2.5%**	1.9%	3.1%	
93%				
93%				
93%				
93%	**61.6%**	46.2%	77.0%	
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
36%				
5%	**18.5%**	13.3%	23.6%	
5%				908
5%	**1.8%**	1.3%	2.2%	
5%				
5%				
5%	**4.8%**	3.6%	5.9%	908
5%	**2.0%**	1.0%	3.0%	908
5%	**9.9%**	7.5%	12.4%	908
5%	**18.5%**	13.3%	23.6%	
30%	**0.8%**	0.6%	1.0%	
30%				
30%				
30%	**0.5%**	0.4%	0.7%	908
30%	**0.1%**	0.1%	0.2%	908
30%	**0.1%**	0.1%	0.2%	908
30%				
30%	**0.8%**	0.6%	1.0%	
30%	**16.7%**	11.7%	21.7%	
30%	**1.1%**	0.8%	1.4%	908
30%	**11.9%**	8.3%	15.5%	908
30%				
30%	**3.7%**	2.6%	4.8%	908
30%				
30%				
30%	**16.7%**	11.7%	21.7%	
36%				
30%				908

Table A.12: Overview of the food loss records across the food value chain for animal products.

		Milk		**Cheese**		**Butter**	
Product category		Dairy products		Dairy products		Dairy products	
Product group		Dairy products		Cheese		Butter	
Initial products	a) one initial product ->						
	b) two correlated products ->	Milk	Cattle	Raw milk	Cattle	Raw milk	Cattle
Final products		Milk	Beef	Cheese (including curd and whey)	Beef	Butter and skim milk as by-product	Beef
Household consumption (relative to total consumption)		85% -> 85%	85% -> 85%	85% -> 85%	85% -> 85%	85% -> 85%	85% -> 85%
Consumption in food service and catering (relative to total consumption)		15% -> 15%	15% -> 15%	15% -> 15%	15% -> 15%	15% -> 15%	15% -> 15%

					% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]	% (by mass)				[kcal/100g]
Sector	Reference	Process		Reason for losses	REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max	
Milk production					100%	**17.0%**	14.5%	19.5%		100%					100%	**17.0%**	14.5%	19.5%		100%					100%	**17.0%**	14.5%	19.5%		100%				
	Milk yield; live weight of livestock	Milking	III	Illness	100%	**1.0%**	0.5%	1.5%		100%					100%	**1.0%**	0.5%	1.5%		100%					100%	**1.0%**	0.5%	1.5%		100%				
			III	Contamination	100%	**16.0%**	14.0%	18.0%		100%					100%	**16.0%**	14.0%	18.0%		100%					100%	**16.0%**	14.0%	18.0%		100%				
			II	No demand because of quality	100%					100%					100%					100%					100%					100%				
		TOTAL			100%	**17.0%**	14.5%	19.5%		100%					100%	**17.0%**	14.5%	19.5%		100%					100%	**17.0%**	14.5%	19.5%		100%				
Egg production					83%					100%					83%					100%					83%					100%				
	Egg yield; live weight of laying hens	Laying and collecting	III	Illness	83%					100%					83%					100%					83%					100%				
			III	Contamination	83%					100%					83%					100%					83%					100%				
			II	No demand because of quality	83%					100%					83%					100%					83%					100%				
			II	Quality sorting	83%					100%					83%					100%					83%					100%				
			I	"Surplus" cocks	83%					100%					83%					100%					83%					100%				
		TOTAL			83%					100%					83%					100%					83%					100%				
Meat production					83%					100%	**57.0%**	39.1%	74.9%		83%					100%	**57.0%**	39.1%	74.9%		83%					100%	**57.0%**	39.1%	74.9%	
	Live weight of livestock	Slaughtering	III	Illness	83%					100%	**4.0%**	2.0%	6.0%	123	83%					100%	**4.0%**	2.0%	6.0%	123	83%					100%	**4.0%**	2.0%	6.0%	123
			III	Inedible parts	83%					100%	**8.0%**	5.6%	10.4%	100	83%					100%	**8.0%**	5.6%	10.4%	100	83%					100%	**11.0%**	7.7%	14.3%	100
			III	Inedible parts	83%					100%	**11.0%**	7.7%	14.3%	10	83%					100%	**11.0%**	7.7%	14.3%	10	83%					100%	**11.0%**	7.7%	14.3%	10
			III	Inedible parts	83%					100%	**9.0%**	6.3%	11.7%	100	83%					100%	**9.0%**	6.3%	11.7%	100	83%					100%	**6.0%**	4.2%	7.8%	100
			III	Contamination	83%					100%	**13.0%**	9.1%	16.9%	30	83%					100%	**13.0%**	9.1%	16.9%	35	83%					100%	**13.0%**	9.1%	16.9%	30
			II	Quality sorting	83%					100%	**6.0%**	4.2%	7.8%	100	83%					100%	**6.0%**	4.2%	7.8%	100	83%					100%	**6.0%**	4.2%	7.8%	100
		Storage	III	Storage problems	83%					100%					83%					100%					83%					100%				
			I	Stored for too long	83%					100%					83%					100%					83%					100%				
		TOTAL			83%					100%	**57.0%**	39.1%	74.9%		83%					100%	**57.0%**	39.1%	74.9%		83%					100%	**57.0%**	39.1%	74.9%	
Fish production					83%					43%					83%					43%					83%					43%				
	Live weight of entire fish catch	Fishing	III	Illness	83%					43%					83%					43%					83%					43%				
			III	Inedible part or species	83%					43%					83%					43%					83%					43%				
			II	Quality sorting	83%					43%					83%					43%					83%					43%				
		TOTAL			83%					43%					83%					43%					83%					43%				
Trade					83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%		83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%		83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%	
	Food purchased	Trade 1	III	Basic food sorting	83%					43%					83%					43%					83%					43%				
			III	Transport	83%					43%					83%					43%					83%					43%				
			III	Storage problems	83%	**0.5%**	0.3%	0.7%		43%					83%	**0.5%**	0.3%	0.7%		43%					83%	**0.5%**	0.3%	0.7%		43%				
			II	Quality sorting	83%					43%					83%					43%					83%					43%				
			II	Quality sorting	83%					43%					83%					43%					83%					43%				
			I	Stored for too long	83%					43%	**0.7%**	0.2%	1.2%	193	83%					43%	**0.7%**	0.2%	1.2%		83%					43%	**0.7%**	0.2%	1.2%	193
		TOTAL			83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%		83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%		83%	**0.5%**	0.3%	0.7%		43%	**0.7%**	0.2%	1.2%	
Processing					83%					43%	**5.0%**	3.0%	7.0%		83%	**84.7%**	72.0%	97.4%		43%	**5.0%**	3.0%	7.0%		83%	**79.7%**	63.8%	95.6%		43%	**5.0%**	3.0%	7.0%	
	Food purchased	Processing 1	III	Basic food sorting	83%					43%					83%					43%					83%					43%				
			III	Transport	83%					43%					83%					43%					83%					43%				
			III	Storage problems	83%					43%					83%					43%					83%					43%				
			III	Failure	83%					43%					83%	***3.0%***	*2.6%*	*3.5%*	*21*	43%					83%	***13.0%***	*10.4%*	*15.6%*	*33*	43%				
			III	Method of processing	83%					43%	**2.5%**	1.5%	3.5%	193	83%	**61.7%**	52.4%	71.0%	21	43%	**2.5%**	1.5%	3.5%	193	83%	**69.7%**	55.8%	83.6%		43%	**2.5%**	1.5%	3.5%	193
			III	Method of processing	83%					43%					83%	**3.0%**	2.1%	3.9%	21	43%					83%					43%				
			II	Method of processing	83%					43%					83%	**20.0%**	17.0%	23.0%	21	43%					83%	**10.0%**	8.0%	12.0%	33	43%				
			II	Quality sorting	83%					43%	**2.5%**	1.5%	3.5%	193	83%					43%	**2.5%**	1.5%	3.5%		83%					43%	**2.5%**	1.5%	3.5%	193
		TOTAL			83%					43%	**5.0%**	3.0%	7.0%		83%	**84.7%**	72.0%	97.4%		43%	**5.0%**	3.0%	7.0%		83%	**79.7%**	63.8%	95.6%		43%	**5.0%**	3.0%	7.0%	
Food service					13%	**5.1%**	3.0%	7.1%		6%	**17.4%**	11.8%	23.0%		2%	**12.1%**	7.2%	16.9%		6%	**17.4%**	11.8%	23.0%		3%	**4.6%**	2.8%	6.5%		6%	**17.4%**	11.8%	23.0%	
	Food purchased	Preparation	III	Inedible parts	13%					6%	**8.1%**	5.6%	10.5%	193	2%	**4.8%**	2.9%	6.8%	271	6%	**8.1%**	5.6%	10.5%	193	3%					6%	**8.1%**	5.6%	10.5%	193
			III	Inedible parts	13%					6%					2%					6%					3%					6%				
			III	Failure	13%					6%					2%					6%					3%					6%				
			II	Quality sorting	13%					6%	**1.0%**	0.7%	1.3%	193	2%					6%	**1.0%**	0.7%	1.3%	193	3%					6%	**1.0%**	0.7%	1.3%	193
			I	Over-production	13%	**1.9%**	1.2%	2.7%		6%	**4.1%**	2.9%	5.3%	193	2%	**3.0%**	1.8%	4.2%	271	6%	**4.1%**	2.9%	5.3%	193	3%	**1.8%**	1.1%	2.5%	279	6%	**4.1%**	2.9%	5.3%	193
			I	Stored for too long	13%	**1.9%**	1.2%	2.7%		6%					2%	**3.0%**	1.8%	4.2%	271	6%					3%	**1.7%**	1.0%	2.4%	279	6%				
		Serving	I	Plate waste	13%	**1.2%**	0.7%	1.6%		6%	**4.3%**	2.6%	6.0%	193	2%	**1.2%**	0.7%	1.6%	271	6%	**4.3%**	2.6%	6.0%	193	3%	**1.2%**	0.7%	1.6%	279	6%	**4.3%**	2.6%	6.0%	193
		TOTAL			13%	**5.1%**	3.0%	7.1%		6%	**17.4%**	11.8%	23.0%		2%	**12.1%**	7.2%	16.9%		6%	**17.4%**	11.8%	23.0%		3%	**4.6%**	2.8%	6.5%		6%	**17.4%**	11.8%	23.0%	
Retail					70%	**0.8%**	0.5%	1.1%		34%	**1.8%**	1.3%	2.3%		11%	**0.8%**	0.5%	1.1%		34%	**1.8%**	1.3%	2.3%		14%	**0.3%**	0.2%	0.5%		34%	**1.8%**	1.3%	2.3%	
	Food purchased	Sale	III	Transport	70%					34%					11%					34%					14%					34%				
			III	Storage conditions	70%					34%					11%					34%					14%					34%				
			I	Too long on the reatil shelves	70%	**0.3%**	0.2%	0.4%		34%	**1.2%**	0.9%	1.6%	193	11%	**0.3%**	0.2%	0.4%	271	34%	**1.2%**	0.9%	1.6%	193	14%	**0.1%**	0.1%	0.1%	279	34%	**1.2%**	0.9%	1.6%	193
			I	Too long on the reatil shelves	70%	**0.1%**	0.1%	0.2%		34%	**0.1%**	0.0%	0.1%	193	11%	**0.1%**	0.1%	0.2%	271	34%	**0.1%**	0.0%	0.1%	193	14%	**0.1%**	0.1%	0.2%	279	34%	**0.1%**	0.0%	0.1%	193
			I	Too long on the reatil shelves	70%	**0.4%**	0.2%	0.5%		34%	**0.5%**	0.4%	0.6%	193	11%	**0.4%**	0.2%	0.5%	271	34%	**0.5%**	0.4%	0.6%	193	14%	**0.1%**	0.1%	0.1%	279	34%	**0.5%**	0.4%	0.6%	193
			I	Too long on the reatil shelves	70%					34%					11%					34%					14%					34%				
		TOTAL			70%	**0.8%**	0.5%	1.1%		34%	**1.8%**	1.3%	2.3%		11%	**0.8%**	0.5%	1.1%		34%	**1.8%**	1.3%	2.3%		14%	**0.3%**	0.2%	0.5%		34%	**1.8%**	1.3%	2.3%	
Households					70%	**9.0%**	5.4%	12.6%		34%	**16.9%**	10.1%	23.7%		11%	**17.0%**	10.2%	23.8%		34%	**16.9%**	10.1%	23.7%		14%	**8.0%**	4.8%	11.2%		34%	**16.9%**	10.1%	23.7%	
	Food purchased	Preparation	III	Inedible parts (apple cores, meat bones…)	70%					34%	**5.0%**	3.0%	7.0%	193	11%	**3.0%**	1.8%	4.2%	271	34%	**5.0%**	3.0%	7.0%	193	14%					34%	**5.0%**	3.0%	7.0%	193
			II	Taste preferences	70%					34%	**2.6%**	1.6%	3.6%	193	11%					34%	**2.6%**	1.6%	3.6%	193	14%					34%	**2.6%**	1.6%	3.6%	193
		Planning	I	Storage conditions	70%					34%	**2.0%**	1.2%	2.8%	193	11%					34%	**2.0%**	1.2%	2.8%	193	14%					34%	**2.0%**	1.2%	2.8%	193
			I	Purchased / cooked too much	70%	**6.0%**	3.6%	8.4%		34%	**2.0%**	1.2%	2.8%	193	11%	**7.0%**	4.2%	9.8%	271	34%	**2.0%**	1.2%	2.8%	193	14%	**8.0%**	4.8%	11.2%	279	34%	**2.0%**	1.2%	2.8%	193
			I	Purchased / cooked too much	70%	**3.0%**	1.8%	4.2%		34%	**5.3%**	3.2%	7.4%	193	11%	**7.0%**	4.2%	9.8%	271	34%	**5.3%**	3.2%	7.4%	193	14%					34%	**5.3%**	3.2%	7.4%	193
			I	Purchased / cooked too much	70%					34%					11%					34%					14%					34%				
		TOTAL			70%	**9.0%**	5.4%	12.6%		34%	**16.9%**	10.1%	23.7%		11%	**17.0%**	10.2%	23.8%		34%	**16.9%**	10.1%	23.7%		14%	**8.0%**	4.8%	11.2%		34%	**16.9%**	10.1%	23.7%	
Consumption at the retail and food service level					**82%**					**40%**					**13%**					**40%**					**17%**					**40%**				
Final consumption (intake)					**75%**				59	**33%**				193	**11%**				271	**33%**				193	**15%**				279	**33%**				193

Eggs										**Pork**					**Poultry**					**Beef**					**Fish**				
Eggs										Meat products					Meat products					Meat products					Fish				
Eggs										Pork					Poultry					Beef					Fish				
										Pigs					Chickens					Cattle					Fish				
Eggs					Laying hens																								
Eggs					Poultry meat					Pork					Poultry meat					Beef					Fish				
85%	->	85%			85%	->	85%			85%	->	85%			85%	->	85%			85%	->	85%			85%	->	85%		
15%	->	15%			15%	->	15%			15%	->	15%			15%	->	15%			15%	->	15%			15%	->	15%		
	% (by mass)			[kcal/100g]		% (by mass)			[kcal/100g]		% (by mass)			[kcal/100g]		% (by mass)			[kcal/100g]		% (by mass)			[kcal/100g]		% (by mass)			[kcal/100g]
REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max		REF	Ø	min	max	
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%	**1.3%**	0.6%	2.0%		100%					100%					100%					100%					100%				
100%	**1.0%**	0.3%	1.7%		100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%					100%					100%					100%					100%					100%				
100%	**0.3%**	0.3%	0.3%		100%					100%					100%					100%					100%				
100%	**1.3%**	0.6%	2.0%		100%					100%					100%					100%					100%				
99%					100%	**77.6%**	55.5%	99.7%		100%	**31.5%**	24.7%	42.2%		100%	**39.0%**	26.5%	51.5%		100%	**57.0%**	39.1%	74.9%		100%				
99%					100%	**4.0%**	2.0%	6.0%	105	100%	**4.0%**	2.0%	6.0%	200	100%	**4.0%**	2.0%	6.0%	113	100%	**4.0%**	2.0%	6.0%	123	100%				
99%					100%	**9.0%**	6.3%	11.7%	100	100%	**18.0%**	15.0%	24.0%	100	100%	**10.0%**	7.0%	13.0%	100	100%	**8.0%**	5.6%	10.4%	100	100%				
99%					100%	**9.0%**	6.3%	11.7%	100	100%	**3.0%**	2.0%	5.0%	100	100%	**10.0%**	7.0%	13.0%	100	100%	**11.0%**	7.7%	14.3%	10	100%				
99%					100%	**20.0%**	16.0%	24.0%	100	100%	**1.8%**	1.6%	2.0%	100	100%	**13.0%**	9.1%	16.9%	100	100%	**9.0%**	6.3%	11.7%	100	100%				
99%					100%	**2.0%**	1.4%	2.6%	10	100%	**2.4%**	2.0%	2.8%	10	100%	**2.0%**	1.4%	2.6%	10	100%	**13.0%**	9.1%	16.9%	30	100%				
99%					100%					100%	**2.3%**	2.1%	2.4%	10	100%					100%	**12.0%**	8.4%	15.6%	100	100%				
99%					100%	60% x (100% - 40% - 4%) = 33.6%				100%					100%					100%					100%				
99%					100%	**33.6%**	23.5%	43.7%	105	100%					100%					100%					100%				
99%					100%	**77.6%**	55.5%	99.7%		100%	**31.5%**	24.7%	42.2%		100%	**39.0%**	26.5%	51.5%		100%	**57.0%**	39.1%	74.9%		100%				
99%					22%					69%					61%					43%					100%	**35.0%**	9.0%	60.0%	
99%					22%					69%					61%					43%					100%				
99%					22%					69%					61%					43%					100%				
99%					22%					69%					61%					43%					100%	**35.0%**	9.0%	60.0%	
99%					22%					69%					61%					43%					100%	**35.0%**	9.0%	60.0%	
99%	**0.5%**	0.2%	0.8%		22%	**0.7%**	0.2%	1.2%		69%	**0.7%**	0.2%	1.2%		61%	**0.7%**	0.2%	1.2%		43%	**0.7%**	0.2%	1.2%		65%	**0.5%**	0.2%	0.8%	
99%					22%					69%					61%					43%					65%				
99%					22%					69%					61%					43%					65%				
99%	**0.5%**	0.2%	0.8%		22%					69%					61%					43%					65%				
99%					22%					69%					61%					43%					65%				
99%					22%					69%					61%					43%					65%				
99%					22%	**0.7%**	0.2%	1.2%	127	69%	**0.7%**	0.2%	1.2%	245	61%	**0.7%**	0.2%	1.2%	127	43%	**0.7%**	0.2%	1.2%	193	65%	**0.5%**	0.2%	0.8%	
99%	**0.5%**	0.2%	0.8%		22%	**0.7%**	0.2%	1.2%		69%	**0.7%**	0.2%	1.2%		61%	**0.7%**	0.2%	1.2%		43%	**0.7%**	0.2%	1.2%		65%	**0.5%**	0.2%	0.8%	
98%	**1.2%**	0.4%	2.0%		22%	**5.0%**	3.0%	7.0%		68%	**5.0%**	3.0%	7.0%		61%	**5.0%**	3.0%	7.0%		43%	**5.0%**	3.0%	7.0%		65%	**6.0%**	4.0%	8.0%	
98%					22%					68%					61%					43%					65%				
98%					22%					68%					61%					43%					65%				
98%					22%					68%					61%					43%					65%				
98%					22%					68%					61%					43%					65%				
98%	**1.2%**	0.4%	2.0%		22%	**2.5%**	1.5%	3.5%	127	68%	**2.5%**	1.5%	3.5%	245	61%	**2.5%**	1.5%	3.5%	127	43%	**2.5%**	1.5%	3.5%	193	65%	**3.0%**	2.0%	4.0%	
98%					22%					68%					61%					43%					65%				
98%					22%					68%					61%					43%					65%				
98%					22%	**2.5%**	1.5%	3.5%	127	68%	**2.5%**	1.5%	3.5%	245	61%	**2.5%**	1.5%	3.5%	127	43%	**2.5%**	1.5%	3.5%	193	65%	**3.0%**	2.0%	4.0%	
98%	**1.2%**	0.4%	2.0%		22%	**5.0%**	3.0%	7.0%		68%	**5.0%**	3.0%	7.0%		61%	**5.0%**	3.0%	7.0%		43%	**5.0%**	3.0%	7.0%		65%	**6.0%**	4.0%	8.0%	
15%	**36.2%**	21.7%	50.7%		3%	**50.4%**	35.0%	65.8%		10%	**18.3%**	12.5%	24.1%		9%	**50.4%**	35.0%	65.8%		6%	**17.4%**	11.8%	23.0%		9%	**22.2%**	15.3%	29.1%	
15%					3%	**40.3%**	28.2%	52.4%	105	10%	**8.1%**	5.6%	10.5%	245	9%	**40.3%**	28.2%	52.4%	113	6%	**8.1%**	5.6%	10.5%	193	9%	**13.8%**	9.7%	18.0%	
15%	**29.0%**	17.4%	40.6%		3%					10%					9%					6%					9%				
15%					3%					10%					9%					6%					9%				
15%					3%	**2.0%**	1.4%	2.6%	127	10%	**1.0%**	0.7%	1.3%	245	9%	**2.0%**	1.4%	2.6%	127	6%	**1.0%**	0.7%	1.3%	193	9%	**3.0%**	2.1%	3.9%	
15%	**2.2%**	1.3%	3.1%		3%	**5.1%**	3.6%	6.6%	127	10%	**6.3%**	4.4%	8.2%	245	9%	**5.1%**	3.6%	6.6%	127	6%	**4.1%**	2.9%	5.3%	193	9%	**2.8%**	2.0%	3.7%	
15%	**1.7%**	1.0%	2.4%		3%					10%					9%					6%					9%				
15%	**3.3%**	2.0%	4.6%		3%	**3.0%**	1.8%	4.2%	127	10%	**3.0%**	1.8%	4.2%	245	9%	**3.0%**	1.8%	4.2%	127	6%	**4.3%**	2.6%	6.0%	193	9%	**2.6%**	1.5%	3.6%	
15%	**36.2%**	21.7%	50.7%		3%	**50.4%**	35.0%	65.8%		10%	**18.3%**	12.5%	24.1%		9%	**50.4%**	35.0%	65.8%		6%	**17.4%**	11.8%	23.0%		9%	**22.2%**	15.3%	29.1%	
82%	**1.4%**	0.8%	2.0%		18%	**1.2%**	0.9%	1.5%		55%	**1.5%**	1.1%	1.9%		49%	**1.2%**	0.9%	1.5%		34%	**1.8%**	1.3%	2.3%		52%	**3.6%**	2.6%	4.6%	
82%					18%					55%					49%					34%					52%				
82%					18%					55%					49%					34%					52%				
82%	**1.0%**	0.6%	1.4%		18%	**0.6%**	0.4%	0.8%	127	55%	**0.9%**	0.7%	1.2%	245	49%	**0.6%**	0.4%	0.8%	127	34%	**1.2%**	0.9%	1.6%	193	52%	**3.0%**	2.2%	3.8%	
82%	**0.1%**	0.0%	0.1%		18%	**0.1%**	0.0%	0.1%	127	55%	**0.1%**	0.0%	0.1%	245	49%	**0.1%**	0.0%	0.1%	127	34%	**0.1%**	0.0%	0.1%	193	52%	**0.1%**	0.0%	0.1%	
82%	**0.3%**	0.2%	0.5%		18%	**0.5%**	0.4%	0.7%	127	55%	**0.5%**	0.4%	0.6%	245	49%	**0.5%**	0.4%	0.7%	127	34%	**0.5%**	0.4%	0.6%	193	52%	**0.5%**	0.4%	0.7%	
82%					18%					55%					49%					34%					52%				
82%	**1.4%**	0.8%	2.0%		18%	**1.2%**	0.9%	1.5%		55%	**1.5%**	1.1%	1.9%		49%	**1.2%**	0.9%	1.5%		34%	**1.8%**	1.3%	2.3%		52%	**3.6%**	2.6%	4.6%	
81%	**27.0%**	16.2%	37.8%		18%	**41.5%**	24.9%	58.1%		54%	**21.8%**	13.1%	30.5%		48%	**41.5%**	24.9%	58.1%		34%	**16.9%**	10.1%	23.7%		50%	**22.1%**	13.3%	30.9%	
81%	**12.0%**	3.6%	8.4%		18%	**25.0%**	15.0%	35.0%	105	54%	**5.0%**	3.0%	7.0%	245	48%	**25.0%**	15.0%	35.0%	113	34%	**5.0%**	3.0%	7.0%	193	50%	**8.6%**	5.2%	12.0%	
81%	**6.0%**	3.6%	8.4%		18%					54%	**3.7%**	2.2%	5.2%	245	48%					34%	**2.6%**	1.6%	3.6%	193	50%	**3.0%**	1.8%	4.2%	
81%					18%	**2.0%**	1.2%	2.8%	127	54%	**2.0%**	1.2%	2.8%	245	48%	**2.0%**	1.2%	2.8%	127	34%	**2.0%**	1.2%	2.8%	193	50%	**4.0%**	2.4%	5.6%	
81%	**6.0%**	3.6%	8.4%		18%	**8.0%**	4.8%	11.2%	127	54%	**5.0%**	3.0%	7.0%	245	48%	**8.0%**	4.8%	11.2%	127	34%	**2.0%**	1.2%	2.8%	193	50%	**6.5%**	3.9%	9.1%	
81%	**3.0%**	1.8%	4.2%		18%	**2.8%**	1.7%	3.9%	127	54%	**6.1%**	3.7%	8.5%	245	48%	**2.8%**	1.7%	3.9%	127	34%	**5.3%**	3.2%	7.4%	193	50%				
81%					18%					54%					48%					34%					50%				
81%	**27.0%**	16.2%	37.8%		18%	**41.5%**	24.9%	58.1%		54%	**21.8%**	13.1%	30.5%		48%	**41.5%**	24.9%	58.1%		34%	**16.9%**	10.1%	23.7%		50%	**22.1%**	13.3%	30.9%	
96%					**21%**					**64%**					**57%**					**40%**					**59%**				
69%				162	**12%**				127	**50%**				245	**33%**				127	**33%**				193	**46%**				152

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APPENDIX B

SUPPORTING INFORMATION

ENVIRONMENTAL IMPACTS AND HOTSPOTS OF FOOD LOSSES: VALUE CHAIN ANALYSIS OF SWISS FOOD CONSUMPTION

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METHODOLOGY

B.1 MASS AND ENERGY FLOW ANALYSIS

B.1.1 Food consumption at retail level

Food consumption at retail level in the years 2011-2012 is based on statistics by SBV (2014) and Swissfruit (2015), which calculate *available Swiss food production* plus *imports to Switzerland* minus *exports from Switzerland to other countries* and considering *yearly changes in food stocks* (Table B.1). FW at the stage of agricultural production is not included in the *available food production*. Inedible food losses from food processing and changes in water content are considered in their mass and energy balance. FW from the processing and trade industry that is officially quantified (e.g. in the feed statistics) is not included in the reported food consumption at retail level. However, FW that is not used as feed or other marketable products is not officially quantified and may therefore be included in the reported final consumption (SBV, 2014, SBV, 2016). Thus, final consumption at retail level may rather by over- than underestimated.

Table B.1: Swiss food consumption at retail level for 33 food categories analyzed in this paper. Source 1 refers to Swissfruit (2015) and source 2 to SBV (2014). For food categories with different calorific contents of the original products at agricultural level and the processed, final products the calorific content of the final product is highlighted in red (details in Figure B.3). Consumption is quantified in terms of final product. The last column describes the state of the final product that was defined for quantification. Classification details for vegetables are documented in Table B.3.

Food categories	2011-2012 [t/a]	2011-2012 [kg/p/a]	Source	[kJ/p/d]	Original product [kcal/100g]	Final product	Comment to final product
1.1 Table apples	140359	17.6	1	106	52.5	52.5	
1.2 Apple juice	64671	8.1	1	43	52.5	46.0	in tonnes of fruit juice; apple juice: 46 kcal/100g (Yazio.de, 2015)
2.1 Other fresh table fruits	85600	10.8	1	64	51.7	51.7	incl. pears, peaches, nectarines, plums, apricots, mirabelles, cherries
2.2 Other fresh fruit juices	16046	2.0	1	11	51.7	49.6	in tonnes of fruit juice
3.1 Berries	37294	4.7	1	20	37.6	37.6	more than 50% from importation; incl. strawberries, blueberries, raspberries, gooseberries, currant, kiwi
3.2 Exotic and citrus table fruits	344991	43.4	1	164	32.9	32.9	only from importation; incl. ananas, avocado, banana, dates, figs, mango, papaya, table grapes, melons, mandarines, oranges, grapefruits, lemons, limes
3.3 Exotic and citrus fruit juices	129300	16.3	1	64	32.9	34.5	only from importation, in tonnes of fruit juice
4 Canned fruits	7058	0.9	1	17	52.1	171.8	fruits used in the food industry for canning and other convenience food
5 Potatoes	363130	45.7	2	291	55.6	55.6	fresh, including peel (dried if imported as dried potatoes); incl cassava (maniok), sweetpotato, yam
6 Fresh vegetables	588820	74.0	2	161	19.0	19.0	incl. zucchini, white / green asparagus, tomato, spinach, lettuce, iceberg, fennel, cucumber, cauliflower, aubergine, avocado, artichoke, broccoli, pumpkin, melon
7.1 Legumes	25455	3.2	2	16	43.6	43.6	fresh and unpeeled
7.2 Other storable vegetables	180227	22.7	2	49	19.0	19.0	incl. spices, mustard, cabbage white / red, carrot, onion, garlic, celery, radish; fresh and unpeeled
8 Processed vegetables	53079	6.7	2	55	47.6	71.8	incl. dried legumes; calorific content based on Yazio.de (2015)
9 Bread and pastries	416060	52.3	2	1'894	285.4	315.8	cereals without durum wheat (pasta, bulgur, couscous) and without rice and maize; other ingredients of bread not included -> incl. rye, oats, triticale, emmer, millet, sorghum, buckwheat, quinoa, greencorn, carob (Johannisbrot); in tonnes of grain
10 Pasta	120839	15.2	2	537	264.0	308.5	all durum wheat, incl. couscous, bulgur; other ingredients not included; in tonnes of grain
11 Rice	45342	5.7	2	227	347.4	347.4	
12 Maize	18693	2.4	2	65	240.9	240.9	
13 Sugar	330516	41.6	2	1'888	84.5	396.4	incl. starch
14.1 Vegetal oils and fats	134832	17.0	2	1'740	635.0	895.5	incl. olive, rapeseed, soybean, sunflower, castor (Rhizinus) oils; margarine
14.2 Nuts, seeds, oleiferous fruits	44148	5.6	2	382	300.5	601.0	incl. peanuts, pistachio, almonds, chestnuts, cocos, olives, soja; without nutshells
15.1 Milk, other dairy	794408	99.9	2	766	66.9	66.9	in milk equivalents (normed to average fat and protein content of milk)
15.2 Meat co-product from milk	10227	1.3	2	25	110.0	167.1	meat without bones; beef yield from dairy cows is estimated 1.3% of the mass of the corresponding raw milk production (SBV, 2016)
16.1 Cheese, whey	400015	50.3	2	780	67.0	135.3	incl. whey that is consumed (0.24 of raw milk by mass)
16.2 Meat co-product from cheese	8725	1.1	2	21	110.0	167.1	see category 15.2
17.1 Butter, buttermilk, skimmed milk	854688	107.4	2	857	66.9	69.6	incl. buttermilk that is consumed (0.37 of raw milk by mass) and skimmed milk resulting as byproduct from processing
17.2 Meat co-product from butter	7441	0.9	2	18	110.0	167.1	see category 15.2
18.1 Eggs without co-product poultry	91479	11.5	2	161	122.1	122.1	
18.2 Meat from laying hens	4496	0.6	2	8	103.8	127.1	meat without bones; calorific content from SFF, 2008 and SBV, 2009; meat yield from laying hens is estimated 4.9% of the mass of the corresponding egg production (Affentranger, 2011)
19 Pork	197276	24.8	2	809	229.0	284.5	meat without bones
20 Poultry	75846	9.5	2	177	132.0	161.7	meat without bones
21 Beef, horse, veal	107245	13.5	2	258	110.0	167.1	meat without bones, incl. animal fats other than butter
22 Fish, shellfish	60853	7.7	2	100	114.0	114.0	meat without bones
23 Cocoa, coffee, tea	90285	11.4	2	482	370.4	370.4	quantified as coffee and cocoa beans (peeled) and as dried tea; coffee grounds not modelled as waste
All food categories	**5849443**	**735**		**12256**			

Table B.2: Matching of food categories with the classification in the FAO food balance sheets (FAOSTAT, 2016).

Food categories		Items according to Food Balance Sheets referring to Food Supply to Switzerland (FAOSTAT 2016)	
Code	**Category name**	**Code**	**Item**
1.1	Table apples	2617	Apples and products
1.2	Apple juice		
2.1	Other fresh table fruits	2625	Fruits, Other
2.2	Other fresh fruit juices	2620	Grapes and products (excl wine)
3.1	Berries		
3.2	Exotic and citrus table fruits	2611	Oranges, Mandarines
3.3	Exotic and citrus fruit juices	2612	Lemons, Limes and products
		2613	Grapefruit and products
		2614	Citrus, Other
		2615	Bananas
		2619	Dates
		2618	Pineapples and products
4	Canned fruits		
5	Potatoes	2531	Potatoes and products
		2533	Sweet potatoes
6	Fresh vegetables	2534	Roots, Other
7.1	Legumes	2601	Tomatoes and products
7.2	Storable vegetables	2602	Onions
8	Processed vegetables	2605	Vegetables, Other
		2640	Pepper
		2641	Pimento
		2642	Cloves
		2645	Spices, Other
		2546	Beans
		2547	Peas
		2549	Pulses, Other and products
9	Bread and pastries	2511	Wheat and products
10	Pasta	2513	Barley and products
		2515	Rye and products
		2516	Oats
		2517	Millet and products
		2520	Cereals, Other
11	Rice	2805	Rice (Milled Equivalent)
12	Maize	2514	Maize and products
13	Sugar	2542	Sugar (Raw Equivalent)
		2543	Sweeteners, Other
		2745	Honey
14.1	Vegetal oils and fats	2560	Coconuts - Incl Copra
		2570	Oilcrops, Other
		2571	Soyabean Oil
		2572	Groundnut Oil
		2573	Sunflowerseed Oil
		2574	Rape and Mustard Oil
		2575	Cottonseed Oil
		2576	Palmkernel Oil
		2577	Palm Oil
		2578	Coconut Oil
		2579	Sesameseed Oil
		2580	Olive Oil
		2582	Maize Germ Oil
		2586	Oilcrops Oil, Other
14.2	Nuts, seeds, oleiferous fruits	2551	Nuts and products
		2555	Soyabeans
		2561	Sesame seed
		2563	Olives (including preserved)
		2556	Groundnuts (Shelled Eq)
		2558	Rape and Mustardseed
15.1	Milk, other dairy	2848	Milk - Excluding Butter
16.1	Cheese, whey	2743	Cream
17.1	Butter, buttermilk, skimmed milk	2740	Butter, Ghee
18.1	Eggs without co-product poultry	2744	Eggs
19	Pork	2733	Pigmeat
20	Poultry	2734	Poultry Meat
18.2	Meat from laying hens		
21	Beef, horse, veal	2731	Bovine Meat
15.2	Meat co-product from milk	2732	Mutton & Goat Meat
16.2	Meat co-product from cheese	2735	Meat, Other
17.2	Meat co-product from butter	2736	Offals, Edible
22	Fish, shellfish	2781	Fish, Body Oil
		2782	Fish, Liver Oil
		2761	Freshwater Fish
		2762	Demersal Fish
		2763	Pelagic Fish
		2764	Marine Fish, Other
		2765	Crustaceans
		2766	Cephalopods
		2767	Molluscs, Other
		2775	Aquatic Plants
23	Cocoa, coffee, tea	2630	Coffee and products
		2633	Cocoa Beans and products
		2635	Tea (including mate)

Table B.3: Classification of the vegetables according to the Swiss Farmers' Union's statistics (SBV, 2016) (product names in German) into the food categories *fresh vegetables (6)*, *legumes (7.1)*, *other storable vegetables (7.2)*, and *processed vegetables (8).* Bottom: amount of food supply in the aggregated food categories.

MBID (SBV, 2016)	Product name (SBV, 2016)	Food category in this study	Food Supply in 2012	
29802	cassava	7.2 (8)		
29803	yam	7.2 (8)		
29804	chicory	6 (8)		
50101	peas	8		
50102	chickpea	8		
50103	lentils	8		
50105	kidney beans	8		
50106	vicia faba beans	8		
50107	mung beans	8		
50108	other vigna and phaseolus beans	8		
50198	pulses not mentioned elsewhere	8		
50199	pulses general	8		
80101	carrots	7.2 (8)		
80102	white carrots	7.2 (8)		
80103	black salsifies	7.2 (8)		
80104	radish	6 (8)		
80105	beetroot	7.2 (8)		
80106	radish	7.2 (8)		
80107	fennel	6 (8)		
80108	celery	2.7		
80198	roots and tubers not mentioned elsewhere	7.2 (8)		
80201	onions	7.2 (8)		
80202	garlic	7.2 (8)		
80203	leek	6 (8)		
80298	allium-species not mentioned elsewhere	7.2 (8)		
80301	white cabbage	7.2 (8)		
80302	red cabbage	7.2 (8)		
80303	savoy	7.2 (8)		
80304	green cabbage	7.2 (8)		
80305	Brussels sprouts	6 (8)		
80306	Chinese cabbage	6 (8)		
80307	pak choi	6 (8)		
80308	cauliflower	6 (8)		
80309	broccoli	6 (8)		
80310	stem cabbage	6 (8)		
80398	cabbage not mentioned elsewhere	7.2 (8)		
80401	witloof	6 (8)		
80402	iceberg	6 (8)		
80403	field salad	6 (8)		
80404	French spinach	6 (8)		
80405	lettuce	6 (8)		
80407	radicchio	6 (8)		
80408	trevisana	6 (8)		
80409	sugarloaf	6 (8)		
80410	endive	6 (8)		
80498	salads not mentioned elsewhere	6 (8)		
80501	spinach	6 (8)		
80502	spinach beet	6 (8)		
80503	celery stalks	6 (8)		
80504	asparagus	6 (8)		
80505	rhubarb	6 (8)		
80506	cress	6 (8)		
80507	parsley	6 (8)		
80508	artichoke	6 (8)		
80509	kardy	6 (8)		
80510	culinary herbs	6 (8)		
80511	dandelion	6 (8)		
80601	tomatoes	6 (8)		
80602	cucumbers	6 (8)		
80603	pepper	6 (8)		
80604	zucchini	6 (8)		
80605	eggplant	6 (8)		
80606	pumpkin	6 (8)		
80607	melons	6 (8)		
80608	watermelon	6 (8)		
80701	green beans	7.1		
80702	peas	7.1		
80703	sugar peas	7.1		
80799	pulses general	7.1		
80901	cultivated mushrooms	6 (8)		
80902	truffle	6 (8)		
80998	mushrooms not mentioned elsewhere	6 (8)		
89801	caper	6 (8)		
89802	palm	6 (8)		
89803	sprouts of bamboo	6 (8)		
89804	algae	6 (8)		
89898	edible plants not mentioned elsewhere	6 (8)		
89901	vegetables general	6 (8)		
110101	aniseed	6 (8)		
110102	fennel fruits	6 (8)		
110103	ginger	6 (8)		
110104	cardamon	6 (8)		
110105	coriander	6 (8)		
110106	cumin	6 (8)		
110107	caraway	6 (8)		
110108	curcuma	6 (8)		
110109	nutmeg	6 (8)		
110110	clove	6 (8)		
110111	paprika/chili	6 (8)		
110112	pepper	6 (8)		
110113	saffron	6 (8)		
110114	mustard	6 (8)		
110115	vanilla	6 (8)		
110116	juniper	6 (8)		
110117	cinnamon	6 (8)		
110198	spices not mentioned elsewhere	6 (8)		
110199	spices general	6 (8)		
Fresh vegetables (incl. fresh vegetables for processing)		6 (8)	77.6	kg/p/a (FS, fresh)
thereof used for processing (SZG, 2013)		8	3.6	kg/p/a (FS, fresh)
thereof **unprocessed**		**6**	**74.0**	**kg/p/a (FS, fresh)**
Storable vegetables (incl. storable vegetables for processing)		7.2 (8)	25.4	kg/p/a (FS, fresh)
thereof used for processing (SZG, 2013)		8	2.7	kg/p/a (FS, fresh)
thereof **unprocessed**		**8**	**22.7**	**kg/p/a (FS, fresh)**
Fresh legumes		**7.1**	**3.2**	**kg/p/a (FS, fresh)**
Processed vegetables (dried, imported legumes)		8	0.7	kg/p/a (dried)
expressed in FS with 19% DM content (SBV, 2016)		8	3.8	kg/p/a (FS, fresh)
Processed vegetables (domestic production + imports)		8	10.1	kg/p/a (FS, fresh)
DM content after processing 151% of fresh fruits (SBV, 2016)		**8**	**6.7**	**kg/p/a (FS, processed)**

B.1.2 Update of food waste flows of the food value chain

The mass and energy flow analysis of food and FW is based on data from Beretta et al. (2013) and updated with recent literature. The main updates are discribed in the following section.

In **agricultural production** a study of post-harvest losses of exotic tree fruits in Jamaica is used to estimate the losses of exotic and citrus fruits (Palipane and Rolle, 2008). Post-harvest losses are estimated at around 30-35% of the annual production and they assume that half of the losses are due to high quality expectations and half due to fluctuating production and demand, mainly leading to losses during storage. Additionally, they estimate half of the losses to be avoidable and half to be caused by bad weather conditions, plant diseases, and inefficiencies of current best practice.

In **milk production**, Bareille et al. (2015) estimate 0.5% of total milk production for fresh milk and dairy products to be avoidable losses in France. In the processing stage of **cheese production** recent data from Mosberger et al. (2016) and Kopf-Bolanz et al. (2015) is included in the analysis, reporting that 24% of whey was used for human consumption in 2015, 45% fed to swine and 31% fed to calves and shoats. Kopf-Bolanz et al. (2015) classify **whey fed to swine as avoidable FW** since it can be substituted by cereals; however, whey that is used as high quality feed for calves and shoats cannot be substituted by cereals because of its protein composition. We therefore include **whey fed to calves and shoats separately** in the analysis and show the potential environmental benefits of its valorization for human consumption only in Figure 3a of the manuscript (shaded bar; note that the benefits from feeding whey may be underestimated since the specific protein composition of whey and plant based feed is not considered in the substitution model). However, **in an extended scenario, e.g. with less consumption of animal products, also whey presently used as high quality feed could be valorized as human food** and improve the efficiency of the FVC. Additionally to whey, Mosberger et al. (2016) estimate avoidable losses in the dairy industry at 1.7% of dry matter. We assume that energy and dry matter are proportional (see also Figure B.3). Butter is produced in two main steps of processing (Table B.4). In the first step, raw milk is transformed to skimmed milk and cream, which is then transformed to butter and buttermilk. In Swiss **butter production** between 60'000 and 70'000 t of buttermilk are produced each year; thereof, about 37% is valorized for human consumption, the rest fed to livestock (SBV, 2016). Additional avoidable losses are assumed equal to cheese production (1.7% by energy) (Figure B.3).

Table B.4: Mass and energy balance of butter, buttermilk and skimmed milk production from raw milk. Numbers in italic are based on the references mentioned to their right; the other values are deduced from mass and energy balance.

	[kcal/100g]		mass-%	energy-%
Raw milk	*66.9*	*(SBV, 2013)*	100%	100%
Cream	*325.1*	*(Yazio.de, 2015)*	12%	56%
Skimmed milk	*33.0*	*(Yazio.de, 2015)*	88%	44%

	[kcal/100g]		mass-%	energy-%	production 2015 [t/a]	
Cream	325.1		12%	56%		
Butter	*751.2*	*(SBV, 2013)*	4.7%	52%	*43353*	*(SBV, 2013)*
Buttermilk	*37.8*	*(SBV, 2013)*	6.9%	3.9%	*64293*	*(SBV, 2016)*

The losses in the milling stage of the FVC of breads and pastries are updated according to Table B.5, differentiating three types of losses:

(I) cereals that are fed to animals because of a lower cereal demand of the food industry (declassification of cereals)
(II) cereals that are fed to animals because they do not meet the quality standards of bakeries
(III) edible by products from milling (mainly bran).

Table B.5: Avoidable FW in the milling stage of bread cereals. (I) refers to cereals originally produced for human consumption, which are declassified to animal feed because of lower demand than production, assuming that the share of declassified bread wheat in the years 2008-2015 is representative for all bread cereals. (II) refers to cereals originally produced for human consumption, but then diverted to animal feeding because of high quality standards from the bakery industry. They are estimated based on statistical data of the total share of cereals fed to animals (11%) minus declassified cereals (I), using the average between the years 2008-2015. These losses are classified as avoidable FW since the maximum legal concentration for mycotoxins for swine feeding is lower than for human consumption (Swissmill, 2016). (III) refers to edible by-products from milling, mainly bran, wasted due to consumer preferences. The amount is calculated as difference between average cereal input and average flour output of the Swiss milling industry in the years 1990-2014 (SBV, 2016), deducing the share of bran used for human consumption and assuming that the rest is used as animal feed (Reuge, 2013).

	Reason	Percentage by mass	Comment	References
(I)	low demand -> declassification	3.2%	based on wheat, 2008-2015	SBV (2016)
(II)	high quality standards for baking	7.8%	based on bread cereals, 2008-2015	SBV (2016)
(III)	refining (white flour production)	20.1%	assuming 1.05% of bran used for food	SBV (2016), Reuge (2013)

Since the practice of using bread cereals for feeding is a special case for Switzerland (Harder, 2016), the food loss categories (I) and (II) are only applied to domestic cereal production and not to cereal imports. Domestic production is estimated to provide 80% of consumed bread cereals (SBV, 2014).

The result of overall avoidable FW from milling is similar to the estimation by Beretta et al. (2013).

In the processing stage of durum wheat for pasta production the average flour yield is lower than for bread cereals (67% for durum wheat versus 79% for bread cereals) (SBV, 2016) and the share of bran used as food is assumed equal to bread cereals (Figure B.3). No declassification (I) and quality sorting (II) is modeled.

In **retail** the total supermarkets' food losses of all food categories are based on new or updated data from three major retailers in Switzerland. Their data is weighted equally since their quality and reliability is estimated similar. Additionally, data from one discount supermarket chain is used as a proxy for the losses in the discount sector. The losses of supermarkets (83% of the sales of volume) and the losses of discounters (15% of the sales of volume) are weighted according to the volume of sales of these sectors (Ruschmann, 2010). Only one retailer delivered quantitative data about its losses in detailed food categories and referring to all its branches. The relative composition of food losses between these food categories was multiplied to the overall losses to derive loss values per category also for the other retailers.

In the **food service** sector an additional study of food losses in 25 canteen kitchens, hotels, and gastronomic businesses in Austria in 2015 is included in the analysis, estimating avoidable average food losses of all food categories (Hrad and Obersteiner, 2015). Furthermore, an investigation of food losses in 15 Swiss hotels in 2015 is included in the analysis, estimating preparation losses (81 g/meal; assumed to be unavoidable), spoiled food (6 g/meal), surplus production (27 g/meal), serving losses from the counter (12 g/meal), and plate waste (66 g/meal; assuming that 90% are edible parts) (United_Against_Waste, 2015). The total food loss amounts of all food categories reported by the different references are weighted based on own judgement of reliability and representativeness of the investigations: Andrini and Bauen (2005) 16.3%; Baier and Reinhard (2007) 16.3%; SV_Group_AG (2011) 25%; Hrad and Obersteiner (2015) 25%; United_Against_Waste (2015) 16.3%. The gourmet restaurant has been weighted with 1% since gourmet restaurants contribute to the Swiss food service sector by about 1% (Stucki, 2011). The composition of plate waste is based on the average values of two measurements. The first analysis has been conducted in a Swiss canteen, sorting and weighing plate waste of 1'504 guests (ETH_Mensa, 2011). The second analysis is the result of a bachelor thesis that has collected 1.5 tonnes of food waste over two weeks in a Swiss luxury hotel (Maurer, 2014). However, for breads and pastries, sugar, and stimulants only a value from Maurer (2014) was available. The composition of kitchen waste is assumed to be proportional to household FW (Beretta et al., 2013). The values for fruit juices and exotic table fruits are only based on Maurer (2014).

Donations according to Beretta et al. (2013) amounted to 0.15% of total food consumption at the retail level. With present estimates for the years 2013-2015, overall donations amount to 0.2% of total food consumption. The amount of food distributed by Tischlein deck dich (3'248 t) (Tdd, 2015), Schweizer Tafel (4'321 t) (Schweizer-Tafeln, 2016), and Partage (750 t) (Partage, 2016) is updated to the years 2013-2015, including an estimated 2'000 t distributed by Caritas and charity institutions (Caritas_Luzern, 2011). The attribution of total donations to individual food categories is estimated based on the composition of food donated to Tischlein deck dich in 2011 (Segawa et al., 2013): 122% relative to consumption for breads and pastries, 136% for fruits and vegetables, 74% for dairy products, and 48% for meat products. The remaining food categories are estimated to 55% of consumption in order to be consistent with the total amount of food donations (about 10'000 tons or 0.2% of total food consumption). The origin of food donations (retail, food services, processing industry, trade industry) is based on Baier and Deller (2014) and own assumptions (numbers in section B.20). Food losses of donated food are neglected.

Potato losses in agricultural production, trade, and processing are updated with numbers from Willersinn (2015), distinguishing various methods of treatment and differentiating potatoes consumed as fresh and as processed potatoes as well as organic and conventional production according to their share in Swiss consumption. Household losses due to peeling are based on reliable dairies in Willersinn's study, other household losses on representative surveys; however, it is uncertain whether the lower numbers compared to Quested and Johnson (2009) are caused by cultural differences or by underreporting of the people surveyed.

In contrast to Beretta et al. (2013) the following food categories are modeled as separate categories, due to substantial differences in environmental impacts and FW amounts: exotic and citrus fruits; legumes; nuts, seeds, and oleiferous fruits; chocolate, coffee, and tea. Food loss flows from the various stages of the FVC to different treatment methods and donation consider additional publications compared to Beretta et al. (2013) (more details in the next section). Figure B.1 shows an overview of the system boundaries of our previous publication and this study.

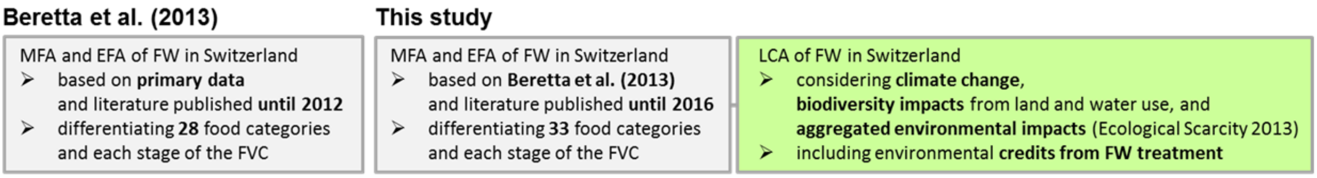


Figure B.1: Overview of the system boundaries of Beretta et al. (2013) and this study.

B.1.3 Waste flows for different treatment methods from each stage of the food chain

Table B.6 shows estimates of the flows of FW (all food categories) from different stages of the FVC to the most important treatment methods (feeding, anaerobic digestion, composting, and incineration) and to donation institutions based on investigations at treatment facilities and expert judgements on the *origin of the substrates*. Publications and references not yet considered by Beretta et al. (2013) include Paganini (2014), Schleiss (2015), Baier and Deller (2014), Kohler (2015), Schweizer-Tafeln (2015), and Tdd (2015). The FW flows modelled in this study, however, are derived from estimations of the *fractions of food lost or wasted* at the various stages of the FVC. The relative shares of FW between different treatment methods according to Table B.6 are used to assign the modelled FW flows from the different stages of the FVC to the various treatment methods, assuming avoidable and unavoidable FW to be sent to different treatment methods in the same shares. The allocation of the FW flows to different food categories is mainly based on own assumptions, since the detailed composition of the biomass substrates is unknown and the relevance for the results of this study is low. The FW flows from agriculture and trade are based on the same assumptions as in Beretta et al. (2013). Liquid FW is assumed to be discarded into the sewer. The share of the treatment methods is illustrated in Figure B.2 for each stage of the FVC. An inventory of the individual FW flows from each stage of the FVC, differentiating by treatment methods and food categories, is provided in section B.20.

Table B.6: Estimated amounts of food losses from processing, retail, food service, and households to different treatment methods, based on literature and expert estimations. The relative flows from each stage of the FVC to the various treatment methods are assumed to be equal for avoidable and unavoidable food losses. The allocation of the FW flows to different food categories is mainly based on own assumptions, since the detailed composition of the biomass substrates is unknown and the relevance for the results of this study is relatively low. The modelled flows are documented in section B.20. The FW flows from agriculture and trade are based on the same assumptions as in Beretta (2015).

		Donation	Ref.	Feeding	Ref.	Anaerobic Digestion*	Ref.	Composting	Ref.	Home Composting	Ref.	Incineration	Ref.	TOTAL	Ref.
Processing	t/a			2306397	2,7,8	173000	2,7	30000	2					2509397	
	%	0.0%		**91.9%**		**6.9%**		**1.2%**		0.0%		0.0%		100.0%	
Retail	t/a	5000	1	8000	1	78000	1	7000	1			3000	1,7	101000	1
	%	5.0%		**7.9%**		**77.2%**		**6.9%**		0.0%		**3.0%**		100.0%	
Food Service	t/a	2000	1	5000	1	205500	1	42000	1			37000	1	291500	1
	%	0.7%		**1.7%**		**70.5%**		**14.4%**		0.0%		**12.7%**		100.0%	
Households	t/a					186400	2,5	46600	2,5	30000	5	449000	5,6	712000	
	%	0.0%		**5.0%**	9	**24.9%**		**6.2%**		**4.0%**		**59.9%**		100.0%	
Total	t/a	10319	3,4	2319397		642900		125600		30000		489000		3617216	
	%	0.3%		64.1%		17.8%		3.5%		0.8%		13.5%		100.0%	

References:

1 Baier and Deller (2014)	4 Tdd (2015)	7 Spycher and Chaubert (2011)
2 Schleiss (2015)	5 Kohler (2015)	8 Paganini (2014)
3 Schweizer-Tafeln (2015)	6 BAFU (2014)	* anaerobic digestion and production of

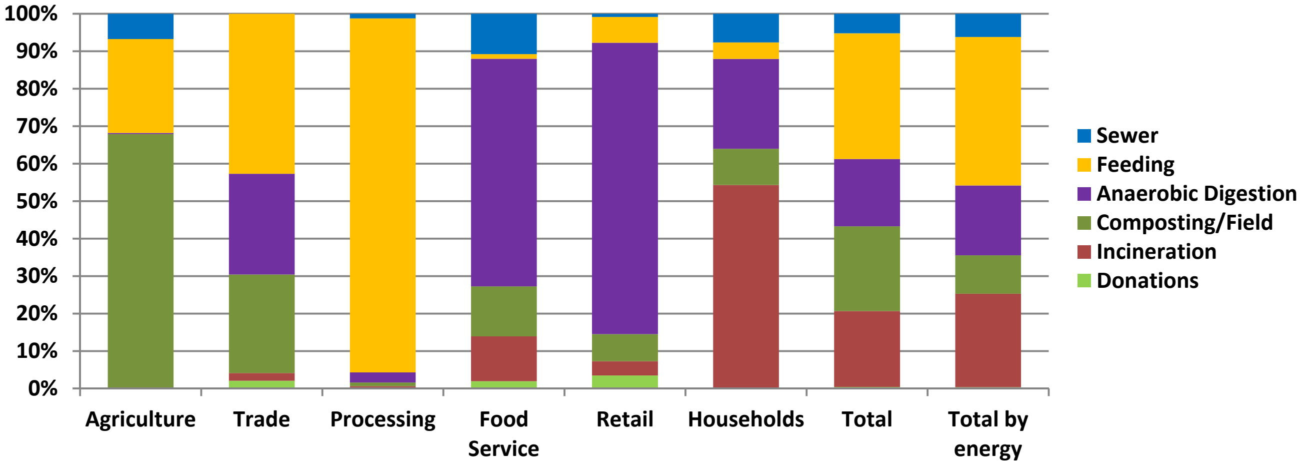
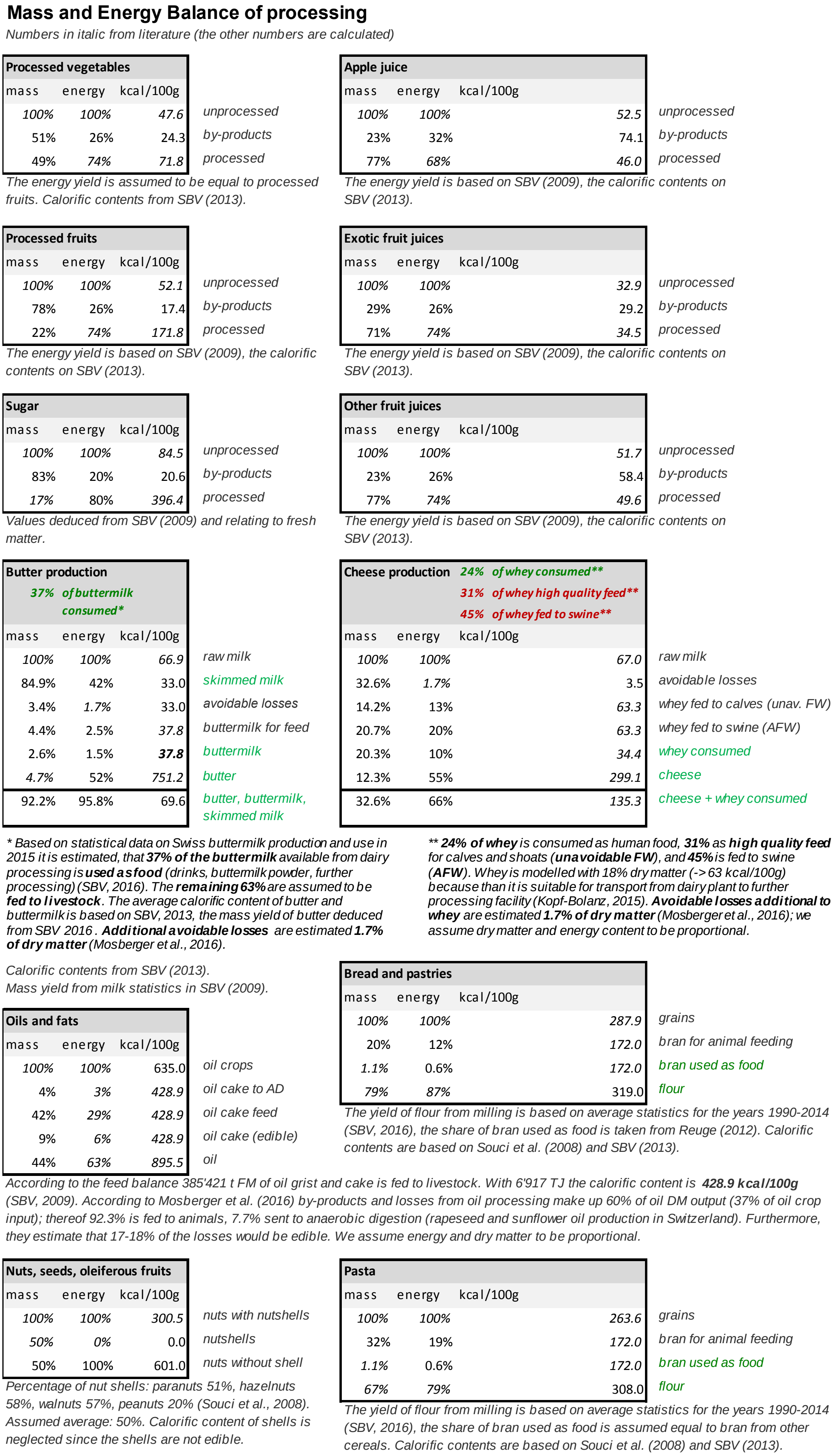


Figure B.2: Relative FW flows to different treatment methods for each stage of the FVC in terms of mass (ww) and for the whole FVC in terms of mass and in terms of energy, based on the assumption that the shares of avoidable and unavoidable losses are equal for each treatment method.

B.1.4 Mass and energy balance of processing

The mass flow analysis is converted to an energy flow analysis based on the calorific contents of the food. Most values are calculated from statistical data from SBV (2009) and SBV (2013), since they have a similar classification of food products. Additionally, data from Yazio.de (2015), Souci (2008), and SFF (2008) is used. An inventory of the calorific contents of each food category is shown in sections B.1.1 and B.20. For 12 product categories we modelled a conversion from original raw products to processed products with a different calorific content. For these products the mass and energy balance is shown in Figure B.3.



Mass and Energy Balance of processing

Numbers in italic from literature (the other numbers are calculated)

Processed vegetables

mass	energy	kcal/100g	
100%	*100%*	*47.6*	unprocessed
51%	26%	24.3	by-products
49%	*74%*	*71.8*	processed

The energy yield is assumed to be equal to processed fruits. Calorific contents from SBV (2013).

Apple juice

mass	energy	kcal/100g	
100%	*100%*	*52.5*	unprocessed
23%	32%	74.1	by-products
77%	*68%*	*46.0*	processed

The energy yield is based on SBV (2009), the calorific contents on SBV (2013).

Processed fruits

mass	energy	kcal/100g	
100%	*100%*	*52.1*	unprocessed
78%	26%	17.4	by-products
22%	*74%*	*171.8*	processed

The energy yield is based on SBV (2009), the calorific contents on SBV (2013).

Exotic fruit juices

mass	energy	kcal/100g	
100%	*100%*	*32.9*	unprocessed
29%	26%	29.2	by-products
71%	*74%*	*34.5*	processed

The energy yield is based on SBV (2009), the calorific contents on SBV (2013).

Sugar

mass	energy	kcal/100g	
100%	*100%*	*84.5*	unprocessed
83%	20%	20.6	by-products
17%	80%	*396.4*	processed

Values deduced from SBV (2009) and relating to fresh matter.

Other fruit juices

mass	energy	kcal/100g	
100%	*100%*	*51.7*	unprocessed
23%	26%	58.4	by-products
77%	*74%*	*49.6*	processed

The energy yield is based on SBV (2009), the calorific contents on SBV (2013).

Butter production

37% of buttermilk consumed*

mass	energy	kcal/100g	
100%	*100%*	*66.9*	raw milk
84.9%	42%	33.0	skimmed milk
3.4%	*1.7%*	33.0	avoidable losses
4.4%	2.5%	*37.8*	buttermilk for feed
2.6%	1.5%	***37.8***	buttermilk
4.7%	52%	*751.2*	butter
92.2%	95.8%	69.6	butter, buttermilk, skimmed milk

Cheese production

24% of whey consumed**
31% of whey high quality feed**
45% of whey fed to swine**

mass	energy	kcal/100g	
100%	*100%*	*67.0*	raw milk
32.6%	*1.7%*	3.5	avoidable losses
14.2%	13%	*63.3*	whey fed to calves (unav. FW)
20.7%	20%	*63.3*	whey fed to swine (AFW)
20.3%	10%	*34.4*	whey consumed
12.3%	55%	*299.1*	cheese
32.6%	66%	*135.3*	cheese + whey consumed

** Based on statistical data on Swiss buttermilk production and use in 2015 it is estimated, that **37% of the buttermilk** available from dairy processing is **used as food** (drinks, buttermilk powder, further processing) (SBV, 2016). The **remaining 63%** are assumed to be **fed to livestock**. The average calorific content of butter and buttermilk is based on SBV, 2013, the mass yield of butter deduced from SBV 2016 . **Additional avoidable losses** are estimated **1.7% of dry matter** (Mosberger et al., 2016).*

*** **24% of whey** is consumed as human food, **31%** as **high quality feed** for calves and shoats (**unavoidable FW**), and **45%** is fed to swine (**AFW**). Whey is modelled with 18% dry matter (-> 63 kcal/100g) because than it is suitable for transport from dairy plant to further processing facility (Kopf-Bolanz, 2015). **Avoidable losses additional to whey** are estimated **1.7% of dry matter** (Mosberger et al., 2016); we assume dry matter and energy content to be proportional.*

Calorific contents from SBV (2013).
Mass yield from milk statistics in SBV (2009).

Bread and pastries

mass	energy	kcal/100g	
100%	*100%*	*287.9*	grains
20%	12%	*172.0*	bran for animal feeding
1.1%	0.6%	*172.0*	bran used as food
79%	*87%*	319.0	flour

The yield of flour from milling is based on average statistics for the years 1990-2014 (SBV, 2016), the share of bran used as food is taken from Reuge (2012). Calorific contents are based on Souci et al. (2008) and SBV (2013).

Oils and fats

mass	energy	kcal/100g	
100%	*100%*	635.0	oil crops
4%	*3%*	*428.9*	oil cake to AD
42%	*29%*	*428.9*	oil cake feed
9%	*6%*	*428.9*	oil cake (edible)
44%	*63%*	*895.5*	oil

*According to the feed balance 385'421 t FM of oil grist and cake is fed to livestock. With 6'917 TJ the calorific content is **428.9 kcal/100g** (SBV, 2009). According to Mosberger et al. (2016) by-products and losses from oil processing make up 60% of oil DM output (37% of oil crop input); thereof 92.3% is fed to animals, 7.7% sent to anaerobic digestion (rapeseed and sunflower oil production in Switzerland). Furthermore, they estimate that 17-18% of the losses would be edible. We assume energy and dry matter to be proportional.*

Nuts, seeds, oleiferous fruits

mass	energy	kcal/100g	
100%	*100%*	*300.5*	nuts with nutshells
50%	*0%*	0.0	nutshells
50%	100%	601.0	nuts without shell

Percentage of nut shells: paranuts 51%, hazelnuts 58%, walnuts 57%, peanuts 20% (Souci et al., 2008). Assumed average: 50%. Calorific content of shells is neglected since the shells are not edible.

Pasta

mass	energy	kcal/100g	
100%	*100%*	*263.6*	grains
32%	19%	*172.0*	bran for animal feeding
1.1%	0.6%	*172.0*	bran used as food
67%	*79%*	308.0	flour

The yield of flour from milling is based on average statistics for the years 1990-2014 (SBV, 2016), the share of bran used as food is assumed equal to bran from other cereals. Calorific contents are based on Souci et al. (2008) and SBV (2013).

Figure B.3: Mass and energy balance of food processing for 12 food categories.

B.2 LIFE CYCLE ASSESSMENT (LCA)

B.2.1 Basic concept

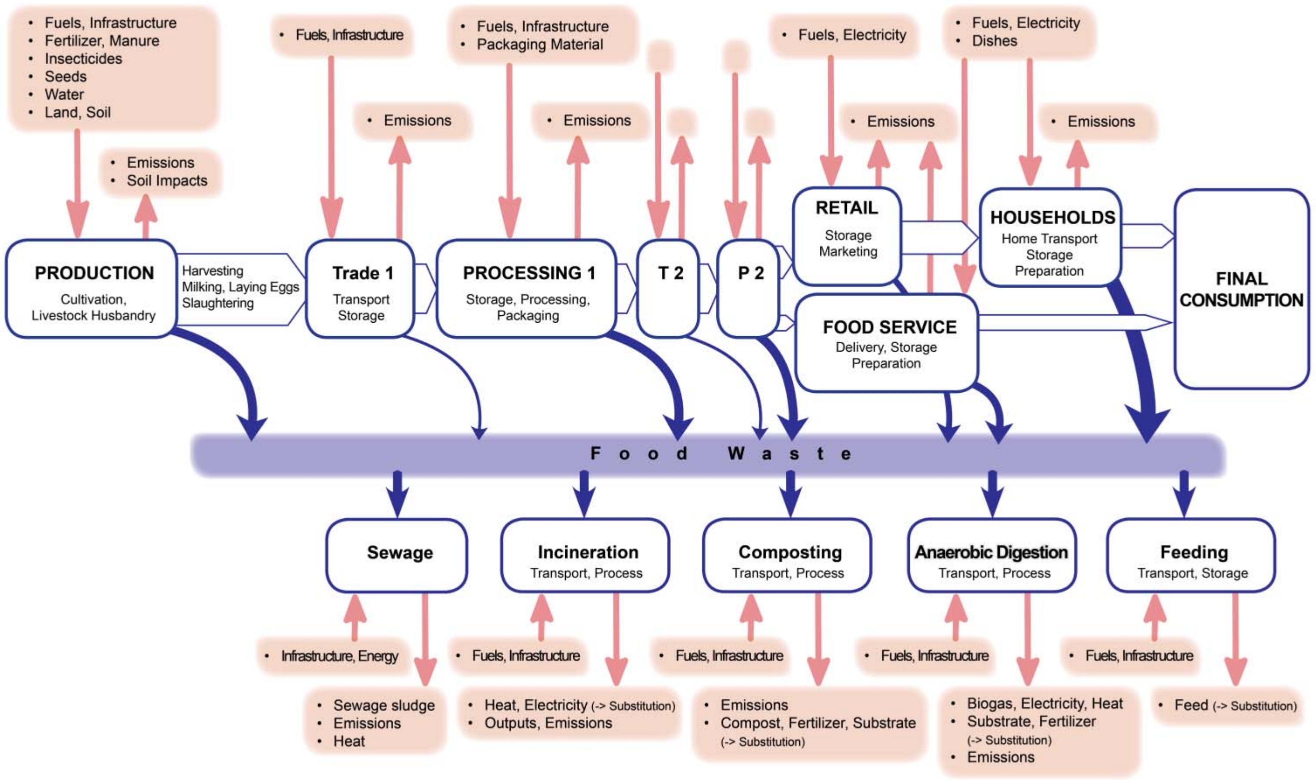


Figure B.4: Basic concept of modelling the environmental impacts of the various processes of the FVC and of the treatment of food losses. Red arrows represent inputs of resources *from* and emissions *to* the environment, white arrows define flows of food and blue arrows of food losses.

B.2.2 Attribution of impacts to food consumption and losses

The goal of our allocation approach is to create an indicator for the environmental impacts that can be avoided by reducing individual waste flows. Therefore at each stage of the FVC, where avoidable food losses occur, the impacts of the previous FVC are defined, including production, transport, storage, processing, preparation, and the impacts of the treatment of the unavoidable losses (which can also be net environmental benefits, e.g. in the case of animal feeding). These impacts are than allocated to consumption and avoidable FW based on the metabolizable energy of the food. The impacts of the treatment of avoidable FW are entirely allocated to FW. It is important to note that both the impacts allocated to consumption and the impacts allocated to FW are a part of the responsibility of the consumers and some other actors along the FVC. This implies that the distinction is not made to allocate responsibilities, but to identify waste flows with high environmental impacts and to prioritize prevention measures. In this perspective our approach does not contradict Nemecek et al. (2016) stating that “food that is not consumed increases the impact per unit of consumed food”. A detailed description of the allocation principle is visualized in Figure B.5.

The agricultural production of food, in some cases, leads to by-products which are used for non-food purposes (e.g. leather, fish bycatch, bonemeal fed to animals or going another valorization step). In these cases a part of the impacts of agricultural production is allocated economically to the by-products. This approach is consistent with Scherhaufer et al. (2015).

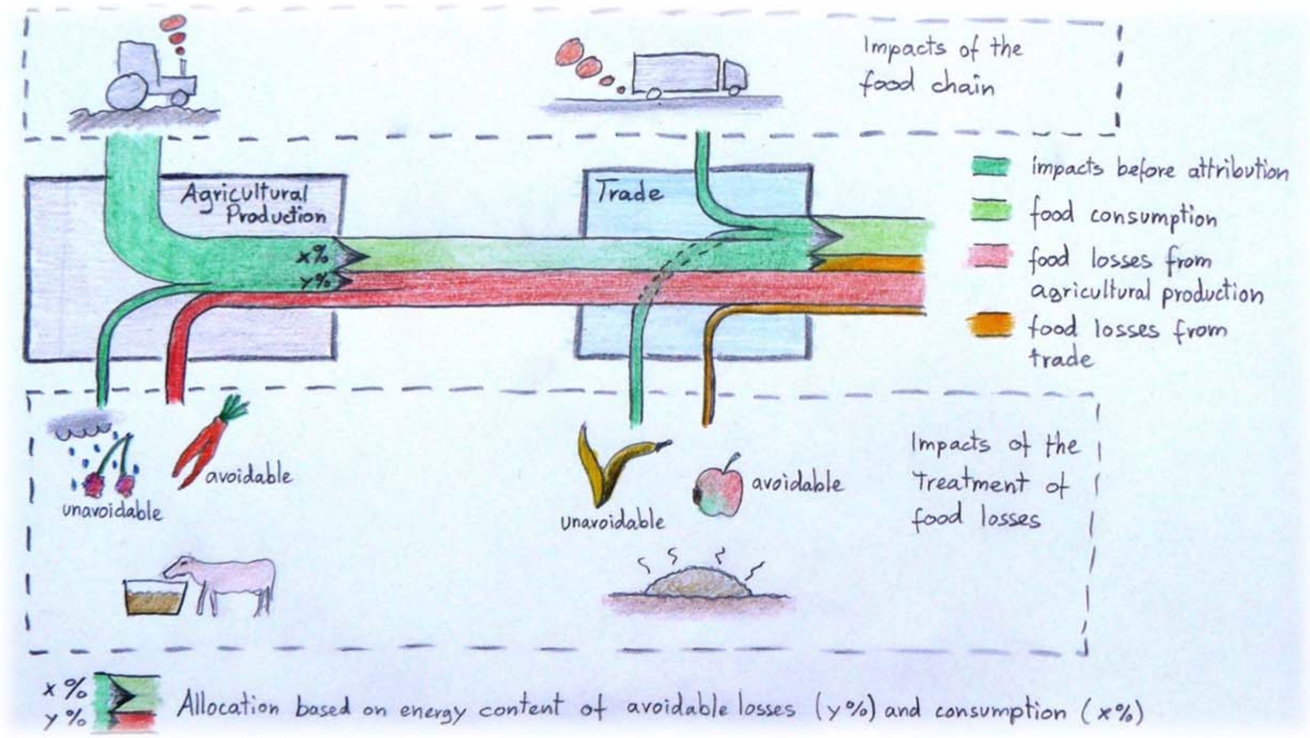


Figure B.5: Visualization of the allocation principle of the environmental impacts to consumption and losses. The impacts from agricultural production (visualized with a tractor and a green flow) and the impacts of the treatment of the unavoidable losses (illustrated with cherries that have perished because of bad weather conditions) are allocated to consumption (green flow) and losses (red flow) proportionally to the metabolizable energy of the products that are delivered to trade and the edible products that are wasted. The impacts of the treatment of the avoidable losses (illustrated with the nonstandard carrot and the red flow), however, are fully allocated to the losses, since they could be avoided with FW prevention. These impacts can also be negative (meaning benefits for the environment, e.g. if the food is used to substitute forage for livestock). At the next stages of the FVC, the same principle is adopted again. The impacts allocated to the losses in trade are illustrated with the orange flow.

The width of the arrows is proportional to the size of the flows. However, it is important to note that the arrows do not represent physical flows, but the theoretical attribution of the environmental impacts from the place where they influence the environment to the consumer who takes the main responsibility for the impacts. In other words, the arrows illustrate the embedded impacts of food consumption and losses.

B.3 LIFE CYCLE INVENTORY (LCI)

B.3.1 Agricultural production

The life cycle inventories of agricultural production are based on the databases shown in Table B.7 and on life cycle inventories established by Eymann et al. (2015), Kreuzer et al. (2014), and Schwab et al. (2014). Table B.7 shows which processes and databases are used for each product category.

Table B.7: Databases and literature used for the life cycle inventory of individual food products. The names of the processes correspond to the original names in the corresponding databases; in some cases they are slightly adapted in order to better represent the Swiss food basket (e.g. the original datasets of orange production in different countries are combined according to the volumes imported to Switzerland and labelled with “orange … CH-import mix”). The weighing factors of the individual datasets are shown in section B.21.

LCA processes (grey background)**, food categories** (red background)	**Database used for LCI**
Table apples	
Apple {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Apple juice	
Apple {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Other fresh table fruits	
Grape {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Pear {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Apricot, at farm (WFLDB 3.0)/FR U	World Food LCA Database 3.0
Peach, at farm (WFLDB 3.0)/CH-Importmix U	World Food LCA Database 3.0
Other fresh fruit juices	
Pear {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Grape {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Berries	
Kiwi {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Strawberry {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Exotic and citrus table fruits	
Avocado {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Banana {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Citrus {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Papaya {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Pineapple {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Mandarin, at farm (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Orange, fresh grade, at farm (WFLDB 3.0)/ES U	World Food LCA Database 3.0
Exotic and citrus fruit juices	
Citrus {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Orange, processing grade, at farm (WFLDB 3.0)/CH-Importmix U	World Food LCA Database 3.0
Canned fruits	
Pear {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Pineapple {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Apricot, at farm (WFLDB 3.0)/FR U	World Food LCA Database 3.0
Peach, at farm (WFLDB 3.0)/CH-Importmix U	World Food LCA Database 3.0
Potatoes	
Potato, organic {CH}| production | Alloc Rec, U	Ecoinvnet 3.2
Potato, Swiss integrated production {CH}| potato production, Swiss integrated production, intensive | Alloc Rec, U	Ecoinvnet 3.2
Fresh vegetables	
Aubergine {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Broccoli {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Cauliflower {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Celery {GLO}| 675 production | Alloc Rec, U	Ecoinvnet 3.2
Cucumber {GLO}| production | Alloc Rec, U (Greenhouse)	Ecoinvnet 3.2
Fennel {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Green asparagus {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Green bell pepper {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Iceberg lettuce {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Lettuce {GLO}| 360 production | Alloc Rec, U (Greenhouse)	Ecoinvnet 3.2
Lettuce {GLO}| 361 production | Alloc Rec, U (Open Field)	Ecoinvnet 3.2
Melon {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Radish {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Spinach {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Tomato {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
White asparagus {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Zucchini {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Legumes	
Fava bean, organic {CH}| production | Alloc Rec, U	Ecoinvnet 3.2
Fava bean, Swiss integrated production {CH}| fava bean production, Swiss integrated production, at farm | Alloc Rec, U	Ecoinvnet 3.2
Other storable vegetables	
Cabbage red {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Cabbage white {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2
Carrot {GLO}| 335 production | Alloc Rec, U	Ecoinvnet 3.2
Onion {GLO}| 855 production | Alloc Rec, U	Ecoinvnet 3.2
Vanilla, at farm (WFLDB 3.0)/MG U	World Food LCA Database 3.0
Processed vegetables	
Fava bean, organic {CH}| production | Alloc Rec, U	Ecoinvnet 3.2
Fava bean, Swiss integrated production {CH}| fava bean production, Swiss integrated production, at farm | Alloc Rec, U	Ecoinvnet 3.2
Carrot {GLO}| 335 production | Alloc Rec, U	Ecoinvnet 3.2
Spinach {GLO}| production | Alloc Rec, U	Ecoinvnet 3.2

Bread and pastries	
Barley grain, organic {CH}| barley production, organic | Alloc Rec, U	Ecoinvnet 3.2
Barley grain, Swiss integrated production {CH}| barley production, Swiss integrated production, extensive | Alloc Rec, U	Ecoinvnet 3.2
Barley grain, Swiss integrated production {CH}| barley production, Swiss integrated production, intensive | Alloc Rec, U	Ecoinvnet 3.2
Rye grain, organic {CH}| rye production, organic | Alloc Rec, U	Ecoinvnet 3.2
Rye grain, Swiss integrated production {CH}| rye production, Swiss integrated production, extensive | Alloc Rec, U	Ecoinvnet 3.2
Rye grain, Swiss integrated production {CH}| rye production, Swiss integrated production, intensive | Alloc Rec, U	Ecoinvnet 3.2
Wheat grain, organic {CH}| wheat production, organic | Alloc Rec, U	Ecoinvnet 3.2
Wheat grain, Swiss integrated production {CH}| wheat production, Swiss integrated production, extensive | Alloc Rec, U	Ecoinvnet 3.2
Wheat grain, Swiss integrated production {CH}| wheat production, Swiss integrated production, intensive | Alloc Rec, U	Ecoinvnet 3.2
Oat, at farm (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Pasta	
Durum wheat, semolina, at plant (for pasta) (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Rice	
Rice {RoW}| production | Alloc Rec, U	Ecoinvnet 3.2
Maize	
Maize grain, organic {CH}| production | Alloc Rec, U	Ecoinvnet 3.2
Maize grain, Swiss integrated production {CH}| production | Alloc Rec, U	Ecoinvnet 3.2
Sugar	
Sugar, from sugar beet {CH}| ONLY sugar beet production, per kg of sugarbeet | Alloc Rec, U	Ecoinvnet 3.2
Sugarcane {BR}| production | Alloc Rec, U	Ecoinvnet 3.2
Vegetal oils and fats	
Palm oil, crude {RoW}| palm oil mill operation | Alloc Rec, U, per kg of refined oil	Ecoinvnet 3.2
Rape oil, crude {CH}| rape oil mill operation | Alloc Rec, U	Ecoinvnet 3.2
Margarine, 60% fat, at plant (WFLDB 3.0)/ES U	World Food LCA Database 3.0
Olive (for olive oil), at farm, per kg of oil (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Sunflower, for Sunflower oil, at farm, per kg of oil (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Nuts, seeds, oleiferous fruits	
Coconut, husked {PH}| production | Alloc Rec, U	Ecoinvnet 3.2
Tofu {RoW}| production | Alloc Rec, U, ONLY soybean production, per kg of soybean, organic	Ecoinvnet 3.2
Whey {RoW}| tofu production | Alloc Rec, U	Ecoinvnet 3.2
Almonds, at farm (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Peanut, at farm (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Olives, at farm, conventional/IT U	Schwab et al., 2014
Olives, at farm, organic/kg/IT U	Schwab et al., 2014
Milk without co-product meat	
milk IP, at farm/CH U	Eymann et al., 2014
milk organic, at farm/CH U	Eymann et al., 2014
Meat co-product from milk	
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U	Kreuzer et al., 2014
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
Cheese without co-product meat	
milk IP, at farm/CH U	Eymann et al., 2014
milk organic, at farm/CH U	Eymann et al., 2014
Meat co-product from cheese	
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U	Kreuzer et al., 2014
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
Butter without co-product meat	
milk IP, at farm/CH U	Eymann et al., 2014
milk organic, at farm/CH U	Eymann et al., 2014
Meat co-product from butter	
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U	Kreuzer et al., 2014
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
Eggs without co-product poultry	
Consumption eggs, laying hens >17 weeks, at farm/NL Energy	Agri Footprint 2015
Egg, national average, at farm gate/kg/FR U	AGRIBALYSE v1.2
Meat from laying hens	
Laying hens >17 weeks, for slaughter, at farm/NL Energy	Agri Footprint 2015
Pork	
Pigs to slaughter, pig fattening, at farm/NL Energy	Agri Footprint 2015
Pork, fresh meat, offal and blood, at slaughterhouse (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Poultry	
Broilers, for slaughter, at farm/NL Energy	Agri Footprint 2015
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/BR U	World Food LCA Database 3.0
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/US U	World Food LCA Database 3.0
Beef…	
Beef, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
beef IP, meat + inwards, intensive cattle fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
beef organic, meat + inwards, Weide-Beef, at slaughterhouse/CH U	Kreuzer et al., 2014
horse meat, at slaughterhouse/CH U	Kreuzer et al., 2014
veal IP, meat + inwards + liver, combined fattening, at slaughterhouse/CH U	Kreuzer et al., 2014
Fish / shellfish	
Large trout, 2-4kg, conventional, at farm gate/kg/FR U	AGRIBALYSE v1.2
Sea bass or sea bream, 200-500g, conventional, in cage, at farm gate/kg/FR U	AGRIBALYSE v1.2
Small trout, 250-350g, conventional, at farm gate/kg/FR U	AGRIBALYSE v1.2
Cocoa, coffee, tee	
Coffee, CH consumption mix, at plant GLO U	World Food LCA Database 3.0
Dark chocolate, at plant, ONLY cocoa, per kg of cocoa bean (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Milk chocolate, at plant, ONLY cocoa, per kg of cocoa bean (WFLDB 3.0)/GLO U	World Food LCA Database 3.0
Tea, dried, at farm (WFLDB 3.0)/CH-Importmix U	World Food LCA Database 3.0

B.3.2 Food value chain

Generally, if datasets on impacts from **agricultural production** are available from different countries for specific food categories, they are weighted by mass based on import and domestically produced shares (SBV, 2013, FAOSTAT, 2015). If datasets for different products within a food category are available, they are weighted by mass according to Swiss consumption of the corresponding products according to SBV (2013). For canned fruits, the composition of the consumption mix is based on the sales from a Swiss supermarket chain (B.21).

For the domestic **transport** from agriculture or from the Swiss border to the processing facility we generally assume inland transport of 100 km by 16-32t truck (Stoessel et al., 2012). Additional, foreign transports for imports are modelled for rice, nuts, seeds, oleiferous fruits, vegetal oils and fats, legumes, vegetables, exotic fruits, and stimulants. The transport distances and the means of transport are based on Stoessel et al. (2012) (B.3.2.1). For milk, meat, berries, and partly for potatoes, fruits, and vege-tables cooling during transport is modelled. Air transport is quantified based on transport distances from a major Swiss retailer (B.3.2.1), assuming that the share of this retailer's sales to total Swiss consumption is equal for papaya and for all fruits and vegetables imported by air (mainly mango, papaya, green asparagus and beans).

The impacts of industrial **processing** of fruit juices and potatoes are based on Walker et al. (2017). For average vegetable processing, data is extrapolated from tomato (Bengoa et al., 2015) and potato processing, assuming an average energy consumption of these two processes. The manufacture of bread, pasta, most vegetal oils, butter, hard cheese, and chocolate is based on Bengoa et al. (2015), the manufacture of dairy products and olive oil on Eymann et al. (2015) and Schwab et al. (2014). Industrial processing of tofu, palm oil, and sugar is based on *ecoinvent 3.2*. For vegetal oils only the process of refining is modelled in the processing stage of the FVC, whereas the production of crude vegetal oil is integrated in the stage of agricultural production.

The energy consumed in retail, food services, and households is allocated to all food categories by mass. In **retail** electricity (1.57 MJ/kg of food), heat (1.44 MJ/kg), water (0.7 l/kg), and fuel (0.46 MJ/kg) consumption are based on yearly data from a Swiss food retail shop (Coop, 2015) and allocated equally to all food categories. The estimation of the amount of products sold is based on the volume of sales and assuming an average price of 7.57 CHF per kg of food (BFS, 2014).

The methodology and assumptions for the life cycle assessment in the **food service sector** and in **households** are described in the main paper.

Logistics for food **donations** are based on a case study with the major Swiss donation institution *Tischlein deck dich* (Tdd, 2015) and modelled as follows: Transport is modelled with freight lorry datasets from *ecoinvent* (ecoinvent, 2016) and average transport distances from Tdd (2015) for the year 2013. Heating of storage rooms with 20°C is modelled with gas, assuming an average gas consumption of German households (16 m^3 of gas/m^2) (Günther, 2013), and cooling is modelled with electricity, assuming the typical efficiency of a 72'000 m^3 cooling house (65 kWh/m^3/a) (Weilhart, 2010).

The following sections complement the information provided in the previous paragraphs.

B.3.2.1 *Trade (transport)*

Table B.8: Assumptions on food transport for 7 product categories with a major share of imported products (exotic and citrus fruits, potatoes, legumes, vegetal oils and fats, nuts and seeds and oleiferous fruits, rice, fresh vegetables). Transport distances for the main import countries are based on Stoessel et al. (2012) and weighing of these imports is done according to the Swiss consumption mix based on Scherer and Pfister (2016) and FAOSTAT (2015), considering the five top import countries. If less than five countries contribute to more than 80% of the imports, only these countries are considered.

Product: Exotic and citrus fruits, based on FAOSTAT (2015)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
Costa Rica (general)	100	Costa Rica (Quepos - Rotterdam)	9738	Costa Rica (Rotterdam - CH)	758	40%
				Spain (Valencia - Spreitenbach)	1398	40%
				Italy	893	20%
TOTAL	**40**		**3895**		**1041**	**100%**

Product: Potatoes, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
Israel (general)	100	Israel (Ashdod - Genoa)	2782	Israel (Genoa - CH)	444	55%
				France	733	19%
				Netherlands	812	10%
TOTAL	**65**		**1822**		**553**	**84%**

Product: Legumes, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
				Germany	729	7.4%
				Spain (Valencia - Spreitenbach)	1398	12.9%
				Italy	893	14.5%
				Netherlands	812	3.8%
				CH	0	44.4%
TOTAL	**-**		**-**		**475**	**83%**

Product: Vegetal Oils and Fats, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
Tasmania (general)	500	Tasmania (Devonport - Rotterdam)	20683	Tasmania	758	6.0%
Tasmania (general)	500	Tasmania (Devonport - Rotterdam)	20683	Tasmania	758	18.0%
(= approximation for Malaysia)				Netherlands	812	7.1%
				Germany	729	12.8%
				CH	0	12.5%
TOTAL	**213**		**8801**		**590**	**56%**

Product: Nuts, Seeds, Oleiferous fruits, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
USA (general)	200	USA (San Francisco - Rotterdam)	14975	USA (Rotterdam - CH)	758	7.0%
				Spain (Valencia - Spreitenbach)	1398	13.4%
				Italy	893	24.2%
				Germany	729	12.1%
Israel (general)	100	Israel (Ashdod - Genoa)	2782	Israel (Genoa - CH)	444	8.3%
(= approximation for Turkey)						
TOTAL	**34**		**1968**		**895**	**65%**

Product: Rice, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
USA (general)	200	USA (San Francisco - Rotterdam)	14975	USA (Rotterdam - CH)	758	9%
India (general, around Patna - Calcutta)	500	India (Calcutta - Rotterdam)	14747	India (Rotterdam - CH)	758	9%
India (general, around Patna - Calcutta)	500	India (Calcutta - Rotterdam)	14747	India (Rotterdam - CH)	758	22%
(approximation for Thailand)				Italy	893	38%
				Spain (Valencia - Spreitenbach)	1398	8%
TOTAL	**202**		**6909**		**879**	**86%**

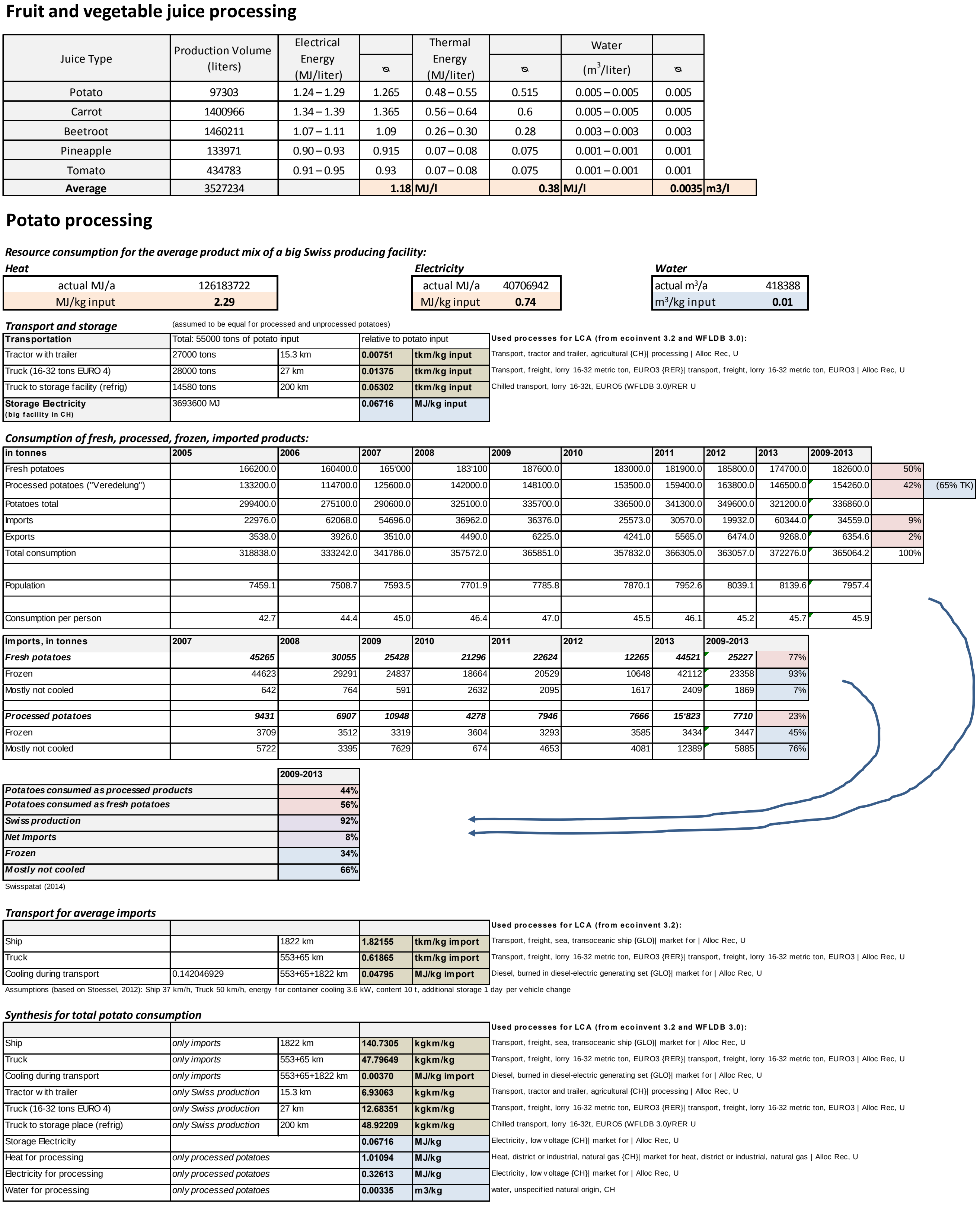
Product: Fresh vegetables, based on net import shares from Scherer and Pfister (2016)

Destination (truck)	Distance [km]	Destination (ship)	Distance [km]	Destination (truck)	Distance	Percentage of Imports
				Slovakia	1044	2%
				Spain (Valencia - Spreitenbach)	1398	13%
				Italy	893	14%
				Germany	729	5%
				Netherlands	812	3%
TOTAL	**-**		**-**		**1053**	**37%**

Table B.9: Assumption on the average air transports for fruit and vegetable imports, based on data from personal communication with a Swiss retailer.

	Consumption CH 2012:		**Share of products imported by air:**	**Average air transport per kg of product:**	
Fresh vegetables:	588'820	t/a	**0.54%**	**35.7**	**kgkm/kg of product**
Exotic and citrus table fruits:	344'991	t/a	**2.17%**	**192.0**	**kgkm/kg of product**

B.3.2.2 Processing



Fruit and vegetable juice processing

Juice Type	Production Volume (liters)	Electrical Energy (MJ/liter)	⌀	Thermal Energy (MJ/liter)	⌀	Water (m^3/liter)	⌀	
Potato	97303	1.24 – 1.29	1.265	0.48 – 0.55	0.515	0.005 – 0.005	0.005	
Carrot	1400966	1.34 – 1.39	1.365	0.56 – 0.64	0.6	0.005 – 0.005	0.005	
Beetroot	1460211	1.07 – 1.11	1.09	0.26 – 0.30	0.28	0.003 – 0.003	0.003	
Pineapple	133971	0.90 – 0.93	0.915	0.07 – 0.08	0.075	0.001 – 0.001	0.001	
Tomato	434783	0.91 – 0.95	0.93	0.07 – 0.08	0.075	0.001 – 0.001	0.001	
Average	3527234		**1.18**	**MJ/l**	**0.38**	**MJ/l**	**0.0035**	**m3/l**

Potato processing

Resource consumption for the average product mix of a big Swiss producing facility:

Heat

actual MJ/a	126183722
MJ/kg input	**2.29**

Electricity

actual MJ/a	40706942
MJ/kg input	**0.74**

Water

actual m^3/a	418388
m^3/kg input	**0.01**

Transport and storage (assumed to be equal for processed and unprocessed potatoes)

Transportation	Total: 55000 tons of potato input		relative to potato input		**Used processes for LCA (from ecoinvent 3.2 and WFLDB 3.0):**
Tractor with trailer	27000 tons	15.3 km	**0.00751**	**tkm/kg input**	Transport, tractor and trailer, agricultural {CH}| processing | Alloc Rec, U
Truck (16-32 tons EURO 4)	28000 tons	27 km	**0.01375**	**tkm/kg input**	Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U
Truck to storage facility (refrig)	14580 tons	200 km	**0.05302**	**tkm/kg input**	Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U
Storage Electricity **(big facility in CH)**	3693600 MJ		**0.06716**	**MJ/kg input**	

Consumption of fresh, processed, frozen, imported products:

in tonnes	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2009-2013**		
Fresh potatoes	166200.0	160400.0	165'000	183'100	187600.0	183000.0	181900.0	185800.0	174700.0	182600.0	50%	
Processed potatoes ("Veredelung")	133200.0	114700.0	125600.0	142000.0	148100.0	153500.0	159400.0	163800.0	146500.0	154260.0	42%	(65% TK)
Potatoes total	299400.0	275100.0	290600.0	325100.0	335700.0	336500.0	341300.0	349600.0	321200.0	336860.0		
Imports	22976.0	62068.0	54696.0	36962.0	36376.0	25573.0	30570.0	19932.0	60344.0	34559.0	9%	
Exports	3538.0	3926.0	3510.0	4490.0	6225.0	4241.0	5565.0	6474.0	9268.0	6354.6	2%	
Total consumption	318838.0	333242.0	341786.0	357572.0	365851.0	357832.0	366305.0	363057.0	372276.0	365064.2	100%	
Population	7459.1	7508.7	7593.5	7701.9	7785.8	7870.1	7952.6	8039.1	8139.6	7957.4		
Consumption per person	42.7	44.4	45.0	46.4	47.0	45.5	46.1	45.2	45.7	45.9		

Imports, in tonnes	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2009-2013**	
Fresh potatoes	***45265***	***30055***	***25428***	***21296***	***22624***	***12265***	***44521***	***25227***	77%
Frozen	44623	29291	24837	18664	20529	10648	42112	23358	93%
Mostly not cooled	642	764	591	2632	2095	1617	2409	1869	7%
Processed potatoes	***9431***	***6907***	***10948***	***4278***	***7946***	***7666***	***15'823***	***7710***	23%
Frozen	3709	3512	3319	3604	3293	3585	3434	3447	45%
Mostly not cooled	5722	3395	7629	674	4653	4081	12389	5885	76%

	2009-2013
Potatoes consumed as processed products	**44%**
Potatoes consumed as fresh potatoes	**56%**
Swiss production	**92%**
Net Imports	**8%**
Frozen	**34%**
Mostly not cooled	**66%**

Swisspatat (2014)

Transport for average imports

					Used processes for LCA (from ecoinvent 3.2):
Ship		1822 km	**1.82155**	**tkm/kg import**	Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U
Truck		553+65 km	**0.61865**	**tkm/kg import**	Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U
Cooling during transport	0.142046929	553+65+1822 km	**0.04795**	**MJ/kg import**	Diesel, burned in diesel-electric generating set {GLO}| market for | Alloc Rec, U

Assumptions (based on Stoessel, 2012): Ship 37 km/h, Truck 50 km/h, energy for container cooling 3.6 kW, content 10 t, additional storage 1 day per vehicle change

Synthesis for total potato consumption

					Used processes for LCA (from ecoinvent 3.2 and WFLDB 3.0):
Ship	*only imports*	1822 km	**140.7305**	**kgkm/kg**	Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U
Truck	*only imports*	553+65 km	**47.79649**	**kgkm/kg**	Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U
Cooling during transport	*only imports*	553+65+1822 km	**0.00370**	**MJ/kg import**	Diesel, burned in diesel-electric generating set {GLO}| market for | Alloc Rec, U
Tractor with trailer	*only Swiss production*	15.3 km	**6.93063**	**kgkm/kg**	Transport, tractor and trailer, agricultural {CH}| processing | Alloc Rec, U
Truck (16-32 tons EURO 4)	*only Swiss production*	27 km	**12.68351**	**kgkm/kg**	Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U
Truck to storage place (refrig)	*only Swiss production*	200 km	**48.92209**	**kgkm/kg**	Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U
Storage Electricity			**0.06716**	**MJ/kg**	Electricity, low voltage {CH}| market for | Alloc Rec, U
Heat for processing	*only processed potatoes*		**1.01094**	**MJ/kg**	Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U
Electricity for processing	*only processed potatoes*		**0.32613**	**MJ/kg**	Electricity, low voltage {CH}| market for | Alloc Rec, U
Water for processing	*only processed potatoes*		**0.00335**	**m3/kg**	water, unspecified natural origin, CH

Figure B.6: Calculation of the environmental impacts of juice and potato processing, based on data from Walker et al. (2017). Data for juice production is used for the approximation of fruit juice, exotic fruit juice, canned fruit, and partly for processed vegetable production (see Tables B.32 and B.33). Data for potato processing is weighted for average Swiss consumption, considering processed and fresh potatoes. Potato transport is based on Stoessel et al. (2012) and Swisspatat (2014), considering the main three import countries (Israel, France, Netherlands; see Table B.8) and Swiss production. Cooling is only modelled for frozen potatoes ("TK").

Processing of dairy, oils, coffee, and chocolate

Weighing of LCA datasets for the processing of different food products

Milk, other dairy		Consumption (SBV, 2014) in kg/p/a	Weighing	Comments
milk, UHT, 3.5% fat, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	462.7	**50.6%**	consumption in raw milk equivalents
cream, 25% fat, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	77.4	**8.5%**	assuming half consumption with 25% fat, half with 29% fat
cream, 29% fat, at dairy/kg milk equivalent, ONLY processing/CH U	(ZHAW)	77.4	**8.5%**	assuming half consumption with 25% fat, half with 29% fat
curd, low- to semi-fat, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	111.9	**12.2%**	consumption in raw milk equivalents
yoghurt, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	185.4	**20.3%**	consumption in raw milk equivalents
TOTAL		914.8	**100.0%**	

Cheese, whey		Consumption (SBV, 2014) in kg/p/a	Weighing	Comments
fresh cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	4.3	**4.0%**	consumption in raw milk equivalents
soft cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	30.6	**28.3%**	consumption in raw milk equivalents
semi-hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	14.6	**13.5%**	consumption in raw milk equivalents
hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U	(ZHAW)	58.6	**54.2%**	consumption in raw milk equivalents
TOTAL		108.0	**100.0%**	

Vegetal oils and fats	Consumption (SBV, 2014) in kg/p/a	Weighing	Comments
Rapeseed oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U	397.5	**54.7%**	
Olive oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U	46.2	**6.4%**	using average of processes from WFLDB and ZHAW
olive oil, extra-virgin, at oil mill, bottled; ONLY processing at oil mill/in IT U (ecoinvent)	46.2	**6.4%**	using average of processes from WFLDB and ZHAW
Sunflower oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U	97.0	**13.4%**	
Palm oil, refined {GLO}| palm oil refinery operation | Alloc Rec, U, ONLY processing, per kg of refined oil (ecoinvent)	139.8	**19.2%**	
TOTAL	726.8	**100.0%**	

Cocoa, coffee, tea	Consumption (SBV, 2014) in kg/p/a	Weighing	Comments
Coffee	11.4	**51.2%**	processing included in agricultural production
Tea	6.1	**27.3%**	impacts from processing not considered
Dark chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U	2.4	**10.7%**	assuming half of the consumption dark, half milk chocolate
Milk chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U	2.4	**10.7%**	assuming half of the consumption dark, half milk chocolate
TOTAL	22.2	**100.0%**	

Figure B.7: The environmental impacts from processing of dairy, oils, coffee, and chocolate are based on data from *ecoinvent*, the *World Food LCA Database*, and from *ZHAW*, and weighted according to Swiss consumption (SBV, 2014). The table shows the datasets and their weighing.

B.3.2.3 Household shopping

The main four means of transport for shopping (car, bus, tram, bicycle) are modelled, covering 89% of the shopping tours. The distances are based on data from the *Swiss Federal Statistical Office* (BFS, 2012). Half of all the rides for shopping are assumed to be done for food purchases and allocated to food products proportionally to mass. The distances per kg of food are shown in Table B.10.

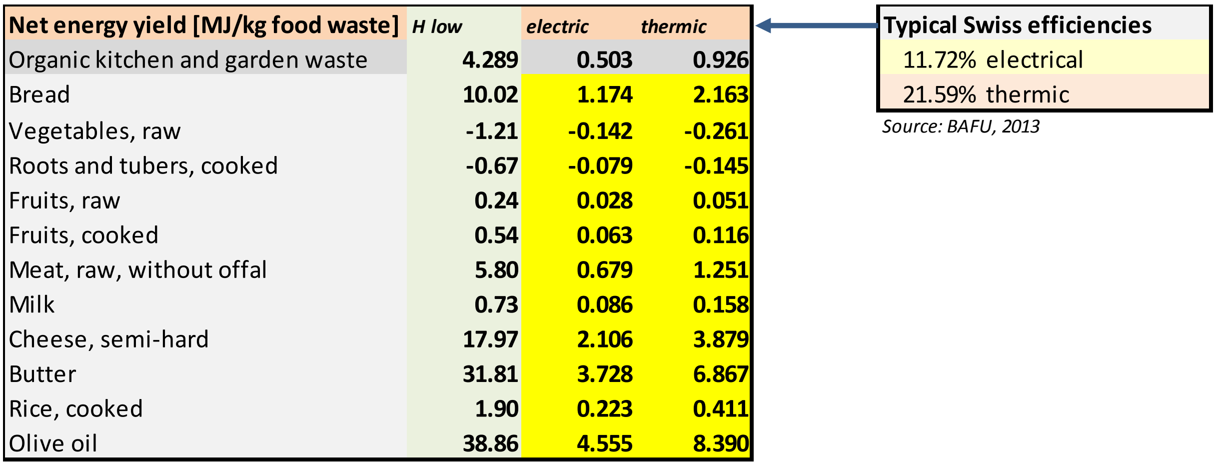
Table B.10: Average householders' shopping distances per kg of food for the main four means of transport; the average number of people per car on shopping tours is 1.64 (BFS, 2012).

Means of transport	Distance	Dataset from ecoinvent 3.2
	[pkm/kg of food]	
Car	**1.11**	Transport, passenger car [RER]| processing | Alloc Rec, U
Bus & Tram	**0.14**	Transport, regular bus [CH]| market for | Alloc Rec, U
	0.14	Transport, tram [CH]| market for | Alloc Rec, U
Bicycle	**0.03**	Transport, passenger, bicycle [CH]| processing | Alloc Rec, U

B.3.3 Food waste treatment

B.3.3.1 Incineration

For incineration with municipal solid waste (MSW) ecoinvent 3.2 data is used for average bio-waste (mixture of garden, yard, food, and kitchen waste) which goes to disposal as part of communal waste mixture (Frischknecht et al., 2003). However, heat and electricity substitution is modelled proportionally to the lower heating value of the different food categories (Schmidt et al., 2007, BLV, 2014). For the electric efficiency of the plant we model the Swiss average of 12.6% and for the thermal efficiency 23.3% (BAFU, 2013). MSW transport is modelled with 21 metric ton collection lorry and 3.1 km (Schleiss, 2015).



Net energy yield [MJ/kg food waste]	*H low*	*electric*	*thermic*
Organic kitchen and garden waste	4.289	0.503	0.926
Bread	10.02	1.174	2.163
Vegetables, raw	-1.21	-0.142	-0.261
Roots and tubers, cooked	-0.67	-0.079	-0.145
Fruits, raw	0.24	0.028	0.051
Fruits, cooked	0.54	0.063	0.116
Meat, raw, without offal	5.80	0.679	1.251
Milk	0.73	0.086	0.158
Cheese, semi-hard	17.97	2.106	3.879
Butter	31.81	3.728	6.867
Rice, cooked	1.90	0.223	0.411
Olive oil	38.86	4.555	8.390

Typical Swiss efficiencies
11.72% electrical
21.59% thermic

Source: BAFU, 2013

Figure B.8: Calculation of the energy that is substituted with the energy produced from the incineration of different types of FW. The values with yellow background are calculated with the typical average efficiencies of Swiss incineration facilities (BAFU, 2013), based on the lower heating value of the waste *(H low)*. *H low* is calculated from the protein, fat, carbohydrate, and water content of the substrates (BLV, 2014) with the following formula:

$$\boldsymbol{H\ low = P * 23\frac{MJ}{kg} + F * 38.9\frac{MJ}{kg} + C * 17.2\frac{MJ}{kg} - 2.441\frac{MJ}{kg} * W} \tag{B.1}$$

with P = protein content, F = fat content, C = carbohydrate content, W = water content in [%].

B.3.3.2 Centralized composting

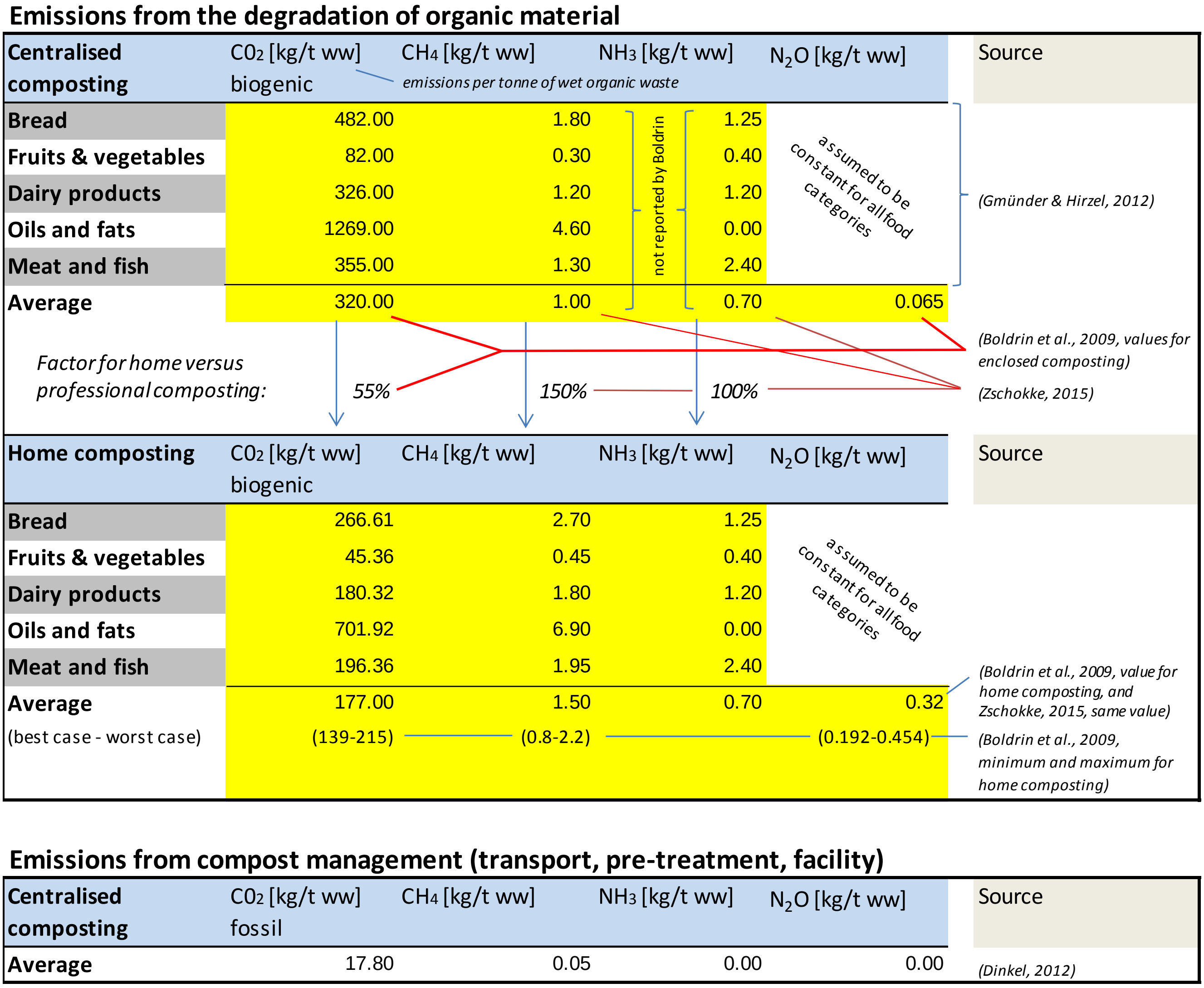
Centralized composting is modeled with a dataset from BFE (2011) referring to a typical Swiss mix of enclosed and open windrow composting. The dataset includs infrastructure of the facility and fossil emissions from management. The potential for fertilizer substitution is based on Boldrin et al. (2009) and Møller et al. (2009). They assume utilization rates (the fractions of the nutrients that can replace inorganic fertilizers, which are dependent on the plant availability of the nutrients) of 20% for N and 100% each for P and K, leading to 2.85 kg N, 2.86 kg P_2O_5, and 4.68 kg K_2O that can be substituted per tonne of wet waste. The yield from 1 kg of FW is estimated 0.4 kg of compost (Andersen et al., 2010). The CO_2, CH_4, and NH_3 emissions from the degradation of organic material are modeled as biogenic emissions since they consist of short-cycle carbon (Christensen et al., 2009). These emissions are adapted to individual food categories (bread, dairy, fruits and vegetables, oils and fats, and meat and fish) based on Gmünder and Hirzel (2012). The N_2O emissions are modeled with a constant average value for enclosed biowaste composting (65 g/t of wet waste) (Boldrin et al., 2009) (see Figure B.9). Improved soil effect is modeled assuming an average between maximum and minimum compost densities so that a tonne of compost can substitute 0.6 tonnes of peat (average between 0.2 and 1 t) for the use in growth media (Møller et al., 2009). Heavy metal emissions are based on vegetable waste analyzes in Denmark (Boldrin et al., 2011). However, in theory only heavy metals from pesticide application and food processing should be considered. Heavy metals originating from atmospheric deposition or taken up from soil during plant growth are not attributable to FW, because they are in a closed cycle. Therefore, the impacts of heavy metals from composting may be over-estimated. Typical transport distances of biowaste collection are estimated 3.5 km for the collection tour plus 2x0.5 km from the village to the composting facility (Schleiss, 2015).

B.3.3.3 Spreading on fields

For fruits and vegetables lost in agricultural production and **spreaded on fields** we model the biogenic emissions equally to centralized composting, since generally the remains on the fields are well spread and therefore decomposed mainly under oxic conditions. Fertilizer substitution is modeled in the same way as centralized composting, because the nutrients mainly remain on the agricultural fields. Potentially improved soil effects are not considered. Heavy metal emissions are modeled neither, since there is no input from outside of the fields (Schleiss, 2015, Zschokke, 2015).

B.3.3.4 Home composting

Regarding composted household FW, 60% is estimated to be collected from municipalities and treated in centralized composting plants and 40% used for **home composting** in the householders' gardens (Kohler, 2015, Schleiss, 2015). For home composting we model suboptimal average conditions leading to higher estimated methane emissions (150%) compared to centralized composting; N_2O emissions are modeled with 323 g/t of wet waste (Boldrin et al., 2009, Schleiss, 2015). One kilo of home compost with average density is estimated to potentially replace 0.285 kg of peat for a similar effect on soil quality. However, we only model 21% peat substitution according to a survey in Denmark where 21% of the compost users actually replace peat when applying compost in their gardens (Andersen et al., 2012). For fertilizer substitution from home compost we model 18% of the potential substitution according to a survey in Denmark where 18% of the compost users actually replace fertilizers when applying compost in their gardens (Andersen et al., 2010).



Emissions from the degradation of organic material

Centralised composting	CO_2 [kg/t ww] biogenic	CH_4 [kg/t ww]	NH_3 [kg/t ww]	N_2O [kg/t ww]	Source
Bread	482.00	1.80	1.25	assumed to be constant for all food categories	(Gmünder & Hirzel, 2012)
Fruits & vegetables	82.00	0.30	0.40		
Dairy products	326.00	1.20	1.20		
Oils and fats	1269.00	4.60	0.00		
Meat and fish	355.00	1.30	2.40		
Average	320.00	1.00	0.70	0.065	(Boldrin et al., 2009, values for enclosed composting)

emissions per tonne of wet organic waste

not reported by Boldrin

Factor for home versus professional composting:	55%	150%	100%		(Zschokke, 2015)

Home composting	CO_2 [kg/t ww] biogenic	CH_4 [kg/t ww]	NH_3 [kg/t ww]	N_2O [kg/t ww]	Source
Bread	266.61	2.70	1.25	assumed to be constant for all food categories	
Fruits & vegetables	45.36	0.45	0.40		
Dairy products	180.32	1.80	1.20		
Oils and fats	701.92	6.90	0.00		
Meat and fish	196.36	1.95	2.40		
Average	177.00	1.50	0.70	0.32	(Boldrin et al., 2009, value for home composting, and Zschokke, 2015, same value)
(best case - worst case)	(139-215)	(0.8-2.2)		(0.192-0.454)	(Boldrin et al., 2009, minimum and maximum for home composting)

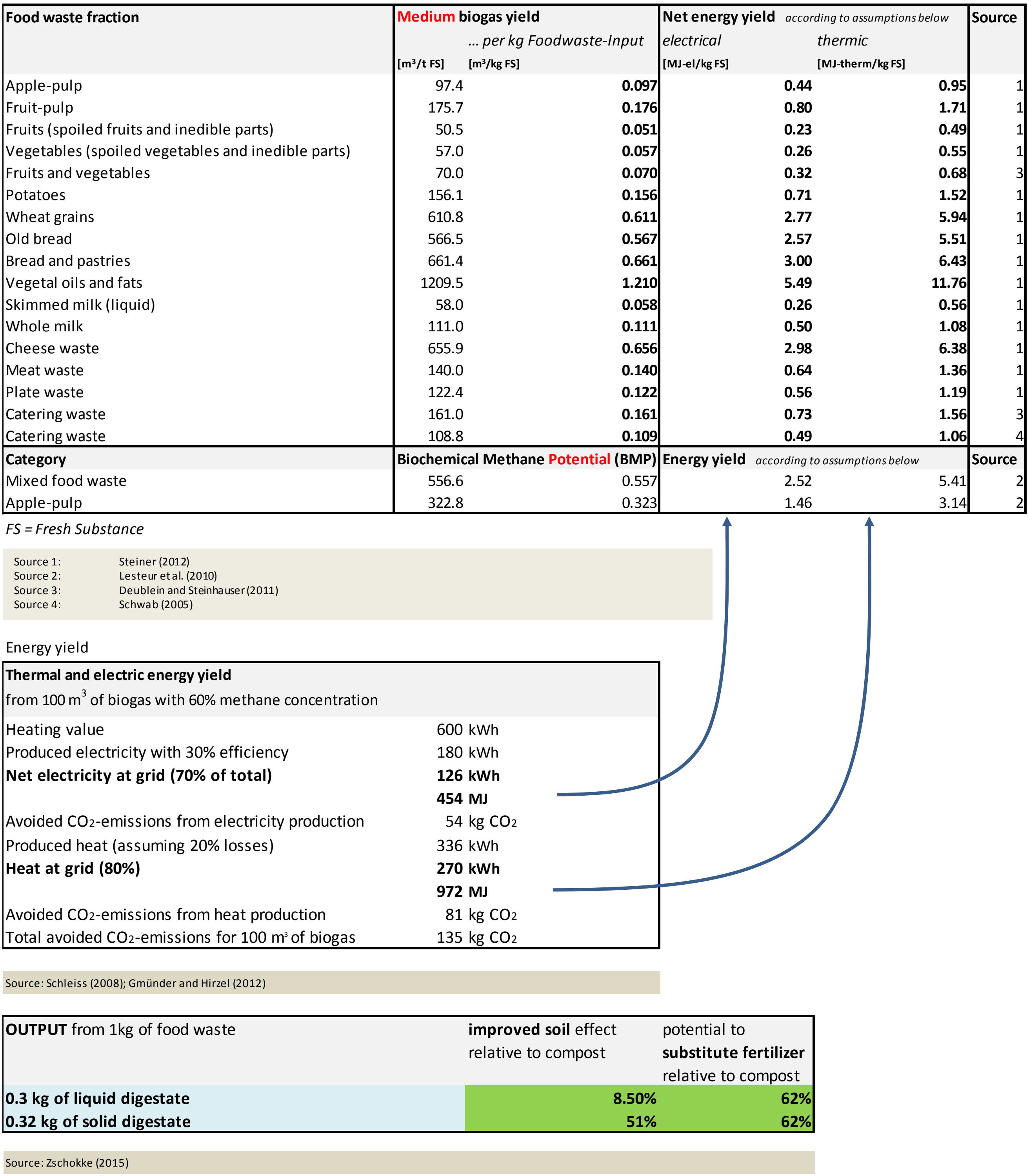
Emissions from compost management (transport, pre-treatment, facility)

Centralised composting	CO_2 [kg/t ww] fossil	CH_4 [kg/t ww]	NH_3 [kg/t ww]	N_2O [kg/t ww]	Source
Average	17.80	0.05	0.00	0.00	(Dinkel, 2012)

Figure B.9: Modelled emissions from the degradation of the organic material and from management in the case of centralized composting (typical Swiss mix of enclosed and open windrow composting) and home composting (with range for best and worst case).

B.3.3.5 *Anaerobic digestion*

Anaerobic digestion is based on a dataset from BFE (2011). The output from 1 kg of average FW is modeled with 0.3 kg of liquid and 0.32 kg of solid digestate (Schleiss, 2015). The emissions and the amount of electricity and heat that can be substituted are modeled proportionally to the medium biogas yields of the various food categories (Figure B.10). The average energy yield from 100 m³ of biogas is estimated 454 MJ of electricity at grid and 972 MJ of heat (Schleiss, 2008). Heavy metal emissions and waste collection are modeled equally to composting. The improved soil effect for solid digestate application is estimated 51% of the application of compost from centralized composting, for liquid digestate application 8.5%, and the amount of P_2O_5 and K_2O fertilizer that can be substituted 62% compared to compost. For nitrogen fertilizer 2.5 kg can be substituted by a ton of liquid digestate and 1.94 kg by a ton of solid digestate (BFE, 2011, Zschokke, 2015).



Food waste fraction	Medium biogas yield [m³/t FS]	... per kg Foodwaste-Input [m³/kg FS]	Net energy yield *according to assumptions below* *electrical* [MJ-el/kg FS]	*thermic* [MJ-therm/kg FS]	Source
Apple-pulp	97.4	**0.097**	**0.44**	**0.95**	1
Fruit-pulp	175.7	**0.176**	**0.80**	**1.71**	1
Fruits (spoiled fruits and inedible parts)	50.5	**0.051**	**0.23**	**0.49**	1
Vegetables (spoiled vegetables and inedible parts)	57.0	**0.057**	**0.26**	**0.55**	1
Fruits and vegetables	70.0	**0.070**	**0.32**	**0.68**	3
Potatoes	156.1	**0.156**	**0.71**	**1.52**	1
Wheat grains	610.8	**0.611**	**2.77**	**5.94**	1
Old bread	566.5	**0.567**	**2.57**	**5.51**	1
Bread and pastries	661.4	**0.661**	**3.00**	**6.43**	1
Vegetal oils and fats	1209.5	**1.210**	**5.49**	**11.76**	1
Skimmed milk (liquid)	58.0	**0.058**	**0.26**	**0.56**	1
Whole milk	111.0	**0.111**	**0.50**	**1.08**	1
Cheese waste	655.9	**0.656**	**2.98**	**6.38**	1
Meat waste	140.0	**0.140**	**0.64**	**1.36**	1
Plate waste	122.4	**0.122**	**0.56**	**1.19**	1
Catering waste	161.0	**0.161**	**0.73**	**1.56**	3
Catering waste	108.8	**0.109**	**0.49**	**1.06**	4
Category	**Biochemical Methane Potential (BMP)**		**Energy yield** *according to assumptions below*		**Source**
Mixed food waste	556.6	0.557	2.52	5.41	2
Apple-pulp	322.8	0.323	1.46	3.14	2

FS = Fresh Substance

Source 1:	Steiner (2012)
Source 2:	Lesteur et al. (2010)
Source 3:	Deublein and Steinhauser (2011)
Source 4:	Schwab (2005)

Energy yield

Thermal and electric energy yield from 100 m³ of biogas with 60% methane concentration	
Heating value	600 kWh
Produced electricity with 30% efficiency	180 kWh
Net electricity at grid (70% of total)	**126 kWh**
	454 MJ
Avoided CO_2-emissions from electricity production	54 kg CO_2
Produced heat (assuming 20% losses)	336 kWh
Heat at grid (80%)	**270 kWh**
	972 MJ
Avoided CO_2-emissions from heat production	81 kg CO_2
Total avoided CO_2-emissions for 100 m³ of biogas	135 kg CO_2

Source: Schleiss (2008); Gmünder and Hirzel (2012)

OUTPUT from 1kg of food waste	**improved soil** effect relative to compost	potential to **substitute fertilizer** relative to compost
0.3 kg of liquid digestate	**8.50%**	**62%**
0.32 kg of solid digestate	**51%**	**62%**

Source: Zschokke (2015)

Figure B.10: Average electrical and thermal yield of typical Swiss AD plants (Dinkel et al., 2012) and differentiation of these average yields by food categories proportionally to medium biogas yields reported from literature (Schwab, 2005, Lesteur et al., 2010, Deublein and Steinhauser, 2011, Steiner, 2012). The bottom table quantifies the average estimated effects of improved soil and fertilizer substitution from digestate application relative to compost from professional composting plants (Zschokke, 2015).

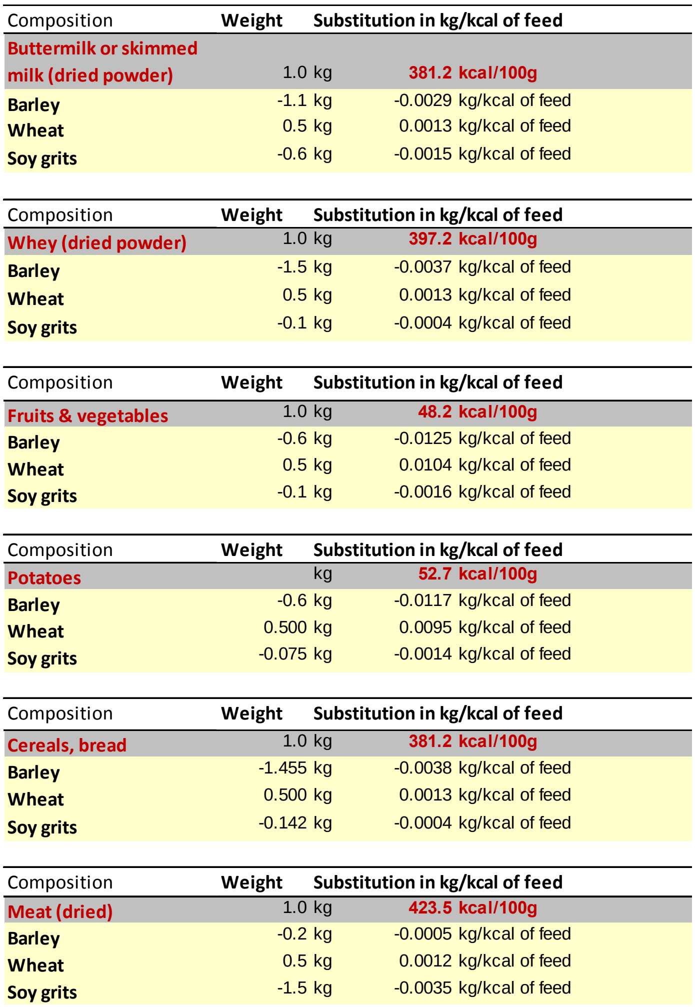
Table B.11: Modelled emissions from anaerobic digestion, based on Dinkel et al. (2012).

Anaerobic digestion	CO_2 fossil [kg/m³ biogas]	CH_4 [kg/m³ biogas]	NH_3 [kg/m³ biogas]	N_2O [kg/m³ biogas]
Average	16.6	0.0101	0	0.00033

B.3.3.6 Animal feeding

We modeled **animal feeding** for swine since this is the most common use of feed from FW in Switzerland (SBV, 2016). The substitution of forage (agricultural production and transport) is modeled with an optimization tool based on (Vadenbo et al., 2016) and Gmünder and Hirzel (2012). For six food categories (fruits and vegetables, whey, milk, cereals, potatoes, dried meat) an optimal feed mixture of barley, wheat, soy grits, phosphate, and lysine supplements is defined that reduces maximally the GHG impacts without exceeding the nutrients of the FW. The nutrients that are considered are raw fibres, proteins, energy, lysine, and phosphorus metabolisable for swine. For each of the 33 food categories modeled in this study one of the above mentioned six categories is attributed and the corresponding feed mix modeled for substitution, considering the energy content of the FW (an inventory of the substituted feed mix for each food category can be found in section B.21). The feed substituted by feeding cheese (247 kcal/100g), buttermilk (11 kcal/100g), and butter (282 kcal/100g) is modeled proportionally to the energy content of raw milk (67 kcal/100g). The modeled substitution of barley and soy grits by milk and dairy products does not consider that the nutritional quality of dairy proteins may be higher compared to soy and barley and may therefore underestimate the environmental credits for using dairy products for feeding. The energy contents are based on SBV (2013) and Beretta et al. (2013) and the environmental impacts of the fodder substituted are modeled with *ecoinvent 3.2* data. Heavy metal impacts are modeled equally to composting, since in both cases they are introduced into the agricultural system.

Table B.12: Feed substitution by different types of FW, adapted from Gmünder and Hirzel (2012) and Vadenbo et al. (2016). The composition of the feed that is substituted is the optimal mix of the three feed components barley, wheat, and soybean meal. The optimization is completed in order to maximize the GHG reduction by substitution of the feed mix. The result is equal to a maximization of cost savings. Negative values refer to the substitution of feed components; positive values mean supplementation of FW. Supplements are limited up to a maximum of 50% the amount of the FW for feeding. The substituted feed mix is not allowed to exceed any of the nutrients of the corresponding FW, including supplements. The following nutrients are considered: energy, proteins, phosphorus, and lysine metabolizable for swine.



Composition	Weight	Substitution in kg/kcal of feed
Buttermilk or skimmed milk (dried powder)	1.0 kg	**381.2 kcal/100g**
Barley	-1.1 kg	-0.0029 kg/kcal of feed
Wheat	0.5 kg	0.0013 kg/kcal of feed
Soy grits	-0.6 kg	-0.0015 kg/kcal of feed

Composition	Weight	Substitution in kg/kcal of feed
Whey (dried powder)	1.0 kg	**397.2 kcal/100g**
Barley	-1.5 kg	-0.0037 kg/kcal of feed
Wheat	0.5 kg	0.0013 kg/kcal of feed
Soy grits	-0.1 kg	-0.0004 kg/kcal of feed

Composition	Weight	Substitution in kg/kcal of feed
Fruits & vegetables	1.0 kg	**48.2 kcal/100g**
Barley	-0.6 kg	-0.0125 kg/kcal of feed
Wheat	0.5 kg	0.0104 kg/kcal of feed
Soy grits	-0.1 kg	-0.0016 kg/kcal of feed

Composition	Weight	Substitution in kg/kcal of feed
Potatoes	kg	**52.7 kcal/100g**
Barley	-0.6 kg	-0.0117 kg/kcal of feed
Wheat	0.500 kg	0.0095 kg/kcal of feed
Soy grits	-0.075 kg	-0.0014 kg/kcal of feed

Composition	Weight	Substitution in kg/kcal of feed
Cereals, bread	1.0 kg	**381.2 kcal/100g**
Barley	-1.455 kg	-0.0038 kg/kcal of feed
Wheat	0.500 kg	0.0013 kg/kcal of feed
Soy grits	-0.142 kg	-0.0004 kg/kcal of feed

Composition	Weight	Substitution in kg/kcal of feed
Meat (dried)	1.0 kg	**423.5 kcal/100g**
Barley	-0.2 kg	-0.0005 kg/kcal of feed
Wheat	0.5 kg	0.0012 kg/kcal of feed
Soy grits	-1.5 kg	-0.0035 kg/kcal of feed

Table B.13: Types of feed (right table) that were used for the approximation of the feed mix that can be substituted by FW from individual food categories (left table). The quantities of the feed mix that can be substituted are modelled proportionally to the energy content of the FW and the feed used for the approximation. For cheese (16.1) and butter (17.1) the losses in agricultural production are modelled with raw milk, the losses in the processing stage with whey and buttermilk (displayed in this table) and the losses after processing with the amount of raw milk which has the same calories as the wasted cheese and butter.

Food category	Energy content of final product in kcal/100g	Feed for approximation (calorie-adapted):
1.1 Table apples	52.5	Fruits and vegetables
1.2 Apple juice	46.0	Fruits and vegetables
2.1 Other fresh table fruits	51.7	Fruits and vegetables
2.2 Other fresh fruit juices	49.6	Fruits and vegetables
3.1 Berries	37.6	Fruits and vegetables
3.2 Exotic and citrus table fruits	32.9	Fruits and vegetables
3.3 Exotic and citrus fruit juices	34.5	Fruits and vegetables
4 Canned fruits	171.8	Fruits and vegetables
5 Potatoes	55.6	Potatoes
6 Fresh vegetables	19.0	Fruits and vegetables
7.1 Legumes	43.6	Fruits and vegetables
7.2 Other storable vegetables	19.0	Fruits and vegetables
8 Processed vegetables	71.8	Fruits and vegetables
9 Bread and pastries	315.8	Cereals and bread
10 Pasta	308.5	Cereals and bread
11 Rice	347.4	Cereals and bread
12 Maize	240.9	Cereals and bread
13 Sugar	396.4	Cereals and bread
14.1 Vegetal oils and fats	895.5	-
14.2 Nuts, seeds, oleiferous fruits	601.0	-
15.1 Milk, other dairy	66.9	Milk, buttermilk
15.2 Meat co-product from milk	167.1	Dried meat
16.1 Whey (for cheese read methodology)	**34.4**	Dried whey
16.2 Meat co-product from cheese	167.1	Dried meat
17.1 Buttermilk (for butter read methodology)	**33.4**	Milk, buttermilk
17.2 Meat co-product from butter	167.1	Dried meat
18.1 Eggs without co-product poultry	122.1	Milk, buttermilk
18.2 Meat from laying hens	127.1	Dried meat
19 Pork	284.5	Dried meat
20 Poultry	161.7	Dried meat
21 Beef, horse, veal	167.1	Dried meat
22 Fish, shellfish	114.0	Dried meat
23 Cocoa, coffee, tea	370.4	Cereals and bread

B.3.3.7 Disposal into the sewage

The environmental impacts of discarding milk into the **sewage** are modeled based on Schmidtlein et al. (2011), who modeled the environmental impacts of waste water from a dairy plant. With the assumption that all the nitrogen in the waste water is coming from milk and that milk has a nitrogen concentration of 9 g/l (Gmünder and Hirzel, 2012) we deduced the milk concentration in the waste water (1.389%) and scaled the impacts accordingly. Due to lack of data we used the same dataset for discarding juices into the sewer and fish bycatch into water bodies.

B.4 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

B.4.1 Regionalized biodiversity assessment

For the **regionalized biodiversity assessment** of agricultural production, water consumption and its impacts are based on Scherer and Pfister (2016), who deduced potential impacts on biodiversity based on precipitation, net primary production and its fraction that is limited by water availability (Scherer and Pfister, 2016). For **blue water consumption** (irrigation water from surface or groundwater resources) Pfister et al. (2011) first calculate the full irrigation water demand based on the crops' water requirement for optimal growth (deduced from remote sensing) and deduct effective precipitation (green water) on a monthly time scale. It represents the minimum amount of water that would be needed if all cropland was fully irrigated without water losses. In a second step, they multiply this number with the ratio of irrigated to total cropland in the corresponding area. The result is the deficit water demand, which will rather underestimate actual irrigation, because the irrigated area may be larger than reported and because irrigation practice may use more water than needed. Therefore, we use expected water consumption that is approximated as geometric mean of full-irrigation and deficit irrigation (Pfister and Bayer, 2014).

The impact of **land occupation** is assessed with the method of Chaudhary et al. (2015), using the updated country-aggregated characterization factors recommended by UNEP Frischknecht et al. (2016), which consider five taxa (mammals, birds, amphibians, reptiles, and plants). They are multiplied with net production and imports from each country to Switzerland (SBV, 2015, Scherer and Pfister, 2016) and aggregated to the 33 food categories modeled in this study.

For **crop derived products**, such as chocolate, the land and water impacts of their main ingredient are modeled (e.g. cocoa beans in the case of chocolate) (Scherer and Pfister, 2016). In order to avoid double counting where the same crop can produce multiple derived products, economic allocation is applied to attribute the impacts of the root product to the derived products (Scherer and Pfister, 2016). For **livestock products** the cultivation of animal feed is taken into account, distinguishing 16 products and three farming systems (extensive, intensive or mixed) at the global level. Mekonnen and Hoekstra (2012) provide feed conversion efficiencies for livestock, allowing to translate the feed mass into weight of carcass, milk, and eggs (Scherer and Pfister, 2016). The concentrate feed is composed of nine crops (neglecting peas and fish meal) which differ in their fractions according to 3 animal categories (dairy and beef cattle, pigs, and poultry) and six world regions although in reality the composition might differ from country to country or even farm to farm (Scherer and Pfister, 2016). The origin of the feed (main import country) is traced back using EXIOBASE (Wood et al., 2015).

Water and land use impacts of food **processing, storage, transportation,** and **sale** are not modeled.

B.4.1.1 Imports per country and crop to Switzerland

Food imports from 157 countries to Switzerland and domestic production are based on Scherer and Pfister (2016), available for 138 food crops and animal products, and then aggregated to the 33 food categories used in this paper. The obtained values for final consumption in each food category differ from the numbers in the mass flow analysis performed in this study, which is mainly based on SBV (2014). Therefore, we multiply the numbers from Scherer and Pfister (2016) by a correction factor defined for each food category. This may be the main reason why our results may slightly differ from the results published by Scherer and Pfister (2016) (e.g. 33% of final consumption is imported in our study, 36% according to Scherer and Pfister (2016)).

B.4.1.2 Limitations of global biodiversity indicators

Indicators of global biodiversity weigh rare, endemic species more than abundant species. However, ecosystem functions depend on **interactions between species**, implying that rare species, especially at high trophic levels, also depend on the presence of abundant species. Therefore, a final assessment of the impacts of human activities on biodiversity should not *only* consider global, but also regional and local biodiversity. Furthermore it can be argued that also ecosystems without rare, endemic species have important regulating, supporting, provisioning, and cultural functions.

Another limitation of present global biodiversity indicators is that they **only consider a few taxa** (mammals, birds, amphibians, reptiles, and plants) for which species richness has been analyzed in different regions of the world. However, the impacts on other taxa which comprise more species and which include species on lower trophic levels may be different.

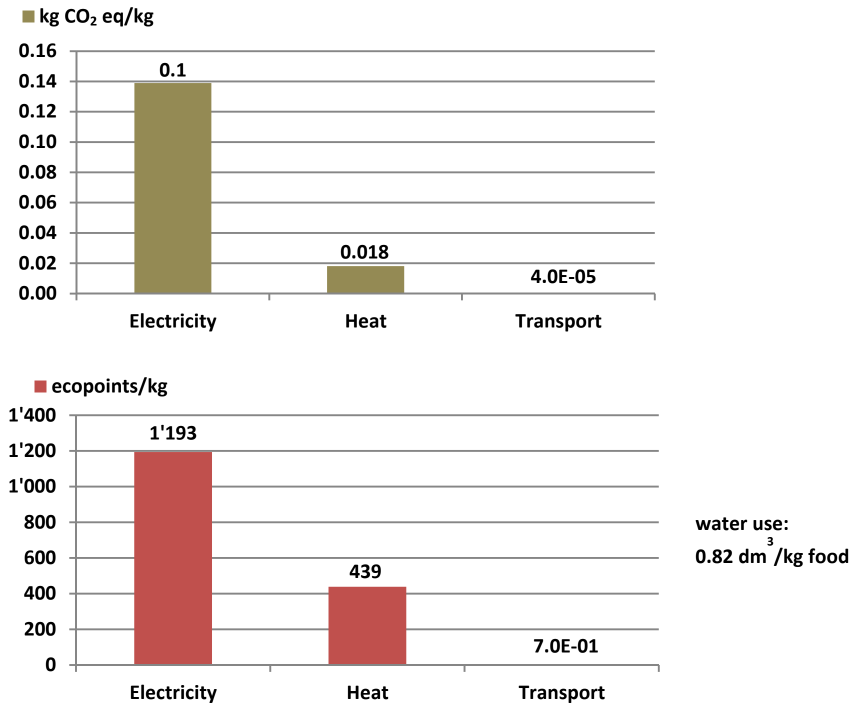
B.4.2 List of environmental indicators integrated in the model

Table B.14: LCIA methods calculated in the model.

LCIA methods	
Land	Land Use
Water	Water Use
Biodiversity	Global Land Biodiversity
Biodiversity	Global Water Biodiviversity
GTP	GTP 100
GWP	GWP 100
Ecological Scarcity 2013	TOTAL ecopoints
->	Water resources
->	Energy resources
->	Mineral resources
->	Land use
->	Global warming
->	Ozone layer depletion
->	Main air pollutants and PM
->	Carcinogenic substances into air
->	Heavy metals into air
->	Water pollutants
->	POP into water
->	Heavy metals into water
->	Pesticides into soil
->	Heavy metals into soil
->	Radioactive substances into air
->	Radioactive substances into water
->	Noise
->	Non radioactive waste to deposit
->	Radioactive waste to deposit
Recipe endpoint	World ReCiPe H/A Single Score
Recipe midpoint	Freshwater eutrophication
Energy (CED 1.09)	CED Total

B.4.3 Impacts of the stages of the food value chain

B.4.3.1 Retail



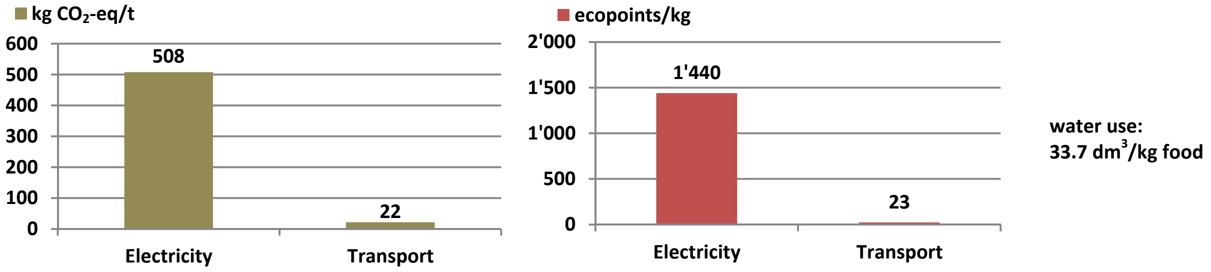
water use:
0.82 dm^3/kg food

Figure B.11: Environmental impacts of retail from electricity (assuming the Swiss electricity mix), heat (assuming natural gas), and transport (assuming freight lorry >32t, Euro 3) in kg CO_2-eq per kg of food and in ecopoints per kg of food (Frischknecht et al., 2013); water use in dm^3/kg of food. The numbers are calculated based on data from a Swiss retailer (Coop, 2015).

Interpretation of Figure B.11:

The main environmental impacts in retail are from electricity consumption; heat is 3-6 times less important and transport only contributes to 0.02-0.04% of the total impacts of retail.

B.4.3.2 Food service



water use:
33.7 dm^3/kg food

Figure B.12: Environmental impacts of food services from electricity (assuming the Swiss electricity mix), transport and water use, expressed in kg CO_2-eq per ton of food and in ecopoints per kg of food (Frischknecht et al., 2013). Based on SV Group AG (SV_Group_AG, 2017) we estimate that half of the products are from the main supplier (90 km via 18t cooled EURO 3 lorry) and the rest from minor suppliers (45 km by 3.5-18t EURO 3 lorries, 50% cooled) and that the average water use of food services is 33.7 dm^3/kg food.

Interpretation of Figure B.12:

a) The numbers are based on the catering company *SV Group AG,* who estimates that 20% of electricity consumption in their restaurants is used for cooking, 20% for cooling, 15% for ventilation, 17% for lightening, 5% for cleaning, and 13% for other activities.

b) Transport is much less important than the impacts at the restaurants (1-3% of total impacts of food services).

B.4.3.3 Households

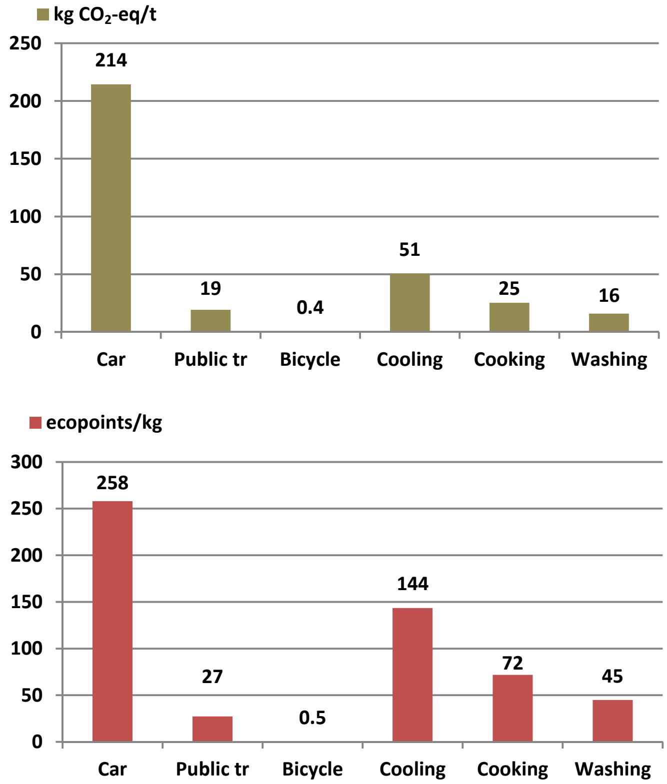


Figure B.13: Environmental impacts of average Swiss households in kg CO_2-eq per ton of food and in ecopoints per kg of food (Frischknecht et al., 2013) for the following activities: shopping by car, shopping by public transport, shopping by bicycle, cooling and storage, cooking and baking, and dish washing. Water use is not considered.

Interpretation of Figure B.13:

a) Since about 70% of the distance for shopping is done by car (BFS, 2012) and since **cars** have **higher environmental impacts per km than trams and buses (10-35% of cars)** and **bicycles (4-6% of cars)**, shopping by car is responsible for most of the food related environmental impacts of households (66% by GHG impacts and 47% by ecopoints).

b) From the food related activities at home cooling has the highest impacts, followed by cooking and baking and by dish washing.

B.4.4 Impacts of food waste treatment

B.4.4.1 Composting

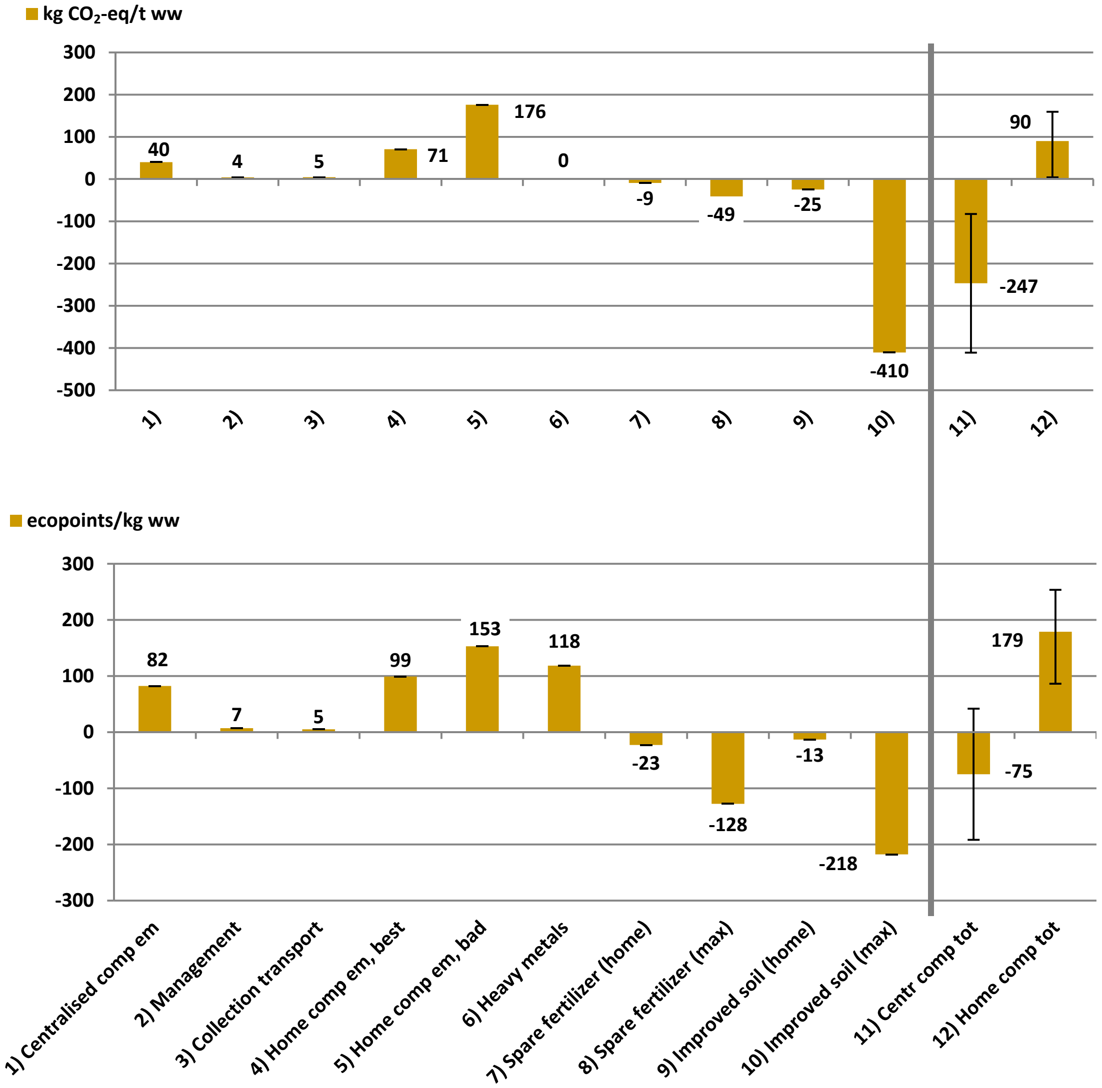


Figure B.14: Global warming (top graph) and ecopoints (ecological scarcity 2013, bottom graph) from different components and practices of FW composting. Numbers refer to the treatment of 1 kg of wet waste (ww) and to an average mix of FW. Abbreviations: comp = composting, centr = centralized, em = emissions, tot = total.

Interpretation of Figure B.14:

1) Centralized composting shows the biogenic emissions of a typical **Swiss mix of enclosed and open windrow composting**.
2) Management shows the impacts of the compost **facility and its management**.
3) **Collection transport** is based on the estimation of 3.5 km for the collection tour plus 2x0.5 km from the village to the composting facility (Schleiss, 2015).
4) -5) Emissions of **best and bad practice home composting** are based on Boldrin et al. (2009). In this paper's model we use average values between best and bad practice.
6) **Heavy metal** emissions are based on vegetable waste analyzes in Denmark (Boldrin et al., 2011). Since the origin of the metals is unknown, also metals from agricultural provenience may be included (-> closed cycle, no net emission -> potential over-estimation).
7) Benefits from the **substitution of inorganic fertilizers in home composting** are based on a survey in Denmark where 18% of the compost users actually replace fertilizers when applying compost in their gardens(Andersen et al., 2010). Thus, for home composting we model 18% of the substitution rate in centralized composting.
8) **Fertilizer substitution in centralized composting** is based on Boldrin et al. (2009) and Møller et al. (2009). They assume utilization rates (the fractions of the nutrients that can replace inorganic fertilizers, which is dependent on the availability of the nutrients) of 20% for N and 100% each for P and K, leading to 2.85 kg N, 2.86 kg P_2O_5, and 4.68 kg K_2O that can potentially be substituted per ton of composted wet waste (Andersen et al., 2010).
9) **Improved soil effect from home compost**, assuming that 1 kg of home compost with average density can potentially replace 0.285 kg of peat for a similar effect on soil quality. From this, 21% peat substitution is modeled, based on a survey in Denmark where 21% of the compost users actually replace peat when applying compost in their gardens (Andersen et al., 2012).
10) **Maximum potential improved soil effect**, if 1 kg of compost substitutes 1 kg of peat. However, in this paper we model 60% of the maximum potential, since we assume average compost densities so that 1 kg of compost from centralized composting can substitute an average between 0.2 and 1 kg of peat for the use in growth media (Møller et al., 2009).

7)-10) The potential benefits from fertilizer substitution and the improved soil effect are **only justified if appropriate incentives and guidance on the good use of manure and compost are provided**. Otherwise a higher compost and digestate availability may rather lead to eutrophication than to the substitution of resources (Gebert, 2015).

11) **Total** net impact of **centralized composting**, including environmental credits from substitution. Error bars show best case (50% heavy metal impacts, 1:1 substitution of peat with compost) and worst case (100% heavy metal impacts, 20% peat substitution).
12) **Total** net impact of **home composting**, including environmental credits from product substitution. a) shows best case (50% heavy metal impacts, 2x18% of compost users replacing fertilizer and 2x21% peat) and b) bad case (100% heavy metal impacts, 0.5x18% of compost users replacing fertilizer and 0.5x21% peat).

B.4.4.2 Anaerobic digestion

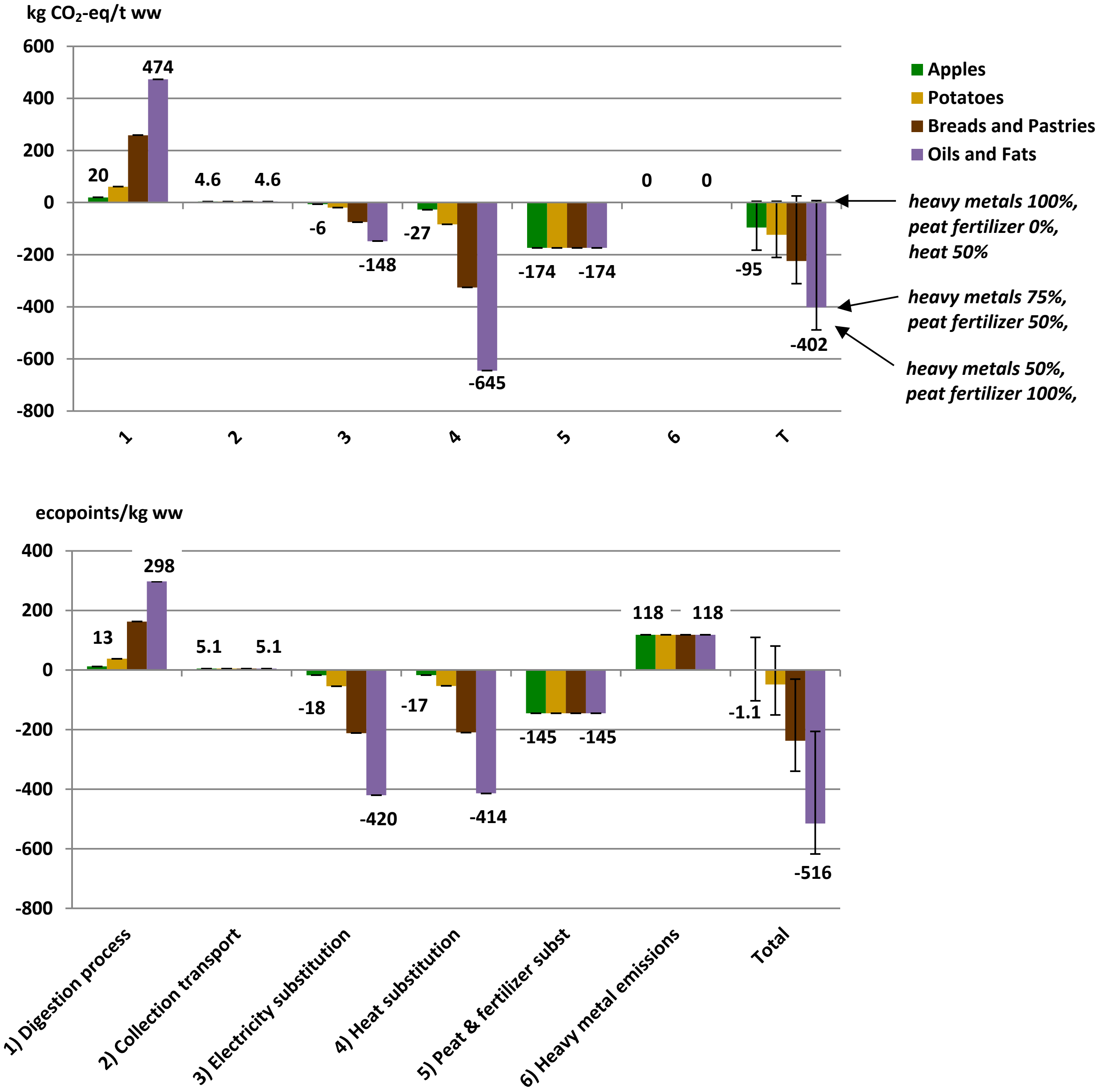


Figure B.15: Global warming (top graph) and ecopoints (ecological scarcity 2013, bottom graph) from different components of anaerobic digestion of different food categories. Numbers refer to the treatment of 1 kg of wet waste (ww).

Interpretation of Figure B.15:

1) Emissions from the **process of anaerobic digestion**, including environmental exchanges due to bio-waste pre-treatment (including the disposal of contaminants), biowaste digestion, and post-composting of digested matter.
2) Impacts from **collection and transport** of bio-waste, based on the estimation of 3.5 km for the collection tour plus 2x0.5 km from the village to the composting facility (Schleiss, 2015).
3) Credits for the **substitution of electricity (Swiss electricity mix)**, assuming 20% losses and 80% yield at grid (454 MJ from 100 m^3 of biogas with 60% methane concentration) (Schleiss, 2008).
4) Credits for the **substitution of district or industrial heat from natural gas**, assuming 30% efficiency and 70% yield at grid (972 MJ from 100 m^3 of biogas with 60% methane concentration) (Schleiss, 2008).
5) **Peat and fertilizer substitution** from the application of liquid and solid digestate. The improved soil effect for solid digestate application is estimated 51% of compost application from centralized composting, for liquid digestate application 8.5%, and the amount of P_2O_5 and K_2O fertilizer that can be substituted 62% compared to compost. For nitrogen fertilizer, 2.5 kg can be substituted by a ton of liquid digestate and 1.94 kg by a ton of solid digestate (BFE, 2011, Zschokke, 2015).
6) **Heavy metal** emissions are based on vegetable waste analyzes in Denmark (Boldrin et al., 2011). Since the origin of the metals is unknown, also metals from agricultural provenience may be included (-> closed cycle, no net emission -> potential over-estimation of the effects).
7) **Total** net impact of **anaerobic digestion.** The average values assume 75% of the heavy metal effec and 50% of the credits for improved soil and fertilizer substitution. The error bars show the worst case with 100% heavy metal effect, 50% heat substitution, and no peat and fertilizer substitution, and the best case with 100% heat, peat, and fertilizer substitution and 50% of the heavy metal effect.

B.4.4.3 Animal feeding

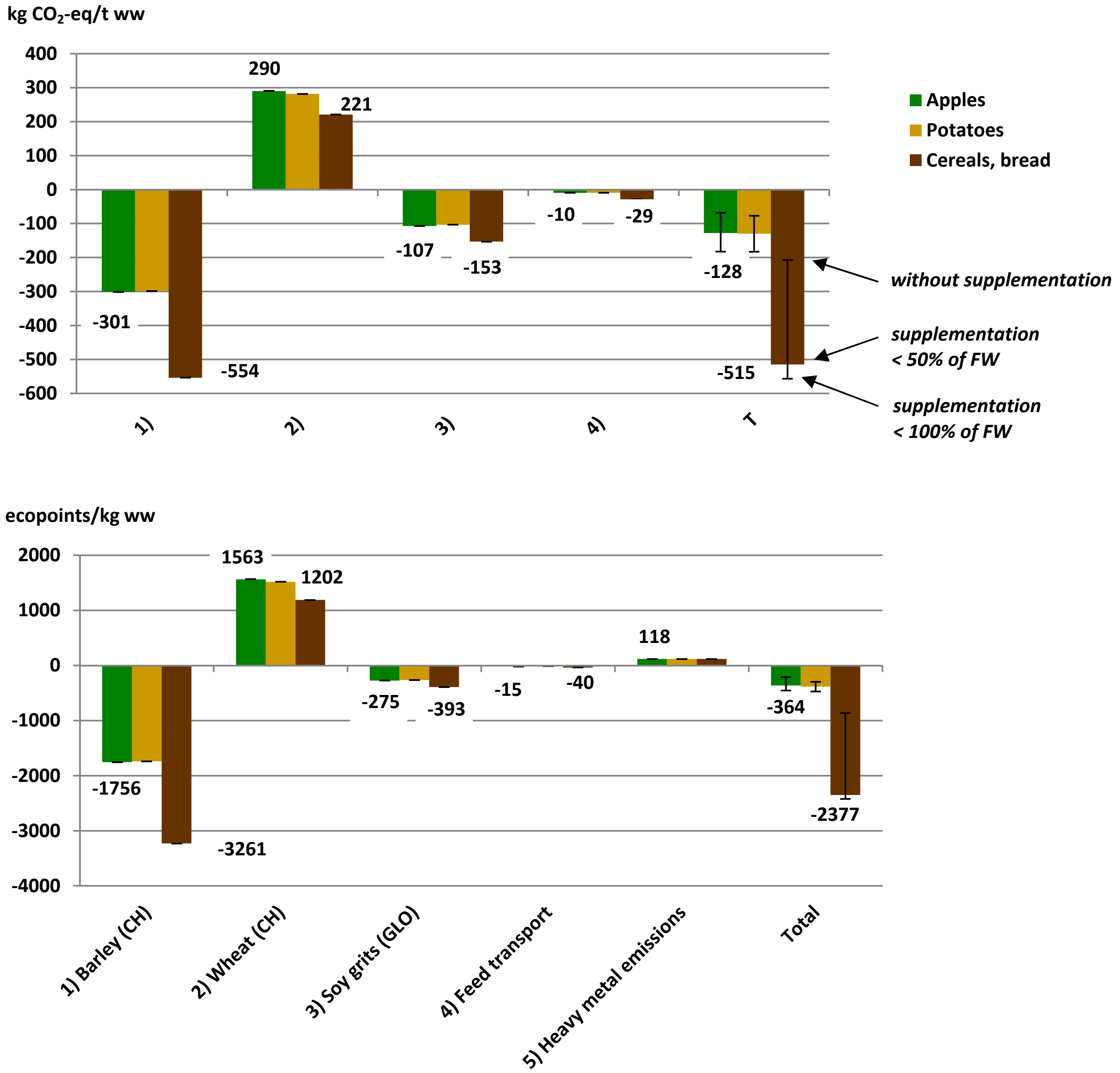


Figure B.16: GHG (kg CO_2-eq) and ecopoint impacts and savings (ecological scarcity 2013) per kg of food that is used for the substitution of feed by feeding apples, potatoes, and cereals or bread to swine. Wheat is used for supplementation and therefore has positive impacts. "Total" shows the net environmental savings. Numbers refer to wet weight (ww). Average values refer to the feed mix of barley, wheat, soy grits, phosphate, and lysine supplements with maximum GHG impacts to be substituted without exceeding the FW's nutrients, allowing FW supplementation with individual feed components up to 50% of the amount of the FW in order to improve its nutritional value and thus maximize the net cost and GHG savings of the substituted feed. The error bars show the maximum net savings if 100% supplementation is possible and the minimum savings if no supplementation is possible.

Interpretation of Figure B.16:

1) -3) Credits for the substitution of the **agricultural production of different feeds** that provide the same nutritional value for swine as the FW used for feeding. Positive values show the impacts of feeds used for supplementation of FW for optimizing its nutritional value.

4) Benefits from the substitution of the **transport of the feed** (barley and wheat from Switzerland, soy grits from the main global producers, primarily Brasil and USA). The additional transport of FW used for feeding is ignored.

5) **Heavy metal** emissions are based on vegetable waste analyzes in Denmark (Boldrin et al., 2011). The impacts are assumed to be equal to FW composting and anaerobic digestion, because in both cases the metals are reintroduced into the agricultural system. Since the origin of the metals is unknown, also metals from agricultural provenience may be included (-> closed cycle, no net emission -> potential over-estimation of the effects).

T) **Total**, net environmental credits for **feeding FW.**

-> In the case of feeding bread cereals, the modeled credits make up between 50 and 90% of the impacts related to the production of bread cereals (490 kg CO_2-eq/t, 3'170 UBP/kg). Possibly, in practice bread cereals used for feeding often replace forage cereals. The yield of bread wheat (winter and summer wheat) lies between 70 and 85% of forage wheat in Switzerland (SBV, 2009), so the environmental benefits of forage wheat substitution may be in a similar range as the benefits in the modeled scenario.

ADDITIONAL RESULTS AND DISCUSSION

B.5 MASS AND ENERGY FLOW ANALYSIS (MFA, EFA)

B.5.1 Overview

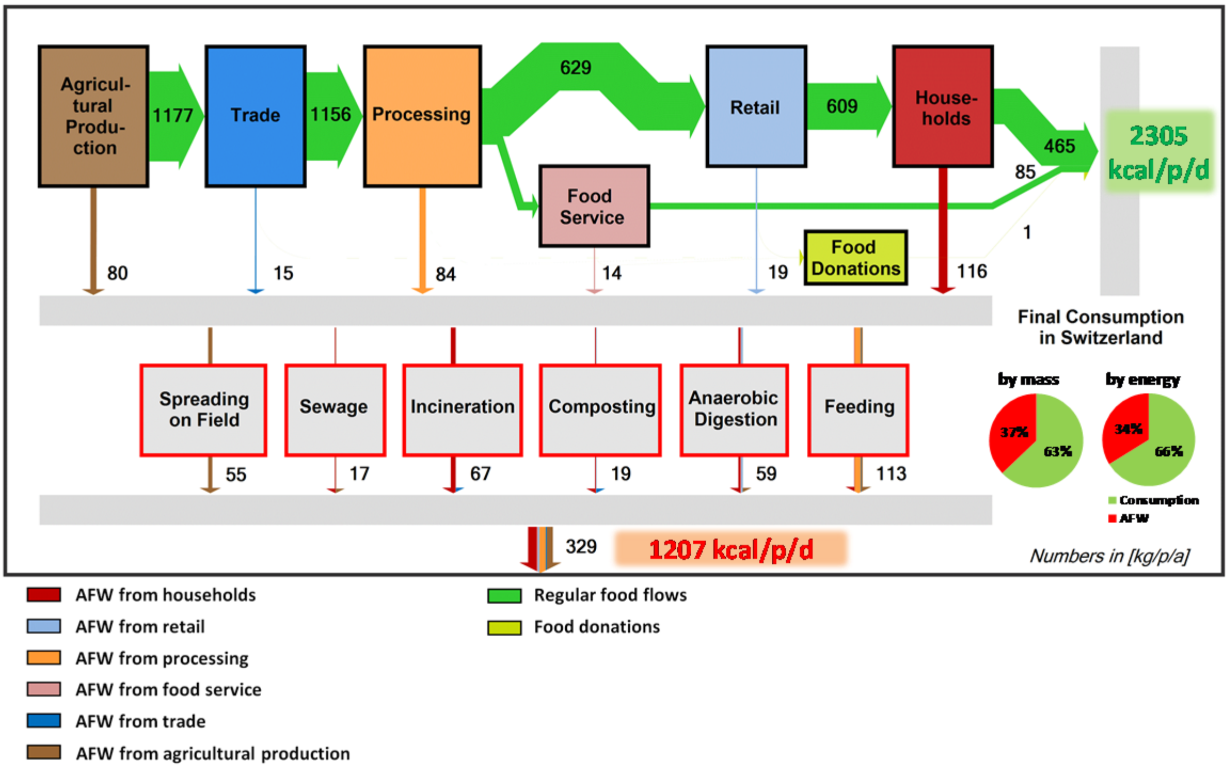
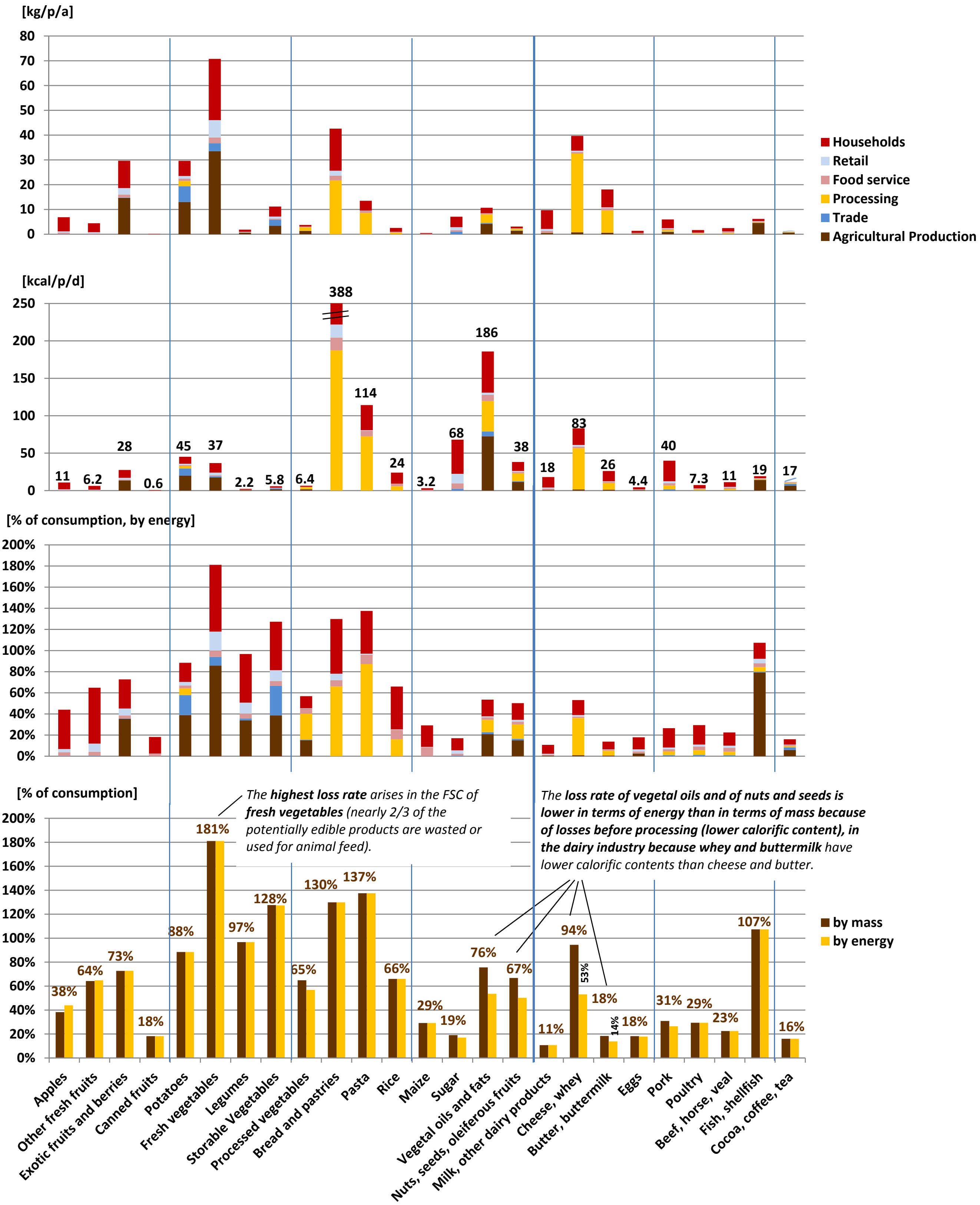


Figure B.17: Mass flow analysis of Swiss food consumption, food donations and avoidable food losses in kg/p/a. Final consumption and total avoidable food waste are quantified in kcal/p/d. The pie charts show the share of final consumption and avoidable food waste (FW) by mass and by energy.

B.5.2 Avoidable mass and energy losses for each food category



*The **highest loss rate** arises in the FSC of **fresh vegetables** (nearly 2/3 of the potentially edible products are wasted or used for animal feed).*

*The **loss rate of vegetal oils and of nuts and seeds is lower in terms of energy than in terms of mass because of losses before processing** (lower calorific content), **in the dairy industry because whey and buttermilk** have lower calorific contents than cheese and butter.*

Figure B.18: Absolute FW for each food category in terms of mass (top graph, in kg/person/year) and energy (second graph, in kcal/p/d) and relative FW compared to final consumption (=100%) by energy (third graph, for each stage of the FVC) and by mass and energy (bottom graph, comparison of mass and energy).

B.6 ENVIRONMENTAL IMPACTS

B.6.1 Comparison of consumption, losses, and treatment

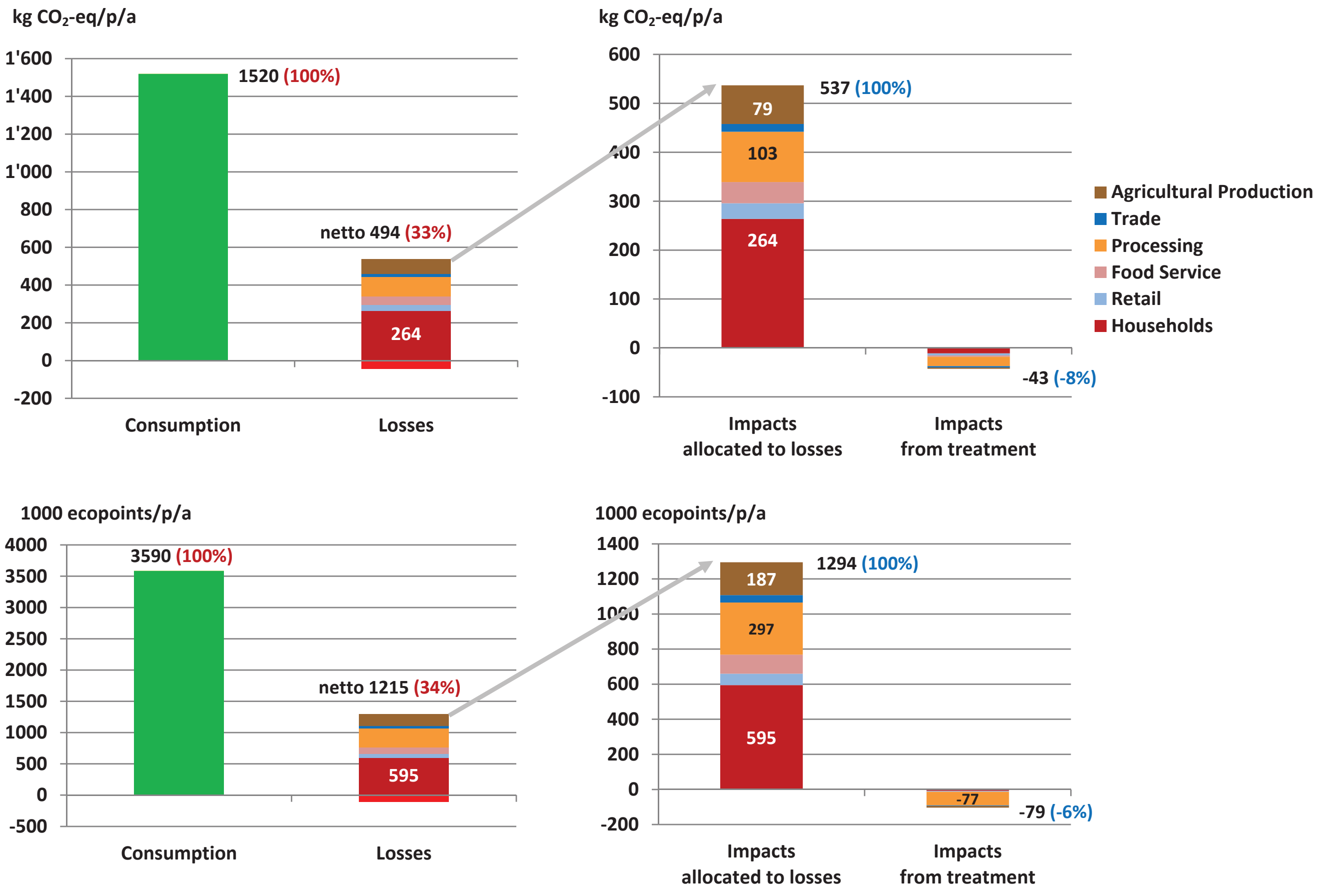


Figure B.19: Climate change 100a (IPCC 2013, top graphs) and ecopoints (environmental scarcity 2013, bottom graphs) allocated to food consumption and food losses, including FW treatment and differentiating the stages of the FVC where the food is wasted. In the right graphs only the impacts of FW are shown, comparing the impacts from the FVC and the impacts from FW treatment.

Interpretation of Figure B.19:

a) The total environmental impacts of FW amount to about one third of the impacts of consumption.

b) The most relevant food losses in terms of GHG and ecopoints result from **households and** the **processing industry**.

c) The net environmental **credits for FW treatment** are **10 – 20 times lower than** the **impacts allocated to** the **FW**.

B.6.2 Overview of environmental impacts (ecopoints)

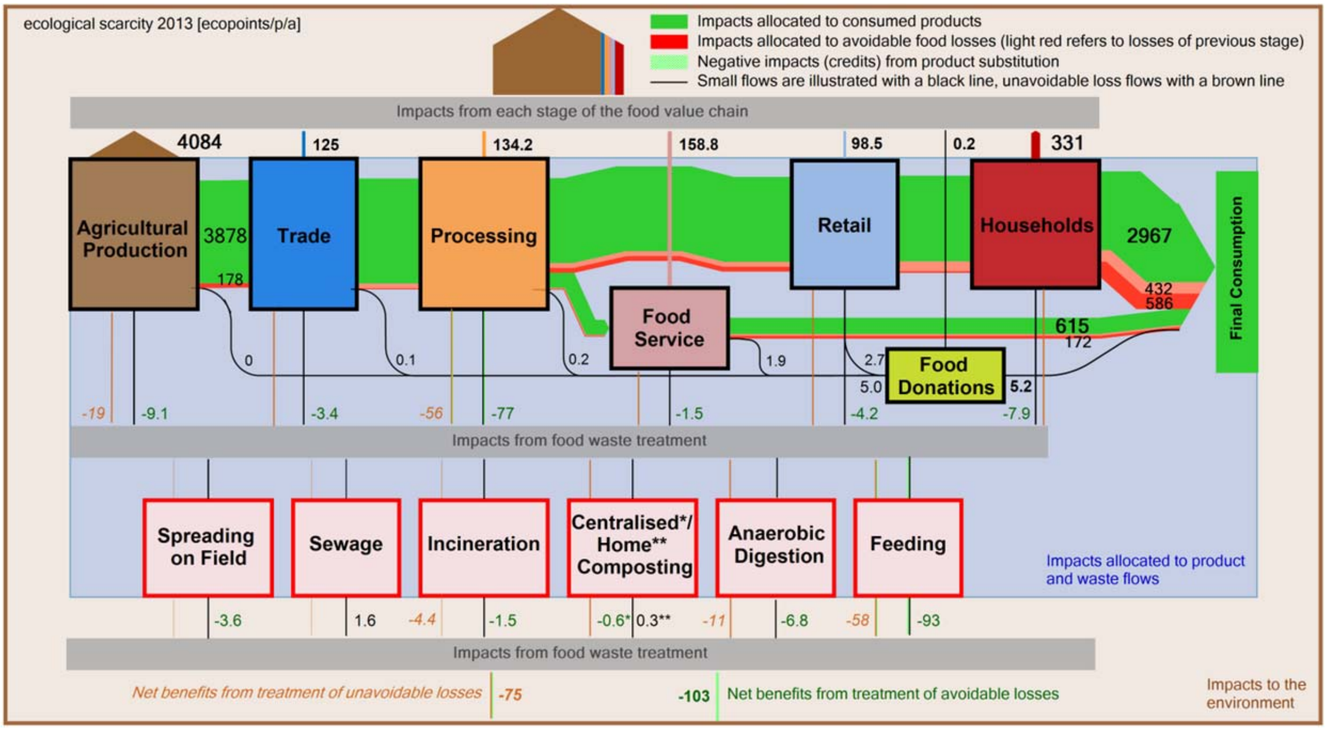


Figure B.20: Environmental impacts (ecological scarcity 2013) of Swiss food consumption, including the production and treatment of FW. The vertical flows on the top show the impacts arising at the various stages of the FVC, the flows at the bottom the net environmental benefits of FW treatment, considering credits from the substitution of resources and energy (forage, fertilizer, electricity, heat, improved soil effect). The size of the arrows is proportional to the impact; however, small flows are highlighted with a black line for better visibility. Negative flows (environmental benefits) are marked with green numbers and impacts from the treatment of unavoidable losses with brown numbers in italic (only major flows are shown). The horizontal flows visualize the cumulated impacts of the upstream processes of the FVC, including FW treatment. The attribution to consumption (green) and waste (red) is based on the metabolizable energy content of the food and the avoidable FW.

B.6.3 Environmental impacts of each stage of the food value chain

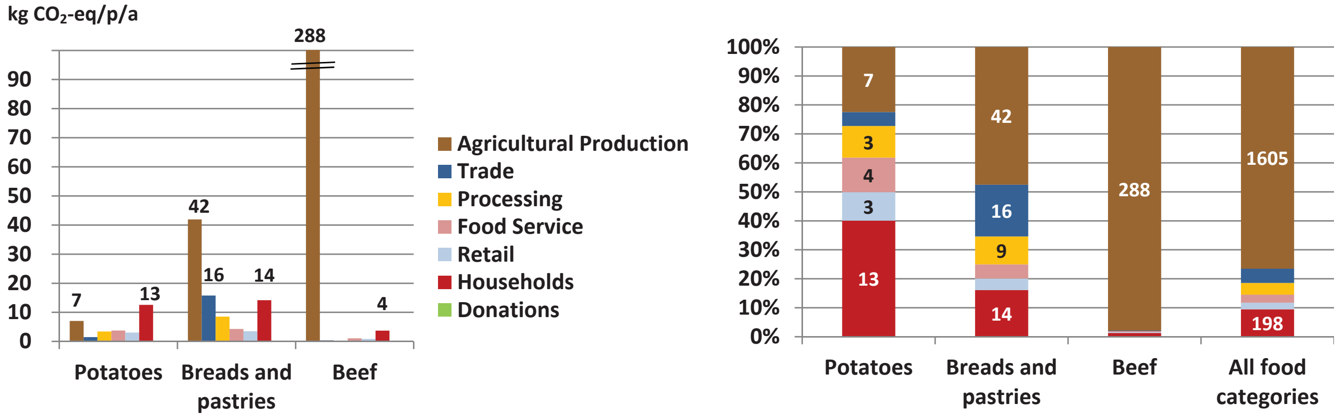


Figure B.21: Environmental impacts of each stage of the FVC related to the consumption of an average Swiss person (left) and relative contributions (right) for the example of potatoes, breads and pastries, and beef and for all food categories.

Interpretation of Figure B.21:

a) The impacts are very variable between food categories, especially for agricultural production (about 40x higher for beef than potatoes).

b) The **contribution of the different stages of the FVC varies between products**. For products with relatively high agricultural impacts (e.g. beef) the impacts from the downstream supply chain are negligible, whereas for potatoes the major impacts are caused by households (driving for shopping, cooking, storing, freezing, washing the dishes…).

c) The impacts from driving for shopping, from cooking, freezing, etc. are allocated to consumption and losses based on the energy content of the food. However, a reduction of FW may not necessarily lead to a proportional reduction of the mentioned impacts. For example, if 10% less food has to be purchased as a consequence of FW reduction, this does not mean that people go shopping less frequently; maybe they buy 10% less each time. Therefore, **the real environmental benefits of reducing FW depend on the overall behavioral changes of the consumers**.

d) In average **almost 80% of the overall climate impacts of food consumption are caused by agricultural production**, about 10% by households, and the rest by processing, trade, food services, and retail.

B.6.4 Environmental impacts of food production and the food value chain

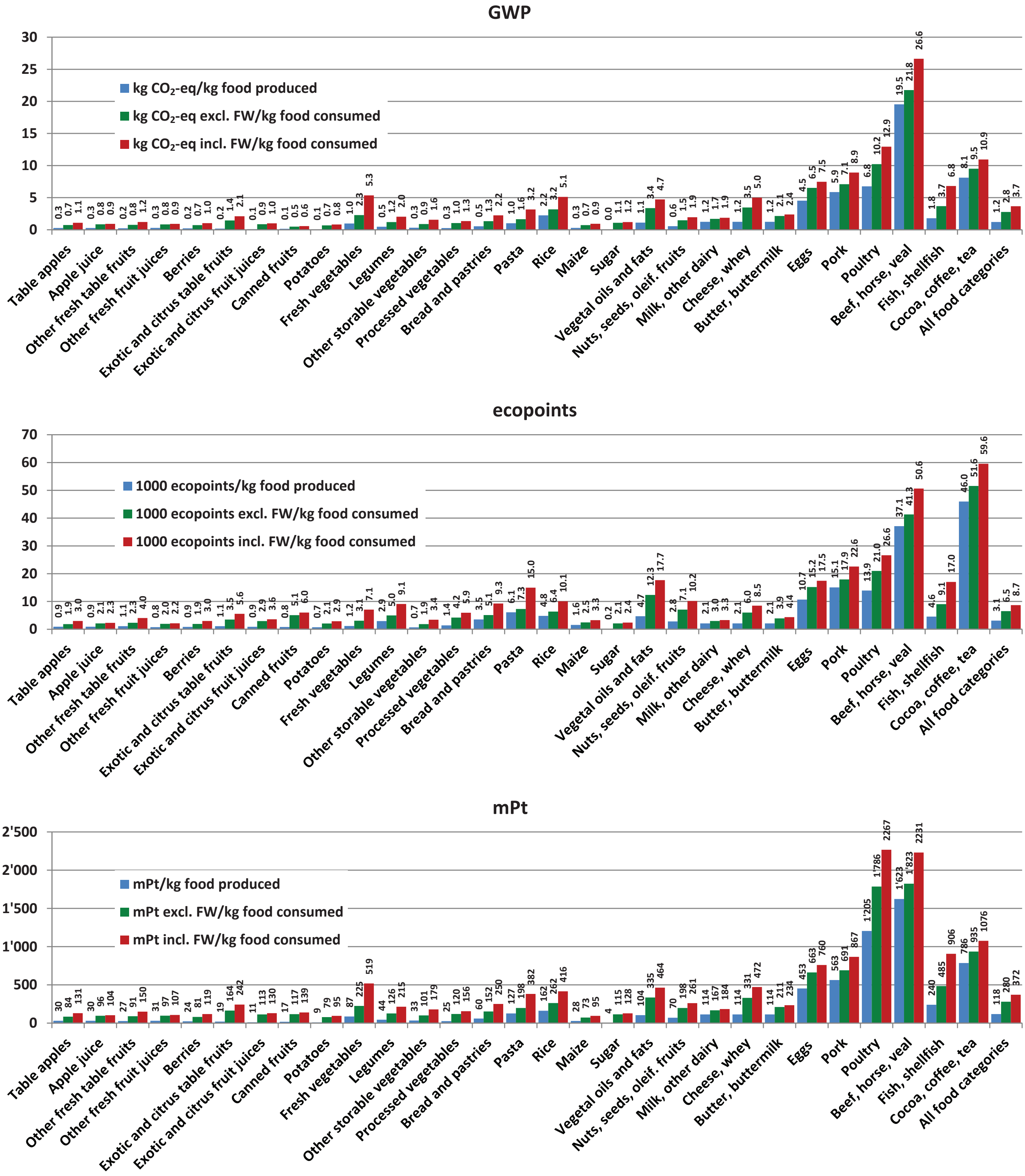


Figure B.22: Environmental impacts of agricultural production (blue) and the whole FVC including impacts at the household level, but excluding the impacts allocated to FW (green; scenario without FW), and including also the impacts from FW (red; present situation), expressed with GHG impacts (top graph), ecological scarcity 2013 (middle), and Recipe (Goedkoop et al., 2013) (bottom graph). Note that the numbers are defined per kg of food and that the food at the agricultural level also includes inedible parts (e.g. live weight of livestock, sugar beets etc.).

B.6.5 Impacts from avoidable food losses relative to consumption and comparison of the stages of the food value chain

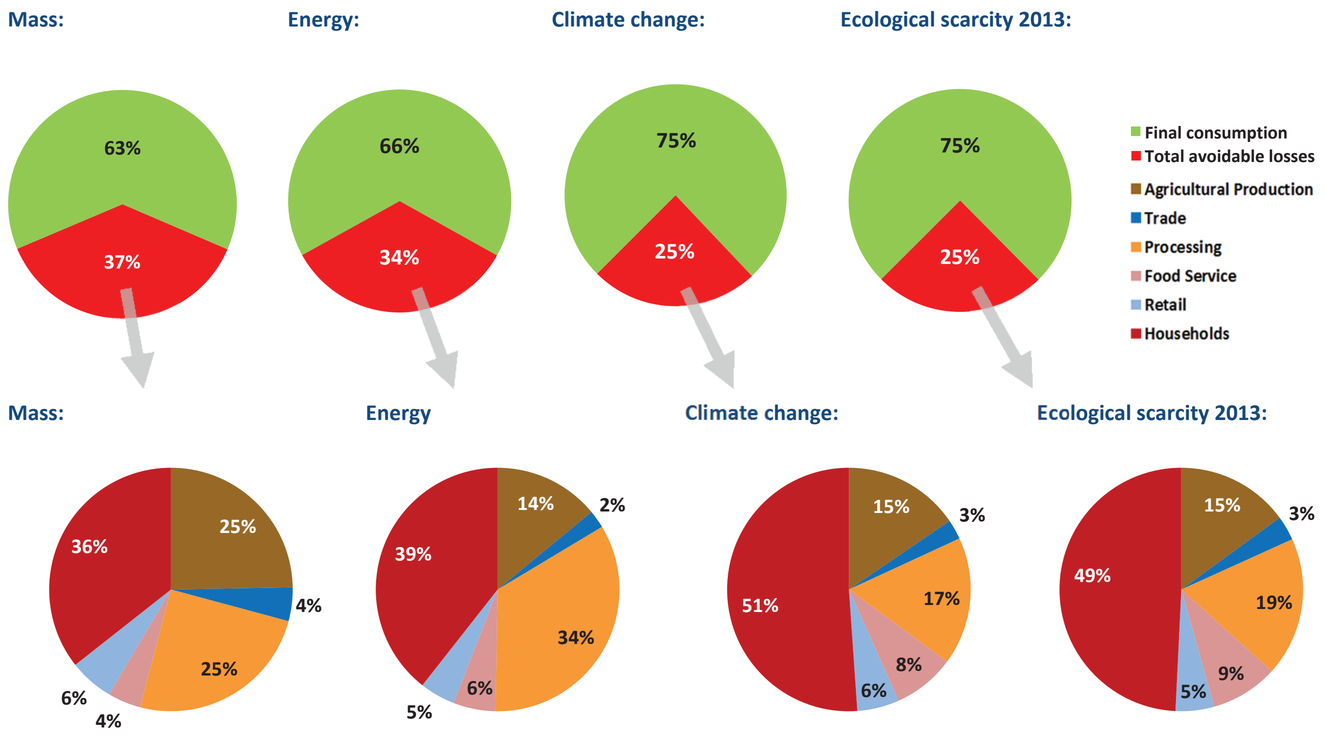


Figure B.23: Share of consumption and avoidable FW by mass, by energy, and by environmental impacts from the FVC and the treatment of FW. The total losses are shown by the red slice of the pie charts in the first row. The second row shows at which stage of the FVC these losses occur.

Interpretation of Figure B.23:

a) The share of FW relative to consumption is highest in terms of mass. The average energetic content of FW is lower than for the consumed food (e.g. whey and cheese). The **share of environmental impacts is lower than the quantitative share of FW** for four reasons: (I) The losses in the early stages of the FVC do not contribute to the impacts of the later stages of the FVC (see Figure B.5). (II) Products with lower-than-average environmental impacts (e.g. vegetables) tend to be wasted more than losses with high environmental impacts per kg (e.g. meat). (III) The environmental impacts allocated to FW are reduced by the credits from treatment (e.g. substitution of electricity and feed). (IV) The environmental impacts are allocated according to the energetic content of the food and not according to mass (see section B.2.2).

b) The **food losses at the end of the FVC** (households and food services) generally have higher average energy contents and **cause more environmental impacts per kg** than losses in the early stages of the FVC (see also Figure B.24). Reasons may be that they are more processed, usually leading to higher calorific densities and additional environmental impacts, and that they have caused more environmental impacts because of the accumulation of impacts across the FVC.

c) The share of FW impacts between the stages of the FVC is similar for climate impacts and for the method of Ecological Scarcity.

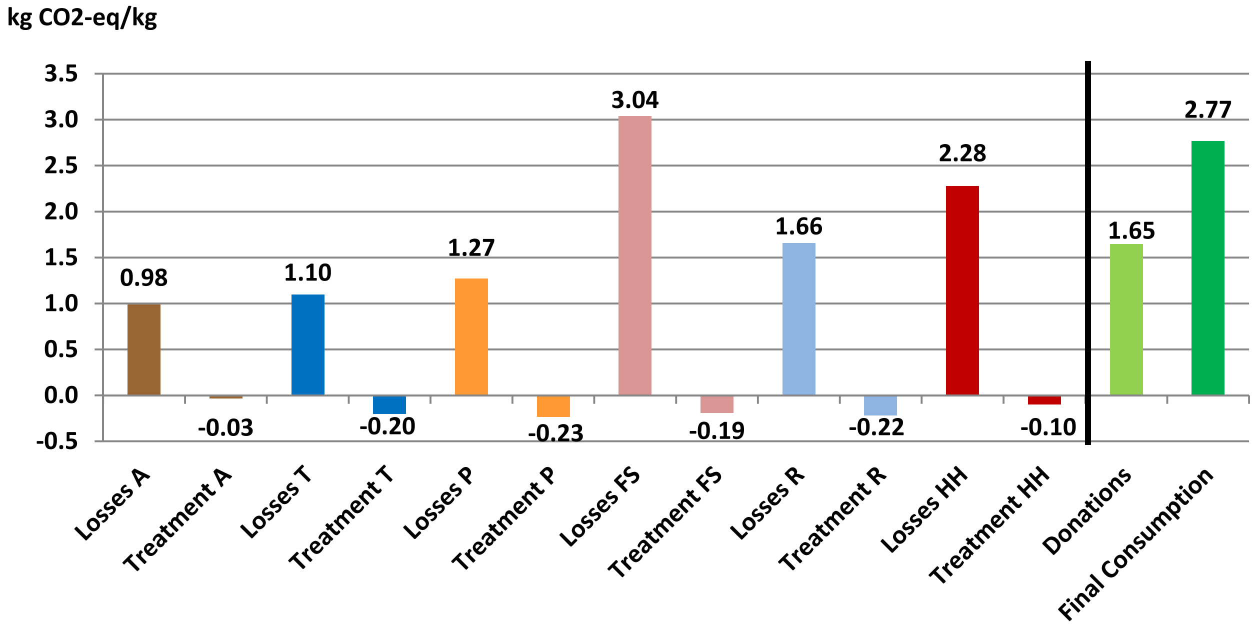


Figure B.24: Carbon footprint per kg of food loss.

Interpretation of Figure B.24:

a) The **most relevant** food losses in terms of **GHG per kg** of waste result **from consumption** (food service and households).

b) There is a **trend of increasing impacts per kg of FW from the beginning to the end of the FVC**. However, different FW compositions lead to different average impacts per kg of FW, explaining partly why the losses in the food service sector are higher than the losses in households (one aspect is meat, which has high average impacts per kg of FW and which contributes to about 7% of FW in food services, but only 5% in households). Additionally, different amounts of unavoidable losses also lead to different impacts allocated to one kg of FW.

c) The **environmental credits from** FW **treatment are relatively low** compared to the impacts of the FVC; the credits are highest for FW from the processing industry, since most of these losses are fed to livestock.

d) The average product mix of donated food has lower environmental impacts than average food consumption.

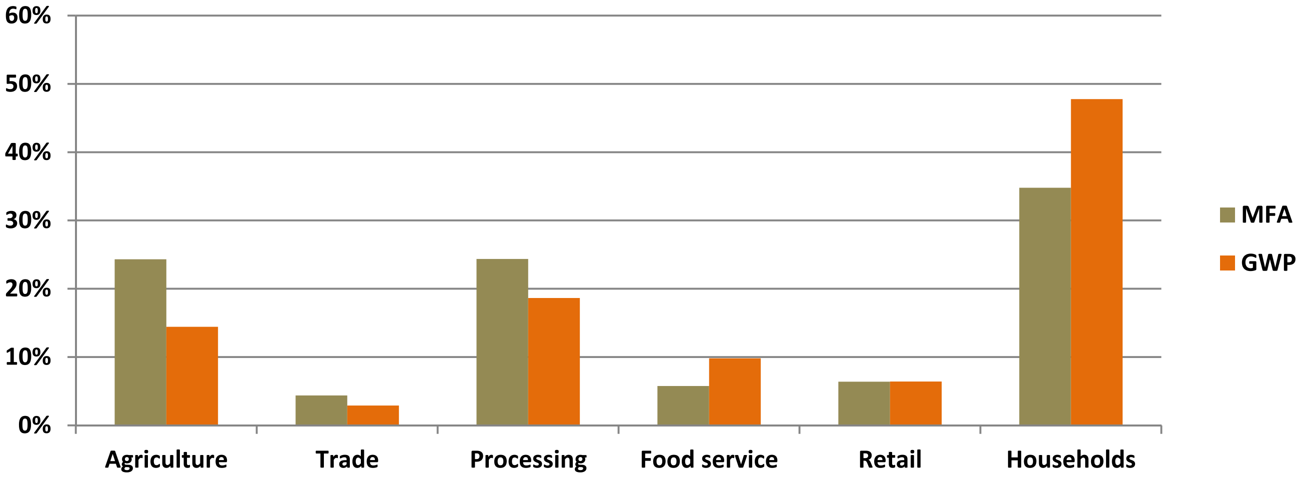


Figure B.25: Contribution of each stage of the FVC to mass and GHG of FW. The general pattern, that the early stages of the FVC contribute more in terms of mass than in terms of carbon footprint and the late stages more in terms of carbon footprint, is consistent with global data from FAO (2013).

B.7 COMPARISON BETWEEN FOOD CATEGORIES

Impacts from each stage of the food value chain per food category

The environmental impacts of food losses differ substantially between food categories. The comparison of the *total impacts related to Swiss consumption* reveals food categories and stages of the FVC, where a **reduction of the rate of food loss** is most effective. The comparison of the impacts *per kg of food loss*, however, reveals sections, where the environmental benefits of **saving a kg of food** are most effective. The results are shown for climate impacts, for ecological scarcity 2013, and for CED 1.09.

B.7.1 Global Warming Potential (GWP 100)

Interpretation of Figure B.26:

I. The **most relevant food categories** regarding the GHG impacts of total FW are **fresh vegetables, cheese and whey, beef, breads and pastries, milk, and vegetal oils and fats**. However, the impacts **per 1kg of FW** are most important for **beef, poultry, coffee and chocolate, pork, and eggs**. If the impacts are expressed **per 1kcal of FW**, **beef** is still the most important food category, but it is closely followed by **fresh vegetables**. Also **exotic fruits** and **other vegetables** have higher impacts than in a per-kg-perspective, since they have a low calorific content. However, this has to be interpreted carefully, because the nutritional value of fruits and vegetables mainly lies in their high content of vitamins and minerals rather than calories.

II. **Most of the impacts** due to avoidable food losses are created **in households**. However, for some categories processing is also important, for fresh vegetables also agricultural losses. The highest potential of saving environmental impacts by diverting by-products from processing to human consumption is associated with the **valorization of whey from cheese production** (only 50-60% of the calories of the raw milk go into the final product cheese). Whey used as high quality fodder (according to Kopf-Bolanz et al. (2015) 31% of total whey production) is not included in this chapter, but shown in Figure 3 of the manuscript (more information in chapter B.1.2).

III. **Treatment** of food losses leads to net environmental **benefits** in most food categories. However, the impacts are **low compared to the impacts of the supply chain**. The most relevant environmental credits from treatment result in **feeding bread and pastry losses from milling** (declassified cereals and cereals not meeting the standards for baking), in the treatment of household bread losses (mainly electricity and heat credits from incineration), and in feeding whey to animals.

IV. The environmental impacts allocated to 1 kg or 1 kcal of FW generally increase over the FVC due to the accumulation of impacts and because inedible parts are removed (e.g. bones). However, the impacts in the FVC of butter are an exception since the losses in the processing industry mainly consist of buttermilk with lower nutritional values than raw milk and therefore lower allocated impacts of production per kg (allocation proportional to the nutritional value). The losses in retail and consumption consist of butter with higher nutritional value and therefore higher environmental impacts per kg. Furthermore, the losses in processing of fish, maize, oleiferous fruits, and canned fruits have slightly lower impacts per kcal compared to agricultural production, because of the higher credits from treatment (mainly feeding and anaerobic digestion).

Important assumptions and limitations of Figure B.26:

I. Losses of processing vegetal oils and beef are based on rough estimations for Europe by Gustavsson and Cederberg (2011).

II. Losses of households are based on the assumption, that Swiss households waste the same share of the purchases as UK households in each food category.

III. For the references and uncertainties of treatment amounts, see section B.1.3.

IV. 20-30% of the milk losses from households are assumed to be fed to animals and to replace feed.

V. For breads and pastries no specific data on food losses in the food service sector is available; we assume that they are proportional to household bread and pastry losses.

VI. In order to compare the nutritional value of different fractions of FW, a more sophisticated indicator has to be developed, considering not only kcal, but also proteins, fats and their quality, minerals, vitamins, and other ingredients with nutritional value.

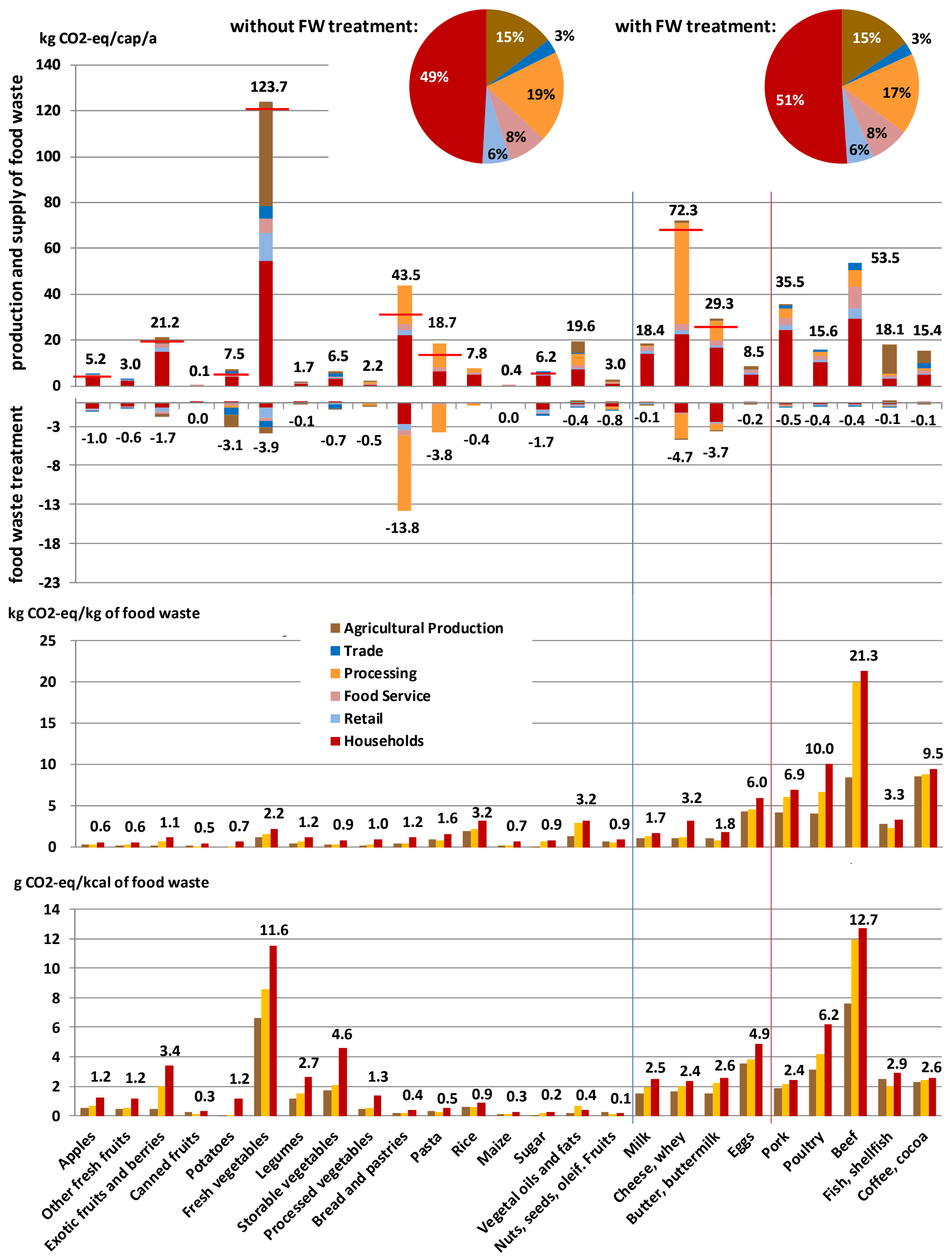


Figure B.26: Top graphs: Climate impacts (GWP 100) of the production and supply of FW and of FW treatment (net environmental impacts of treatment are mainly negative due to credits from product substitution) per average Swiss consumer per year, for each food category and each stage of the FVC. Note that the scale displaying the impacts of treatment is magnified to improve visibility. The pie charts show the share of net FW impacts at each stage of the FVC for all food categories, including (right) and excluding (left) the impacts from treatment. Bottom graphs: Climate impacts of the production, supply, and treatment of FW from agriculture, processing, and households, per kg and per kcal of FW, respectively. Note that the products in agriculture and partly in processing also contain inedible parts, reducing the impacts per kg of FW. FW from cheese and butter processing mainly consists of whey and buttermilk with lower calorific content and therefore lower allocated impacts per kg. The net impacts per kcal from the processing of fish are lower than the impacts from production because of credits for animal feeding.

B.7.2. GLOBAL TEMPERATURE CHANGE POTENTIAL (GTP 100)

> *"Global temperature change potential (GTP) is an instantaneous normalized metric and uses as an indicator the global average temperature increase of the atmosphere at a future point in time that results from the emission (the absolute GTP (AGTP), in K./kg). The temperature increase is determined for a specific time horizon and is divided by the temperature increase caused by an equivalent amount of CO₂. Both GWP and GTP thus express results in terms of g CO₂-equivalent. The benefit of a metric reflecting the temperature change is that it is closer to actual impacts compared with radiative forcing, even though its quantification is more uncertain than GWP." (Frischknecht et al., 2016)*

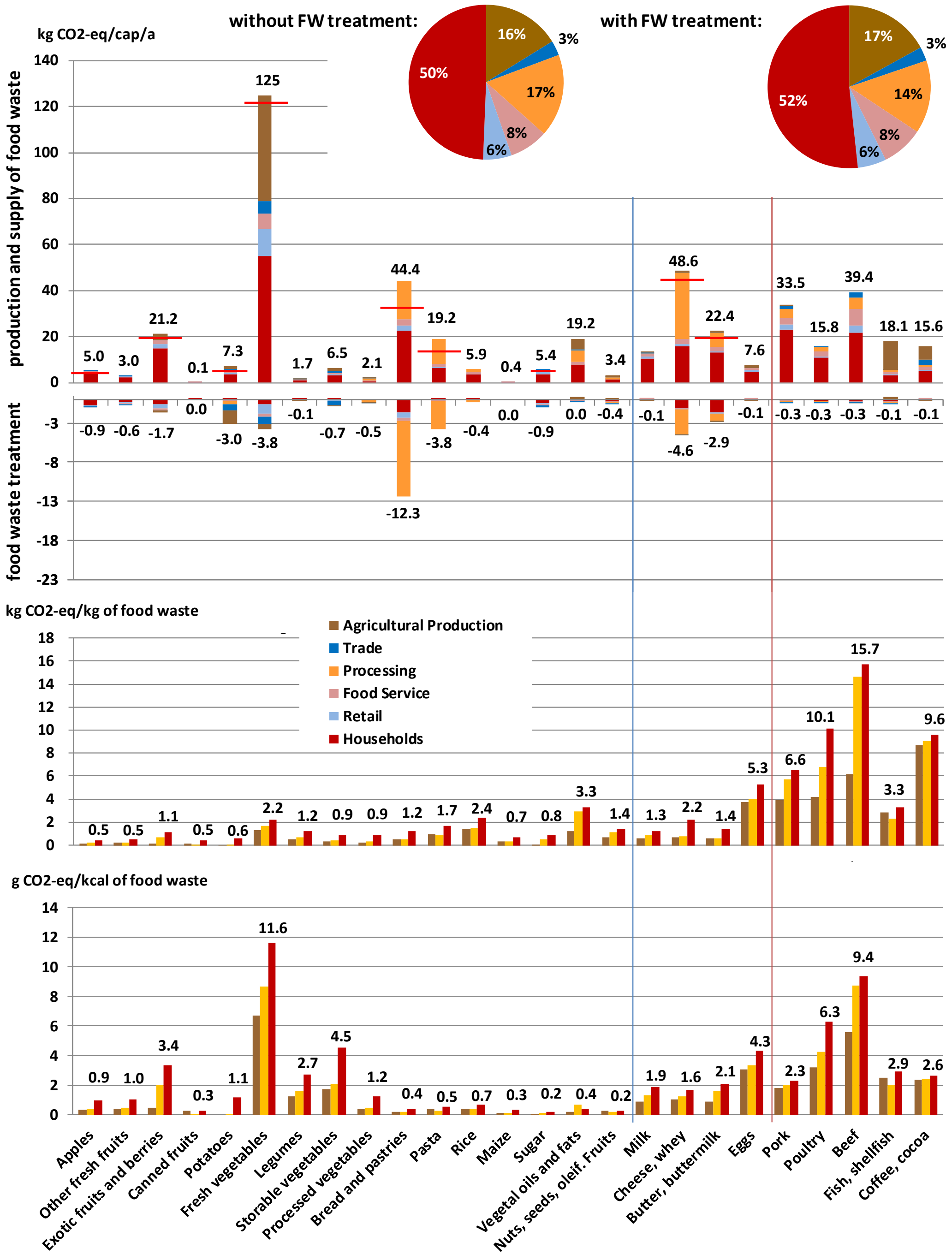


Figure B.27: The same graph as in Figure B.26, but calculated with the impact method of global temperature change potential 100a (GTP 100) (Frischknecht et al., 2016). The results are in the same range as with the impact method GWP 100, except for beef and cow milk. The main reason is high methane emissions which have lower relative impacts compared to CO₂ with GTP 100 than with GWP 100 (Frischknecht et al., 2016). Nevertheless, the differences are too small to influence the ranking of the products, except for vegetables and beef in the per-calorie perspective.

B.7.3. ECOLOGICAL SCARCITY 2013

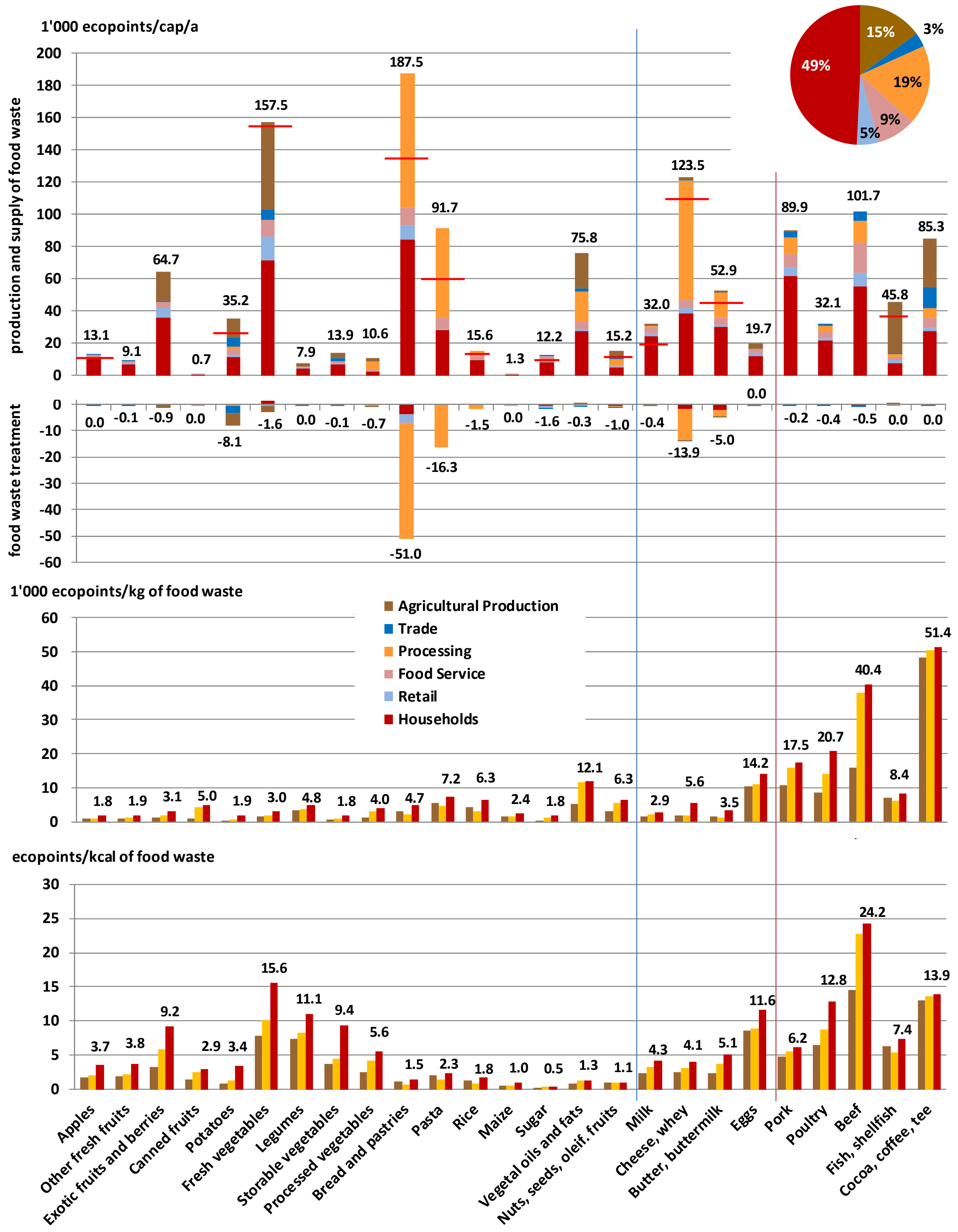


Figure B.28: Top graphs: Ecopoints (Frischknecht et al., 2013) of the production and supply of FW and of FW treatment (net environmental impacts of treatment are mainly negative) per average Swiss consumer per year, for each food category and each stage of the FVC. Note that the scale displaying the impacts of treatment is magnified to improve visibility. Bottom graphs: Ecopoints of the production, supply, and treatment of FW from agriculture, processing, and households, per kg and per kcal of FW, respectively. Note that the products in agriculture and partly in processing also contain inedible parts, reducing the impacts per kg of FW. The net impacts per kcal from the processing of fish, rice, pasta, and other products are lower than the impacts from production because of credits for animal feeding.

B.7.4. CUMULATED ENERGY DEMAND (CED 1.09)

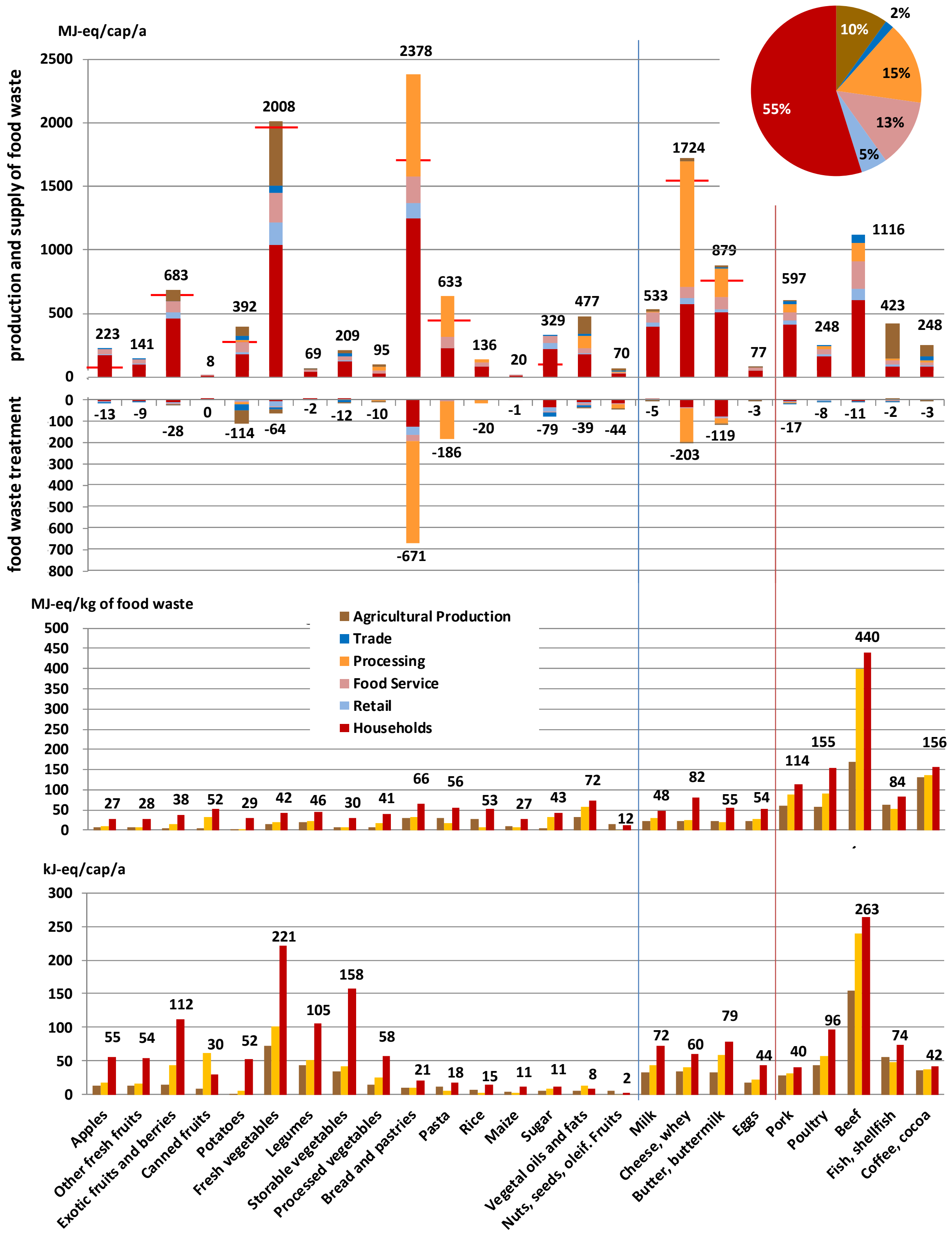


Figure B.29: Top graphs Cumulated energy demand (CED 1.09) of food losses and treatment per average Swiss consumer per year, for each food category and for each stage of the FVC, including renewable and non-renewable energy. Note that the scale displaying the impacts of treatment is magnified to improve visibility. The pie chart shows the contribution of each stage of the FVC, including impacts from FW treatment. Bottom graph: CED 1.09 of FW and treatment per kg and per kcal of FW from agricultural production, processing, and households. Note that the products in agriculture and partly in processing also contain inedible parts, reducing the impacts per kg of FW.

B.7.5 Freshwater Eutrophication Recipe

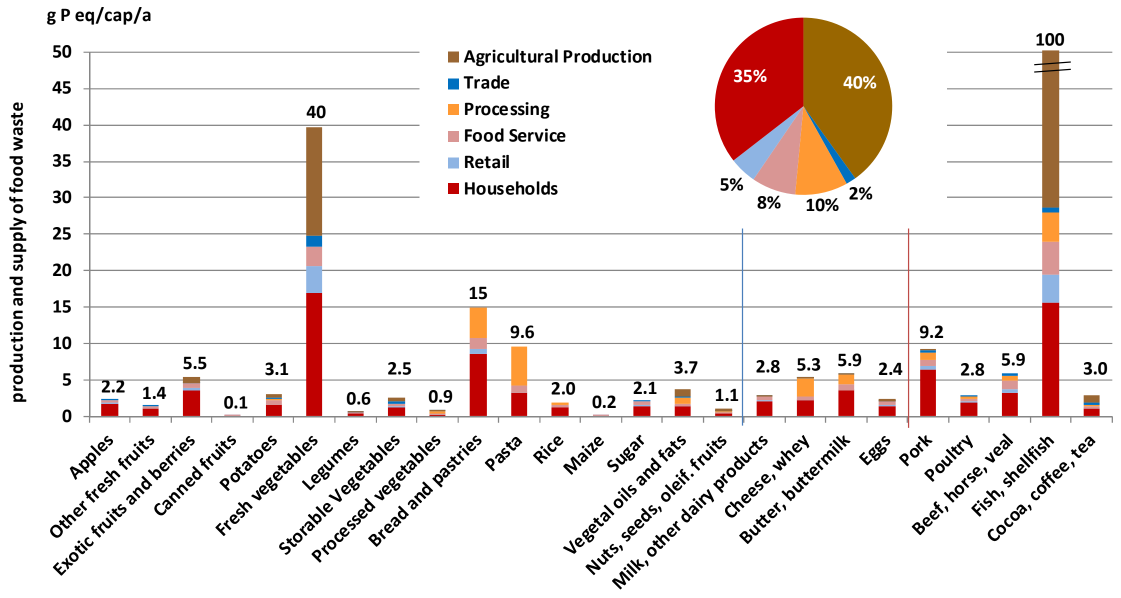


Figure B.30: Freshwater Eutrophication Recipe of food losses per average Swiss consumer per year, for each food category and for each stage of the FVC. The pie chart shows the contribution of each stage of the FVC.

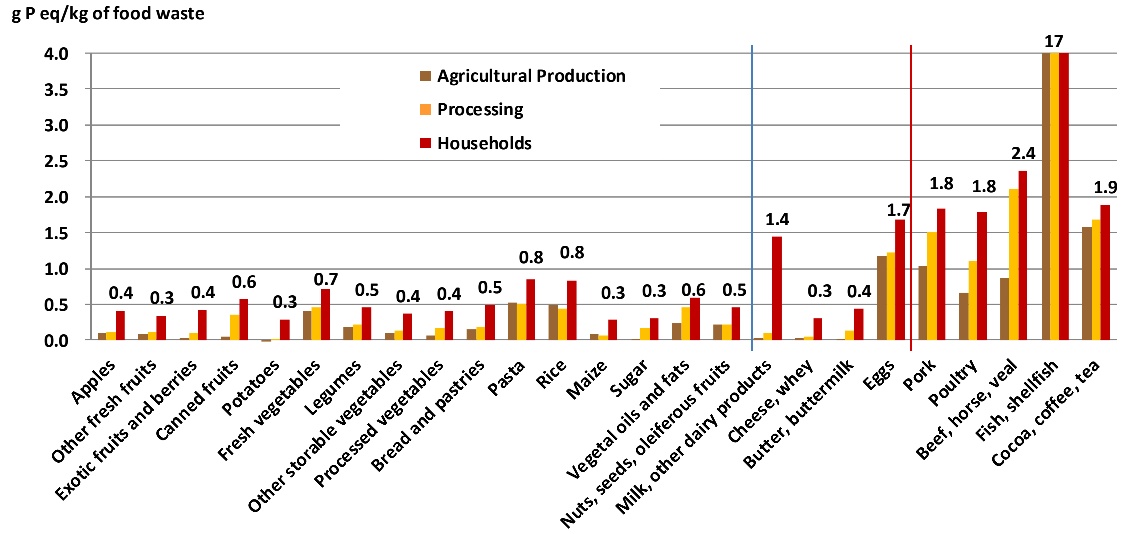


Figure B.31: Freshwater Eutrophication Recipe of food losses per kg of food waste for each food category. The numbers indicate the impact of household FW (highest impacts due to accumulation of effects across the FVC).

Interpretation and assumptions of Figure B.31:

a) The highest impacts are calculated for fish losses, based on datasets for trout and sea bass production from Agribalyse (Colomb et al., 2015). However, the impacts for sea fish may be lower.

b) Most of the impacts are caused by agricultural production and by electricity consumption (a relatively small share of the Swiss electricity mix is produced in German coal power plants with high eutrophication impacts).

c) The high impact of milk losses in households is based on the assumption that milk is discarded into the sewer with environmental impacts based on data from Eymann et al. (2015) about wastewater treatment from a dairy plant.

d) Mostly animal products have higher eutrophication impacts per kg than plant based products. The high per-consumer-impacts of fresh vegetable FW is mainly caused by high FW amounts.

B.8 COMPARISON OF THE CLIMATE IMPACTS OF FOOD WASTE WITH OTHER SECTORS

Table B.15: Comparison of the GHG caused by household FW and by total FW with the total emissions of consumption and the domestic emissions of production in 2011 (BAFU, 2014), with the direct CO_2-emissions caused by Swiss mobility in 2013, by Swiss passenger cars only (BFS, 2015) and by Swiss leisure mobility by cars (BFS, 2016).

GHG impacts from FW compared to other sectors	**Household FW** 2.0 x 10^6 t CO_2-eq	**Total FW** 3.9 x 10^6 t CO_2-eq
Total emissions of consumption CH 2011: 110 000 000 t CO_2-eq	**2%**	**4%**
Total domestic emissions CH 2011: 55 000 000 t CO_2-eq	**4%**	**7%**
Mobility CH 2013: 16 000 000 t CO_2-eq	**13%**	**25%**
Mobility by cars CH 2013: 10 560 000 t CO_2-eq	**19%**	**37%**
Leisure mobility by cars CH 2013: 5 670 720 t CO_2-eq	**35%**	**69%**

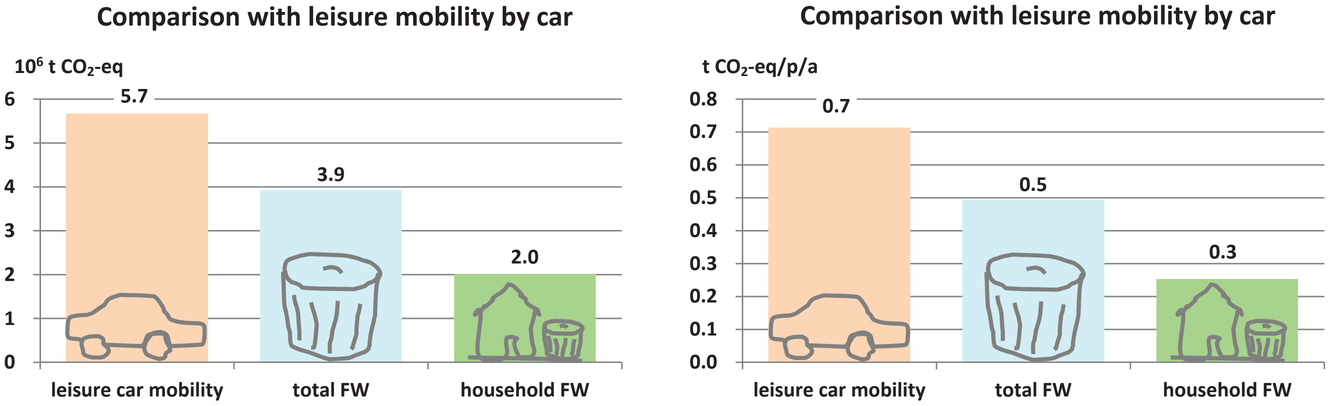


Figure B.32: Comparison of the GHG emitted by household FW and by total FW with the direct CO_2-emissions emitted by Swiss leisure mobility from cars (BFS, 2016). The left graph relates to total Swiss consumption, the right graph to an average Swiss consumer.

Table B.16: Comparison of the ecopoints caused by household FW and by total FW with the total impacts of consumption and the domestic impacts of production in 2011 (BAFU, 2014) and with the impacts caused by Swiss mobility in 2011 (Jungbluth et al., 2012).

Ecopoints from FW compared to domestic impacts	**Household FW** 4.8 x 10^{12} ecopoints	**Total FW** 9.7 x 10^{12} ecopoints
Total impacts of consumption CH 2011: 160 x 10^{12} ecopoints	**3%**	**6%**
Total domestic impacts CH 2011: 75 x 10^{12} ecopoints	**6%**	**13%**
Mobility CH 2011: 19 x 10^{12} ecopoints	**25%**	**51%**

B.9 CLIMATE IMPACTS COMPARED TO AMOUNTS

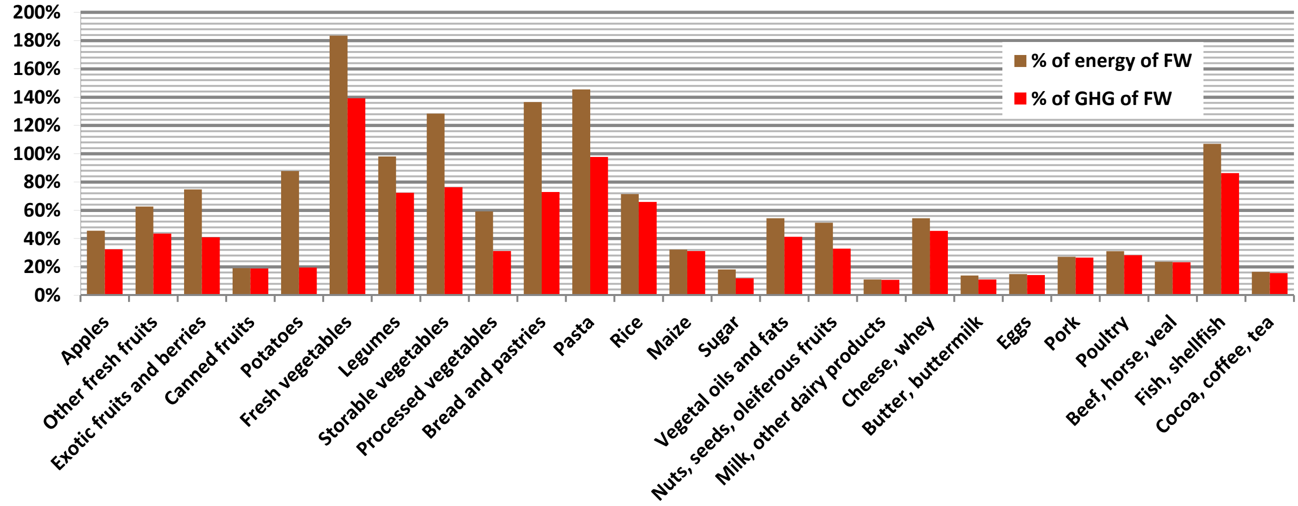


Figure B.33: Comparison of the energy and the environmental impacts (GHG) of FW relative to consumption (100% corresponds to the energy intake of total food consumption or to the environmental impacts attributed to consumption in the corresponding food category). Red columns above 100% mean that more GHG are related to the losses than to consumption.

Interpretation of Figure B.33:

a) For 1 MJ of fresh vegetable consumption nearly 3 MJ of vegetables have to be grown; the related environmental impact in terms of GHG is about 230% of the GHG impacts needed to meet the demand without losses.

b) For most food categories the share of the GHG impacts caused by FW is lower than the share of the energetic content of FW. Therefore, the **percentage of FW amount is only a good indicator for the environmental impacts for products with the major impacts resulting in agricultural production and without relevant credits from FW treatment** (e.g. meat, milk, cocoa). For other products the percentage of FW amounts can be significantly higher than the percentage of related environmental impacts.

B.10 LAND USE

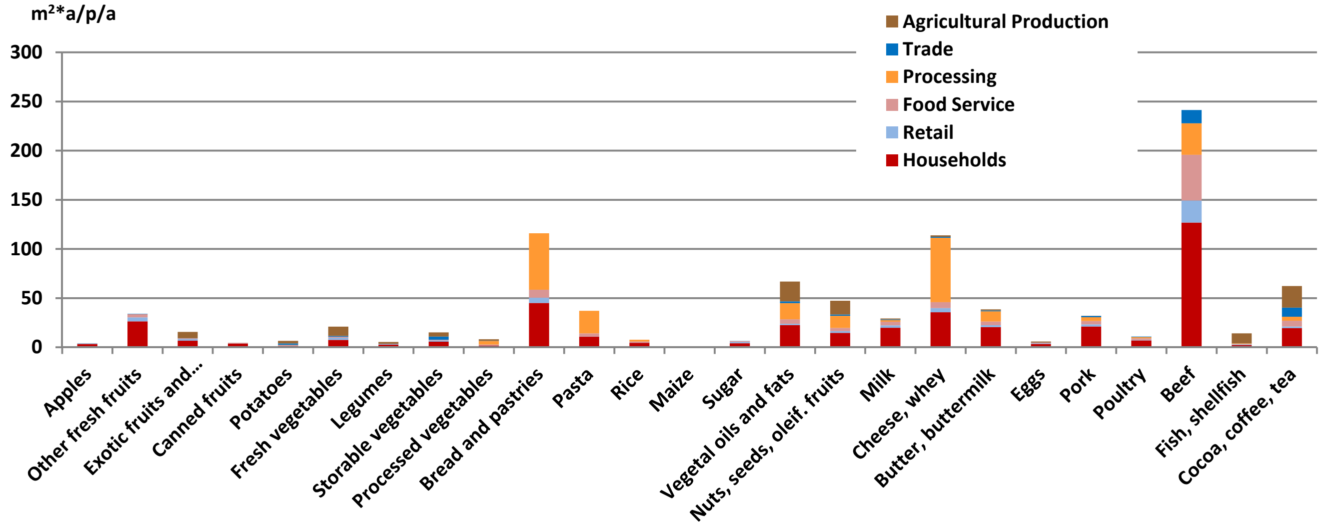


Figure B.34: Land use allocated to FW per person and year arising at the individual stages of the FVC.

B.11 WATER USE

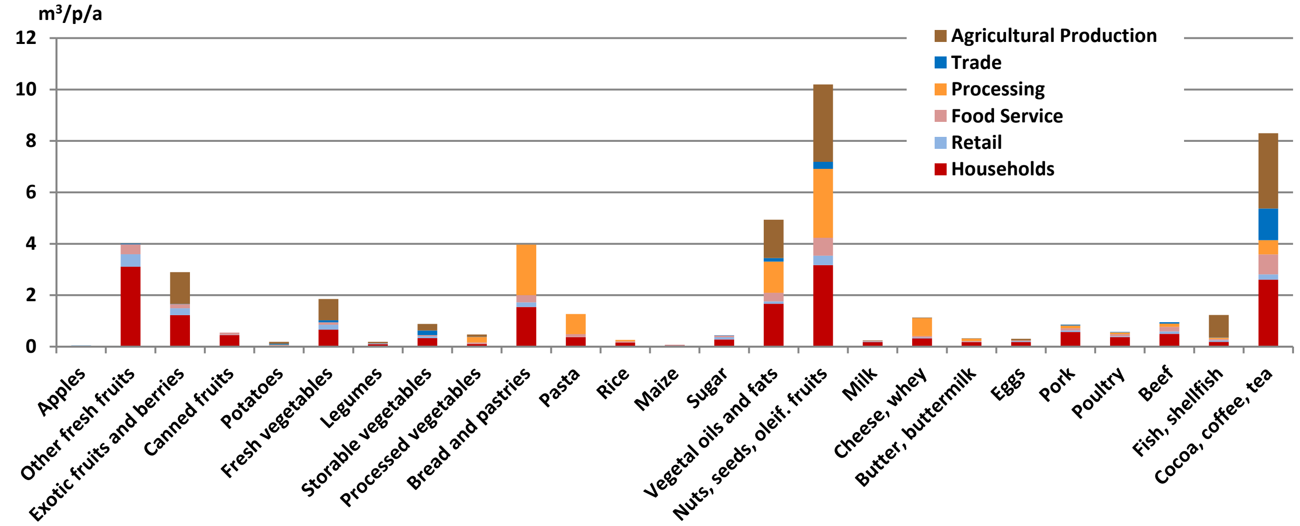


Figure B.35: Blue water use (irrigation water from surface or groundwater resources) allocated to FW per person and year arising at the individual stages of the FVC.

B.12 COMPARISON OF THE IMPACTS FROM FOOD WASTE PREVENTION AND DIFFERENT METHODS OF TREATMENT

The environmental impacts from the treatment of food losses depend on the composition of the losses (substrate), on the treatment technology (anaerobic digestion with or without subsequent composting of the digestate, with biogas purification or combined heat and power production, centralized composting versus home composting, etc.), and on the substituted products (electricity mix, energy source for heating, utilization rate of heat, fertilizer and peat substitution, origin and allocation of heavy metals, etc.). The subsequent section shows a comparison between FW prevention and different treatment technologies for some specific cases.

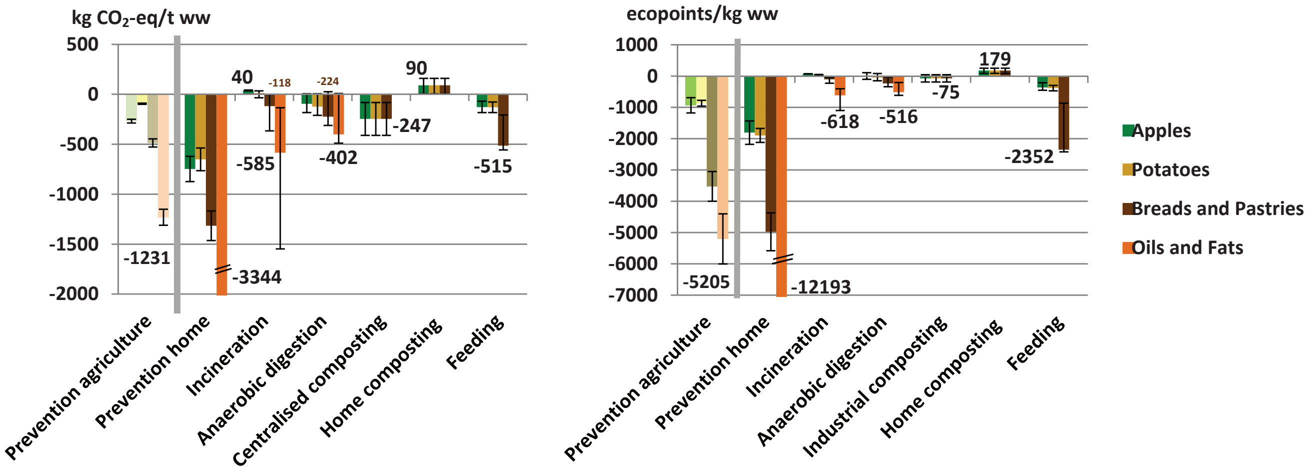


Figure B.36: Environmental benefits in terms of GHG (left) and ecopoints (ecological scarcity 2013, right), if 1 kg of FW is avoided or used for different methods of FW treatment.

Assumptions and explanations of Figure B.36:

Figure B.36 shows the environmental benefits, if 1 kg of FW at the agricultural level (unprocessed, e.g. cereals, oil seeds) or at home (final product) is **avoided**, assuming that less food has to be produced. The results are calculated for the categories apples, potatoes, breads & pastries, and oils & fats and expressed as GHG (left) and ecopoints (ecological scarcity 2013, right). The uncertainty bars show the standard deviation from Monte Carlo analysis. The alternatives show the environmental benefits if the same FW (final product, i.e. bread, oil, etc.) is

> **incinerated** (average for Switzerland; best case is the incineration plant of Basel with thermic optimization, the worst case Niederurnen with electrical optimization); substitution is modeled with the Swiss electricity mix and natural gas

> **digested** (best case with electricity and heat substitution and full digestate application, worst case with 50% heat use and 50% digestate application)

> **composted industrially** (best case with 100% compost use for peat and fertilizer substitution e.g. in growth media, worst case with 20% peat substitution, depending on the density of the substrates reported by Boldrin et al. (2009); no differentiation between food categories, assuming an average mix of FW)

> **composted at home** (best case and worst case emissions are modeled according to Boldrin et al. (2009); peat and fertilizer replacement is based on a survey in Denmark (Andersen et al., 2010, Andersen et al., 2012), reporting that 21% of householders replace peat and 18% inorganic fertilizer (the best scenario assumes 200% of this replacement, the worst scenario 50%; no differentiation between food categories, assuming an average mix of FW)

> **fed to swine** (best case with substitution of an optimal feed mix of barley, wheat, soy grits, and lysine; with the option to supplement each of these components up to the same amount as the FW fed to the animals in order to optimize the feed mix -> the nutrients of the FW plus the supplements must at minimum correspond to the nutrients of the substituted feed; worst case without option of supplementing).

Interpretation of Figure B.36:

a) **FW prevention** creates **by far more environmental benefits** than any of the FW treatment options, because the embedded impacts of food are much higher than the benefits from FW treatment. The benefits for prevention of agricultural FW cannot directly be compared with the other benefits because they refer to the original, unprocessed products (1t of unprocessed cereals, oil seeds).

b) **If FW prevention is not possible**, FW with high nutritional value (e.g. bread) creates the major GHG savings when used for animal feeding. In terms of ecopoints, even products with lower calorific content (e.g. apples, potatoes) are **preferably used for animal feeding**.

c) Anaerobic digestion (AD) and incineration have the advantage of environmental credits from energy substitution, whereas composting and partly AD have the advantage of environmental credits from fertilizer substitution and from the improved soil effect, which is modeled as peat substitution. Since the **energy yield increases with the energetic content of the substrate**, fats and oils are preferably incinerated or digested, whereas fruits and vegetables are preferably composted.

d) The **improved soil effect** is **not differentiated by food categories in this model**, even though it is usually higher for substrates with high contents of carbon and organic matter. This effect would rather support the conclusion in paragraph c).

e) The energy yields from incineration are calculated proportionally to the lower heating value of the substrates; the energy yields from anaerobic digestion (AD) are average values from various literature sources, partly based on empirical values. Therefore the environmental **credits from high energy crops (oils and fats) may be overestimated, especially in the case of incineration.**

f) The results **for FW of animal products** are not shown since they are hypothetical (**hygiene issues are not considered** and the content of organic matter and water are not differentiated between food categories, thus overestimating the improved soil credits for animal products). However, **for animal products anaerobic digestion (or in some cases incineration) may be the most appropriate option after animal feeding**.

B.13 REGIONALIZED BIODIVERSITY IMPACTS

B.13.1 Share of impacts in Switzerland and import countries

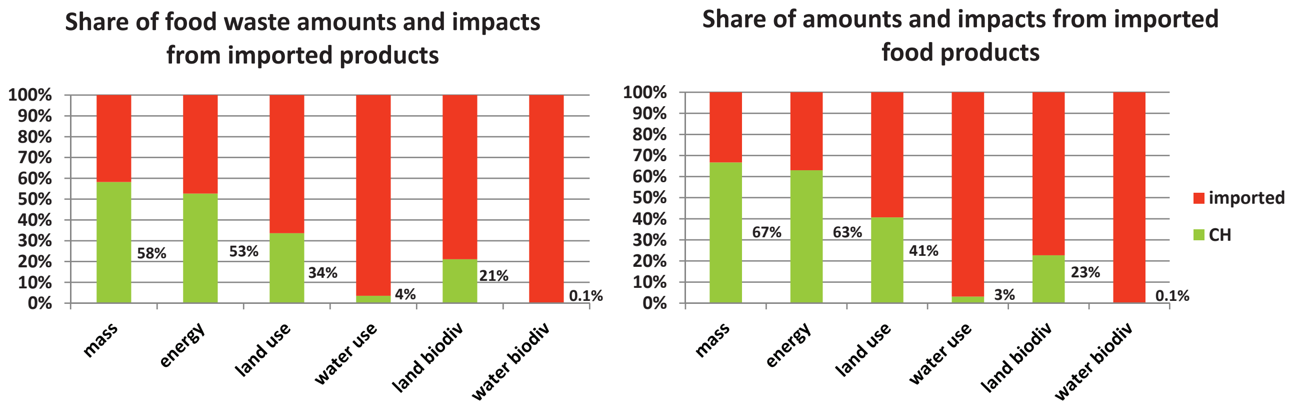


Figure B.37: The left graph shows the share of the amounts (mass and energy) and the environmental impacts (land use in m^2a, water use in m^3, global biodiversity in _gPDF-eq*a_) of FW of imported products and of Swiss products (CH). The right graph shows the same numbers relating to total food consumption (including FW).

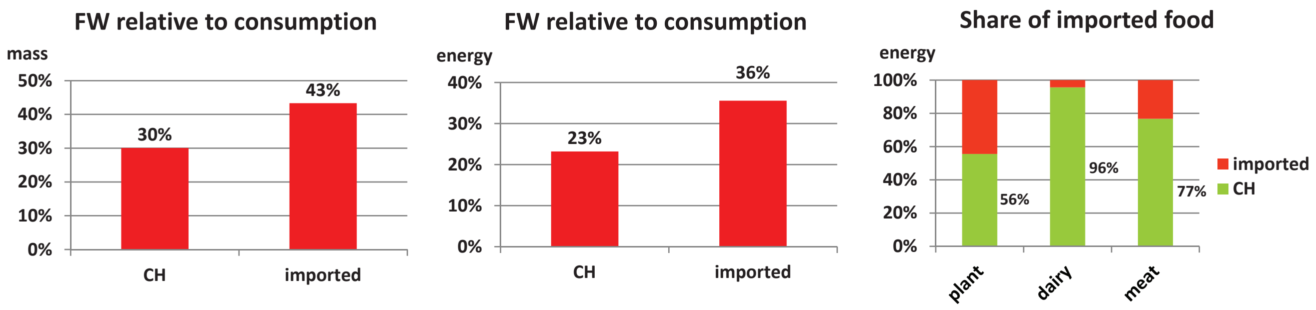


Figure B.38: Avoidable FW relative to the entire consumption in terms of mass (left) and in terms of energy (middle) for domestic products (CH) and imported products. The right graph shows the share of imported food for the food groups *plant products*, *dairy products,* and *meat and fish*.

Figure B.37 and Figure B.38:

a) Even though less than 50% of the products that are wasted are imported, **most impacts take place in the import countries**, especially for water use and biodiversity. For water use a reason may be that water availability is relatively high in Switzerland, for global biodiversity that the number of endemic species is low in Switzerland compared to other countries. However, **the biodiversity impactson a regional or local level may be higher** in Switzerland.

b) The **land impacts on global biodiversity are more important in import countries** (about 80%) even though a high fraction of land use takes place in Switzerland (30-40%).

B.13.2 Products with the highest impacts

B.13.2.1 *Global biodiversity impacts from land use*

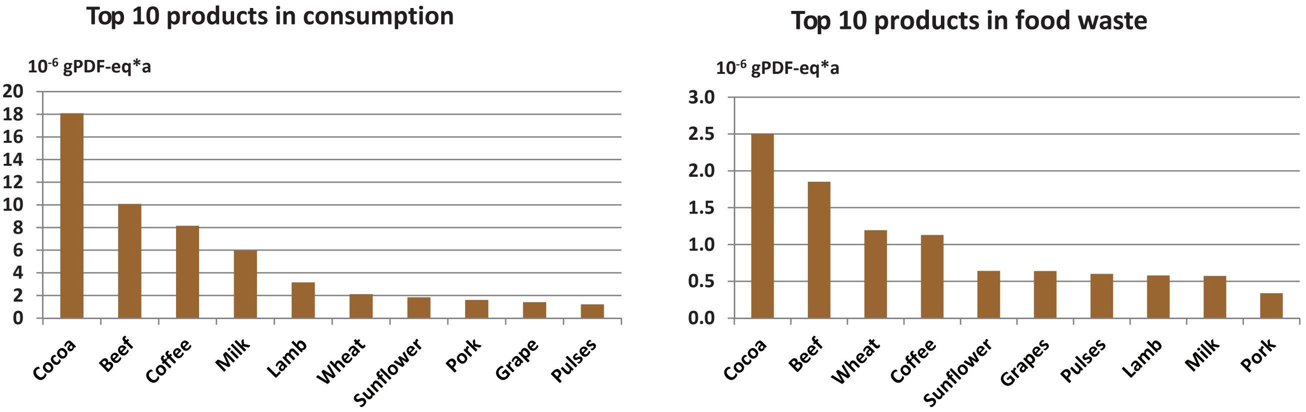


Figure B.39: Top ten food categories with the highest global biodiversity impact from *land* use related to total Swiss food consumption including FW (left) and to FW (right).

B.13.2.2 *Global biodiversity impacts from water use*

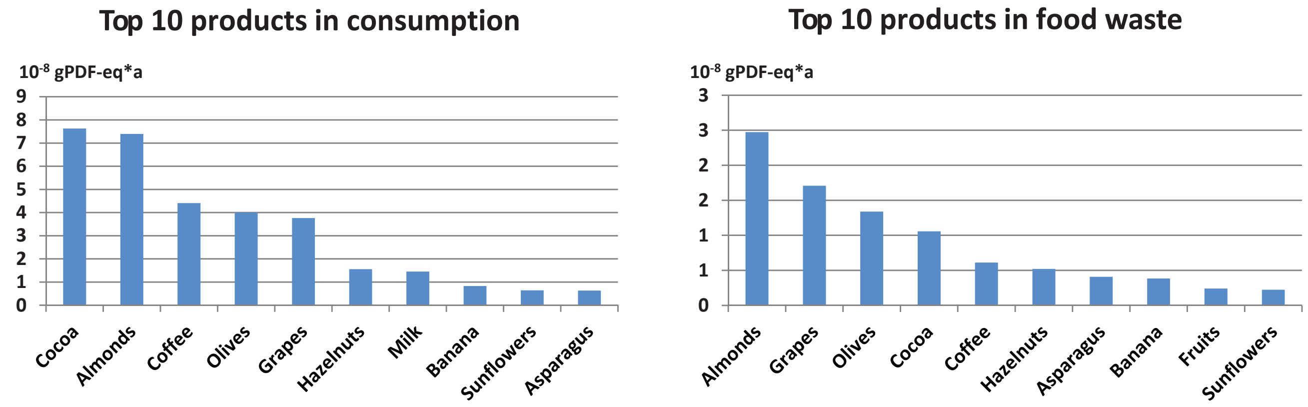


Figure B.40: Top ten products from a list of 140 products with the highest global biodiversity impact from *water* use related to Swiss food consumption (left) and losses (right). Considering the impacts from FW almonds, grapes, and olives rank higher than for the impacts of consumption. Cocoa moves from the first to the fourth place when considering FW, probably because of its relatively low loss rate.

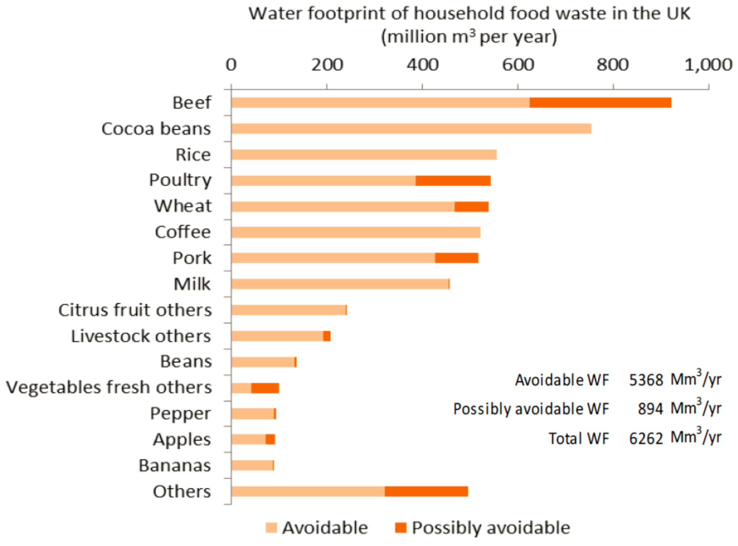


Figure B.41: To compare: Total water footprint of household FW in the UK for major food categories. Reprinted from Chapagain and James (2011).

B.13.3 Localization of impacts

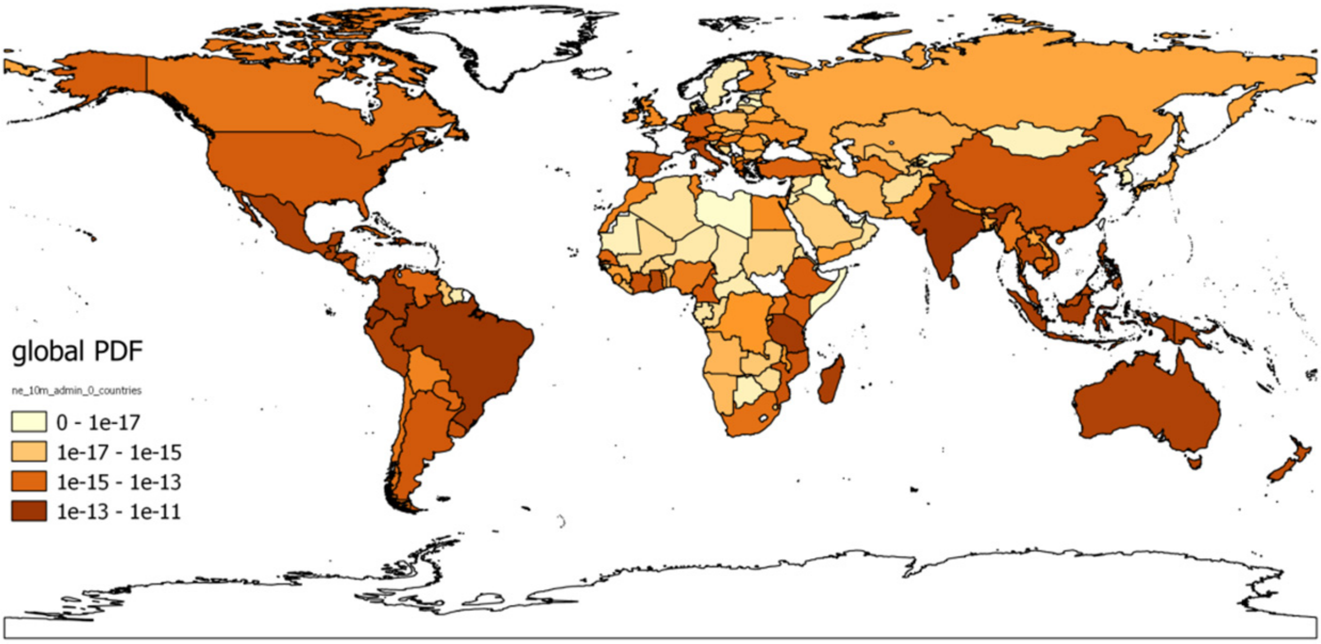


Figure B.42: Global biodiversity impact from *land* and *water* use in gPDF-eq*a, resulting from FW that is related to Swiss food consumption (production and net imports). The map is based on open source data from GDAL (GDAL, 2017).

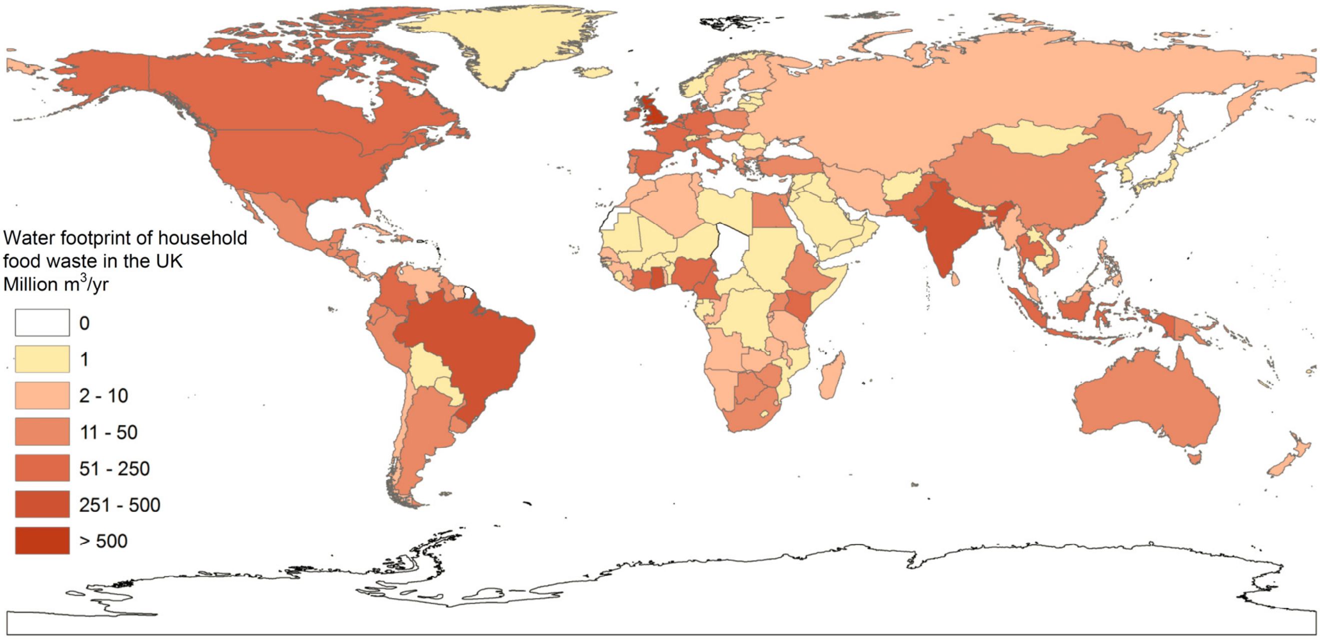


Figure B.43: To compare: The UK's external water footprint of household FW. Reprinted from Chapagain and James (2011).

B.14 COMPARISON WITH HOTSPOTS REPORTED BY FAO

FAO (2013) also identified environmentally relevant food losses, but on a global level. They found the following hotspots:

XI. Wastage of **cereals in Asia** emerges as a significant problem for the environment, with major impacts on carbon, blue water and arable land.

XII. **Rice** represents a significant share of these impacts, given the **high carbon-intensity** of rice production methods (e.g. paddies are major emitters of methane), combined with **high quantities of rice wastage**.

XIII. Wastage of **meat,** even though wastage volumes in all regions are comparatively low, generates a substantial impact on the environment **in terms of land occupation** and **carbon footprint**, especially in high income regions (that waste about 67 percent of meat) and Latin America.

XIV. **Fruit** wastage emerges as a **blue water hotspot in Asia, Latin America, and Europe** because of food wastage **volumes.**

XV. **Vegetables** wastage **in industrialized Asia, Europe, and South and South East Asia** constitutes a high carbon footprint, mainly due to large wastage **volumes**.

Vegetables and cereals (mainly due to high quantities) and meat (mainly due to high impacts per kg) are consistent with our results. However, we identify bread cereals as more important than rice, probably because of lower rice consumption in Switzerland compared to Asia. On the other hand, the high Swiss cheese consumption combined with relatively high impacts and the co-product whey, which is rarely used for human food, make cheese an additional hotspot in Switzerland. Fruits seem to be less important in our study as long as a large fraction of the sub-standard products are used for juice production. However, the losses in agriculture are uncertain and do not include the potential of unharvested fruit trees. In terms of blue water footprint, specific fruits are very important, e.g. grapes and banana.

B.15 ENVIRONMENTAL IMPACTS AND BENEFITS FROM FOOD DONATION

Table B.17: Transport distances, gas for heating and electricity for cooling per kg of donated food. The numbers are calculated based on the case study of a major Swiss donation association (Tdd, 2015).

Factors per functional unit			Used ecoinvent processes for LCA
Lorry	168.3	kgkm/kg	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 [RER]| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Rec, U
Lorry	82.9	kgkm/kg	Transport, freight, lorry 16-32 metric ton, EURO3 [RER]| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U
Gas for heating	0.42	MJ/kg	Heat, district or industrial, natural gas [CH]| market for heat, district or industrial, natural gas | Alloc Rec, U
Electricity for cooling	0.05	MJ/kg	Electricity, low voltage [CH]| market for | Alloc Rec, U

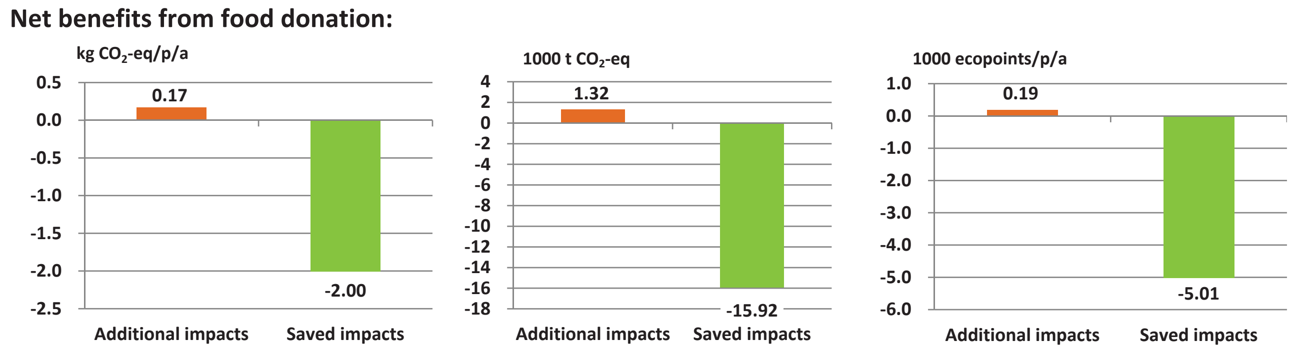


Figure B.44: GHG emitted (left graphs) and ecopoints caused (right graph) by total Swiss food donations (transport, heating, and cooling of storage rooms) divided by all Swiss consumers (Tdd, 2015) and saved impacts by avoiding the additional production of the donated food. The GHG savings are estimated about 12 times higher than the impacts for the distribution logistics, the total saved ecopoints 26 times higher.

B.16 ECONOMICAL RELEVANCE OF FOOD WASTE (FROM LITERATURE)

The direct economic cost of FW of agricultural products, excluding fish and seafood, based on producer prices only, is about USD 750 billion per year, equivalent to the GDP of Switzerland, and the **cost of total FW** about **USD 1 trillion each year**. However, the hidden costs of FW extend much further. In addition to direct economic costs, **environmental costs** reach around **USD 700 billion** and **social costs** around **USD 900 billion** (FAO, 2013). Quested et al. (2013) suggest that the edible food and drink wasted in an average UK home has a retail value of approximately USD 400-650 (£250-400) a year.

DATA RELIABILITY

B.17 PEDIGREE ANALYSIS

Table B.18 shows the pedigree matrix used for the assessment of data reliability, which is illustrated in Table B.34 and Table B.35. A pedigree score was attributed to each data source for the five indicators *reliability, completeness, temporal, geographical, further technological correlation* and for *sample size*. Where several references were used for the same estimate (e.g. *grapes, pears, apricots*, and *peaches* to approximate *non-exotic fresh fruits*), the pedigree scores for *completeness* and *sample size* were attributed to all the references together (*completeness* in this case is 100%, because all *fresh fruits* are assumed to have similar impacts as *grapes, pears, apricots*, and *peaches*; *sample size* is 65%, because *grapes, pears, apricots*, and *peaches* make up 65% of total consumption of *non-exotic fresh fruits*).

Table B.18: Pedigree matrix. *Completeness* means that datasets for a SPECIFIC OR SIMILAR product account for x% of the consumption of a food category, *sample size* that datasets for a SPECIFIC product account for x% of the consumption of a food category. Adapted from Frischknecht et al. (2007).

Pedigree score	1	2	3	4	5 (default)
Reliability (to be checked in report or internet)	Verified data based on measurements	Verified data partly based on assumptions ***or*** non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate or data derived from theoretical information	Non-qualified estimate
Completeness	100-80%	60-80%	40-60%	20-40%	<20%
Sample size	100-80%	60-80%	40-60%	20-40%	<20%
Temporal correlation	2013-2017	2010-2012	2005-2009	2000-2004	Before 2000
Geographical correlation	LCA dataset referring to the same country where most of the products come from	Geographically close countries with the same climatic conditions	Countries with the same or similar climatic conditions	Countries with slightly different climatic conditions	Countries with different climatic conditions or data unknown
Further technological correlation	Same practices in fertilizer application (0-10% difference)	Similar practices in fertilizer application (10-30% difference)	Rather similar practices in fertilizer application (30-50% difference)	Rather different practices in fertilizer application (50-70% difference)	Different practices in fertilizer application (more than 70% difference)

The uncertainty estimations (SD_{g95}) in Table B.34 and Table B.35 were calculated with the formula (B.2) and (B.3).

$$U_{1\text{-}4,a} = [\ln(U_{1,a})]^2 + [\ln(U_{2,a})]^2 + [\ln(U_{3,a})]^2 + [\ln(U_{4,a})]^2 \qquad \text{(B.2)}$$

with:

$U_{1,a}$: uncertainty factor of reliability of reference a

$U_{2,a}$: uncertainty factor of temporal correlation of reference a

$U_{2,b}$: uncertainty factor of temporal correlation of reference b

...

$$SD_{g95} = \exp^{\sqrt{[\ln(U_{1-4})]^2 + [\ln(U_5)]^2 + [\ln(U_6)]^2 + [\ln(U_7)]^2}} \qquad \text{(B.3)}$$

with:

SD_{g95} : uncertainty estimation (square of the geometric standard deviation, 95% interval)

$U_{1\text{-}4}$: average of $U_{1\text{-}4,a}$, $U_{1\text{-}4,b}$,...

The uncertainty factors applied for a specific pedigree score are shown in Table B.19.

Table B.19: Uncertainty factors, applied together with the pedigree matrix. Adapted from Frischknecht et al. (2007).

	Pedigree Score				
Indicator	**1**	**2**	**3**	**4**	**5**
U_1 Reliability	1	1.05	1.10	1.20	1.5
U_2 Temporal correlation	1	1.03	1.10	1.20	1.5
U_3 Geographical correlation	1	1.01	1.02	1.05	1.1
U_4 Further technological correlation	1	1.10	1.20	1.50	2.0
U_5 Completeness	1	1.02	1.05	1.10	1.2
U_6 Sample size	1	1.02	1.05	1.10	1.2
U_7 Basic uncertainty	1.05				

B.17.1 Attribution of pedigree scores

B.17.1.1 Geographical correlation

The geographical correlation is a measure for the similarity of the country an LCA dataset is based on and the main import country of the corresponding product to Switzerland. In this study, the similarity is estimated qualitatively based on climatic conditions such as climate zone and average annual temperature as well as geographical proximity. Table B.20 shows the definition of the pedigree scores, Table B.21 the main origin of each product (import country or Switzerland), the reference country of the corresponding LCA dataset, and the score that was attributed.

Table B.20: Definition of the pedigree scores for geographical correlation

Score	Definition
1	The origin of the LCA dataset is the same country as most of the products come from
2	Geographically close countries with the same climatic conditions
3	Countries with the same or similar climatic conditions
4	Countries with slightly different climatic conditions
5	Countries with different climatic conditions or data unknown

Table B.21: Geographical correlation of individual products

Product	Main import country	Reference	Country of LCA data	Score	Comments/assumptions
Apples					
Apples	Switzerland	(SBV, 2015)	Switzerland	1	
Fresh Fruits					
Peach and Pear	Switzerland	(SBV, 2015)	Switzerland	1	
Grapes	Switzerland	(SBV, 2015)	Spain	3	Slightly different climate
Apricots	Switzerland	(SBV, 2015)	France	2	Similar climate, neighbouring countries
Berries, exotic, citrus fruits					
Kiwi	Italy	(SBV, 2015)	Italy	1	
Strawberry	Spain	(SBV, 2015)	Switzerland	3	Slightly different climate
Avocado	Peru	(FAOSTAT, 2016)	Israel	4	Slightly different climate, no proximity
Banana	Colombia	(SBV, 2015)	Colombia	1	
Citrus (Lemmon)	Spain	(SBV, 2015)	Italy	4	Slightly different climate, no proximity
Papaya	Brazil	(SBV, 2015)	Brazil	1	
Pineapple	Costa Rica	(SBV, 2015)	Costa Rica	1	
Mandarin	Spain	(FAOSTAT, 2016)	Spain	1	
Orange ES	Spain	(SBV, 2015)	Spain	1	
Orange CH-Import	Spain	(SBV, 2015)	Brazil	4	Slightly different climate, no proximity
Canned Fruits					
Pear and Peach	Switzerland	(SBV, 2015)	Switzerland	1	
Grape	Switzerland	(SBV, 2015)	Spain	3	Slightly different climate
Pineapple	Costa Rica	(SBV, 2015)	Costa Rica	1	
Apricot	Switzerland	(SBV, 2015)	France	2	Same climate, neighbouring countries
Potatoes					
Potato organic & Potato	Switzerland	(SBV, 2015)	Switzerland	1	
Fresh Vegetables					
Aubergine	Switzerland	(SBV, 2015)	Switzerland	1	
Broccoli	Switzerland	assumption	Switzerland	1	
Cauliflower	Switzerland	(SBV, 2015)	Switzerland	1	
Celery	Switzerland	(VSGP, 2014)	Switzerland	1	
Cucumber	Switzerland	(SBV, 2015)	Switzerland	1	
Fennel	Switzerland	(VSGP, 2014)	Switzerland	1	
Green asparagus	Mexico	(SBV, 2015)	Switzerland	5	Climatically different, no proximity
Green bell Pepper	Vietnam	(SBV, 2015)	Switzerland	5	Climatically different, no proximity
Iceberg lettuce	Switzerland	(SBV, 2015)	Switzerland	1	
Lettuce Greenhouse	Switzerland	(SBV, 2015)	Switzerland	1	
Lettuce field	Switzerland	(SBV, 2015)	Switzerland	1	
Melon	Spain	(SBV, 2015)	France	3	Similar climate, neighbouring countries
Radish	Switzerland	(VSGP, 2014)	Switzerland	1	
Spinach	Switzerland	(SBV, 2015)	Switzerland	1	
Tomato	Italy	(SBV, 2015)	Switzerland	3	Similar climate, neighbouring countries
White asparagus	Mexico	(SBV, 2015)	Switzerland	5	Climatically different, no proximity
Zucchini	Spain	(SBV, 2015)	Switzerland	3	

Storable Vegetables					
Fava bean organic	Switzerland	(VSGP, 2014)	Switzerland	1	
Fava bean	Switzerland	(VSGP, 2014)	Switzerland	1	
Cabbage red	Switzerland	(FAOSTAT, 2016)	Switzerland	1	
Cabbage white	Switzerland	(FAOSTAT, 2016)	Switzerland	1	
Carrot	Switzerland	(SBV, 2015)	Switzerland	1	
Onion	Switzerland	(SBV, 2015)	Switzerland	1	
Vanilla	Madagascar	(SBV, 2015)	Madagascar	1	
Processed Vegetables					
Fava bean organic	Switzerland	(VSGP, 2014)	Switzerland	1	
Fava bean	Switzerland	(VSGP, 2014)	Switzerland	1	
Carrot	Switzerland	(SBV, 2015)	Switzerland	1	
Spinach	Switzerland	(SBV, 2015)	Switzerland	1	
Bread Wheat					
Barley Grain extensive	Germany	(SBV, 2015)	Switzerland	2	Same climate, neighbouring countries
Barley Grain intensive	Germany	(SBV, 2015)	Switzerland	2	Same climate, neighbouring countries
Rye Grain extensive	Switzerland	(SBV, 2015)	Switzerland	1	
Rye Grain intensive	Switzerland	(SBV, 2015)	Switzerland	1	
Wheat grain organic	Switzerland	(SBV, 2015)	Switzerland	1	
Wheat grain extensive	Switzerland	(SBV, 2015)	Switzerland	1	
Wheat grain intensive	Switzerland	(SBV, 2015)	Switzerland	1	
Oat	Finland	(SBV, 2015)	Canada and Finland	1	
Durum Wheat					
Durum Wheat	Switzerland	(SBV, 2015)	Italy	3	Similar climate, neighbouring countries
Rice					
Rice	Italy	(SBV, 2015)	China and India	4	Slightly different climate, no proximity
Corn					
Maize grain organic	Italy	(SBV, 2015)	USA, Argentina and Brazil	5	Climatically different, no proximity
Maize grain	Italy	(SBV, 2015)	USA, Argentina and Brazil	5	Climatically different, no proximity
Sugar					
Sugar from Beet	Germany	(SBV, 2015)	Switzerland	2	Same climate, neighbouring countries
Sugar from Cane	Brazil	(SBV, 2015)	Brazil	1	
Oils, fats, nuts, seeds					
Palm oil	Malaysia	(SBV, 2015)	Malaysia and Indonesia	1	
Rape oil	Switzerland	(SBV, 2015)	Switzerland	1	
Margarine	Germany	(FAOSTAT, 2016)	Spain	4	Slightly different climate
Olive oil	Italy	(SBV, 2015)	Spain and Italy	1	
Sunflower oil	Tanzania	(SBV, 2015)	Hungary, France, Ukraine	4	Slightly different climate
Coconut	Cote d'Ivoire	(SBV, 2015)	Philippines	3	
Tofu	Brazil	(SBV, 2015)	Canada	4	Slightly different climate, no proximity
Almonds	USA	(FAOSTAT, 2016)	USA and China	1	
Peanut	Egypt	(SBV, 2015)	India and Argentina	3	
Olives org	Italy	(SBV, 2015)	Italy	1	
Dairy, Cheese and Butter					
milk IP	Switzerland	(SBV, 2015)	Switzerland	1	
Milk org	Switzerland	(SBV, 2015)	Switzerland	1	
Beef IP	Switzerland	(SBV, 2015)	Switzerland	1	
veal IP	Switzerland	(SBV, 2014)	Switzerland	1	
Veal org	Switzerland	(SBV, 2014)	Switzerland	1	
Eggs					
Eggs NL	Switzerland 50%, NL 20%, FR 5%	(SBV, 2015)	The Netherlands	2	Climatic difference little relevant for eggs
Eggs average FR		(SBV, 2015)	France	2	Same climate, neighbouring countries
Pork					
Pigs	Switzerland	(SBV, 2015)	The Netherlands	2	Climatic difference little relevant for pigs
Pork	Switzerland	(SBV, 2015)	Germany, Canada and Spain	2	Climatic difference little relevant for pigs
Poultry					
Broilers NL AF	Switzerland 40%, Brazil 22%	(SBV, 2015)	The Netherlands	2	Climatic difference little relevant for hens
Chicken BR WF		(SBV, 2015)	Brazil	1	
Beef					
Beef GLO	Switzerland 74%, Germany 11%, Italy 3%	(SBV, 2015)	Brazil, Australia and USA	5	Climatically different, no proximity
Beef IP		(SBV, 2015)	Switzerland	1	
Beef org		(SBV, 2015)	Switzerland	1	
Horse	Germany	(FAOSTAT, 2016)	Switzerland	2	Same climate, neighbouring countries

Veal	Switzerland	(SBV, 2014)	Switzerland	1	
Fish					
Large trout	Turkey	(SBV, 2015)	France	4	Some climatic similarities, no proximity
Sea bass	France	(SBV, 2015)	France	1	
Small trout	Turkey	(SBV, 2015)	France	4	Some climatic similarities, no proximity
Coffee, Tea, Chocolate					
Coffee	Brazil	(SBV, 2015)	Brazil, Vietnam and Indonesia	1	
Dark chocolate	Ghana	(SBV, 2015)	Canary Islands, Indonesia and Ghana	1	
Milk chocolate	Ghana	(SBV, 2015)	Canary Islands, Indonesia and Ghana	1	
Tea	Brazil (30%), Argentina (24%), Kenia (12%)	(SBV, 2015)	Kenia	3	Some climatic similarities, no proximity, modeled country represents correctly 12% of imports

B.17.1.2 Temporal correlation

The temporal correlation defines how up-to-date a dataset is. Table B.22 shows the definition of the pedigree scores, Table B.23 the scores attributed to individual products.

Table B.22: Definition of pedigree scores for temporal correlation

Score	Definition
1	The LCA dataset dates after 2012
2	The LCA dataset dates between 2010 and 2012
3	The LCA dataset dates between 2005 and 2010
4	The LCA dataset dates between 2000 and 2005
5	The LCA dataset dates before 2000

Table B.23: Temporal correlation of individual products

Product	Reference	Score
Apples		
Apples	(ecoinvent, 2016)	2
Fresh Fruits		
Pear	(ecoinvent, 2016)	2
Grapes	(ecoinvent, 2016)	2
Apricots	(WFLDB, 2015)	2
Peach	(WFLDB, 2015)	2
Berries, exotic, citrus fruits		
Kiwi	(WFLDB, 2015)	2
Strawberry	(ecoinvent, 2016)	2
Avocado	(ecoinvent, 2016)	2
Banana	(ecoinvent, 2016)	2
Citrus	(ecoinvent, 2016)	2
Papaya	(ecoinvent, 2016)	2
Pineapple	(ecoinvent, 2016)	2
Mandarin	(WFLDB, 2015)	2
Orange ES	(WFLDB, 2015)	5
Orange CH	(WFLDB, 2015)	3
Canned Fruits		
Pear	(ecoinvent, 2016)	2
Grape	(ecoinvent, 2016)	2
Pineapple	(ecoinvent, 2016)	2
Apricot	(WFLDB, 2015)	2
Peach	(WFLDB, 2015)	2
Potatoes		
Potato organic & Potato	(ecoinvent, 2016)	3
Fresh Vegetables		
Aubergine	(ecoinvent, 2016)	2
Broccoli	(ecoinvent, 2016)	2
Cauliflower	(ecoinvent, 2016)	2
Celery	(ecoinvent, 2016)	2
Cucumber	(ecoinvent, 2016)	2
Fennel	(ecoinvent, 2016)	2
Green asparagus	(ecoinvent, 2016)	2
Green bell Pepper	(ecoinvent, 2016)	2
Iceberg lettuce	(ecoinvent, 2016)	2
Lettuce Greenhouse	(ecoinvent, 2016)	2
Lettuce field	(ecoinvent, 2016)	2
Melon	(ecoinvent, 2016)	2
Radish	(ecoinvent, 2016)	2
Spinach	(ecoinvent, 2016)	2
Tomato	(ecoinvent, 2016)	2
White asparagus	(ecoinvent, 2016)	2

Zucchini	(ecoinvent, 2016)	2
Storable Vegetables		
Fava bean organic	(ecoinvent, 2016)	4
Fava bean	(ecoinvent, 2016)	4
Cabbage red	(ecoinvent, 2016)	2
Cabbage white	(ecoinvent, 2016)	2
Carrot	(ecoinvent, 2016)	2
Onion	(ecoinvent, 2016)	2
Vanilla	(WFLDB, 2015)	5
Processed Vegetables		
Fava bean organic	(ecoinvent, 2016)	4
Fava bean	(ecoinvent, 2016)	4
Carrot	(ecoinvent, 2016)	2
Spinach	(ecoinvent, 2016)	2
Bread Wheat		
Barley Grain extensive	(ecoinvent, 2016)	4
Barley Grain intensive	(ecoinvent, 2016)	4
Rye Grain extensive	(ecoinvent, 2016)	4
Rye Grain intensive	(ecoinvent, 2016)	4
Wheat grain organic	(ecoinvent, 2016)	4
Wheat grain extensive	(ecoinvent, 2016)	4
Wheat grain intensive	(ecoinvent, 2016)	4
Oat	(WFLDB, 2015)	2
Durum Wheat		
Durum Wheat	(WFLDB, 2015)	4
Rice		
Rice	(ecoinvent, 2016)	3
Corn		
Maize grain organic	(ecoinvent, 2016)	4
Maize grain	(ecoinvent, 2016)	4
Sugar		
Sugar from Beet	(ecoinvent, 2016)	3
Sugar from Cane	(ecoinvent, 2016)	3
Oils, fats, nuts, seeds		
Palm oil	(ecoinvent, 2016)	3
Rape oil	(ecoinvent, 2016)	3
Margarine	(WFLDB, 2015)	4
Olive oil	(WFLDB, 2015)	4
Sunflower oil	(WFLDB, 2015)	4
Coconut	(ecoinvent, 2016)	5
Tofu	(ecoinvent, 2016)	1
Almonds	(WFLDB, 2015)	2
Peanut	(WFLDB, 2015)	2
Olives org	(ZHAW, 2014)	4
Dairy, Cheese and Butter		
Milk IP	(Wettstein, 2016)	3
Milk org	(Wettstein, 2016)	3
Beef IP	(Wettstein, 2016)	3
veal IP	(Wettstein, 2016)	3
Veal org	(Wettstein, 2016)	3
Eggs		
Eggs NL	(Agri-Footprint, 2014)	1
Eggs average FR	(Agri-Footprint, 2014)	3
Pork		
Pigs	(Agri-Footprint, 2014)	2
Pork	(WFLDB, 2015)	3
Poultry		
Broilers NL AF	(Agri-Footprint, 2014)	1
Chicken BR WF	(Wettstein, 2016)	3
Chicken US WF	(Wettstein, 2016)	3
Beef		
Beef GLO	(Wettstein, 2016)	2
Beef IP	(Wettstein, 2016)	3
Beef org	(Wettstein, 2016)	3
Horse	(Wettstein, 2016)	3
Veal	(Wettstein, 2016)	3
Fish		
Large trout	(Colomb, 2016)	3
Sea bass	(Colomb, 2016)	3
Small trout	(Colomb, 2016)	3
Coffee, Tea, Chocolate		
Coffee	(WFLDB, 2015)	4
Dark chocolate	(WFLDB, 2015)	3
Milk chocolate	(WFLDB, 2015)	3
Tea	(WFLDB, 2015)	2

B.17.1.3 Reliability

The reliability is an indicator for the methodological appropriateness and consistency and for the precision and uncertainty of the measurements. Table B.24 shows the definition of the individual scores,

Table B.25 the scores attributed to individual products, and

Table B.26 the data quality description of ecoinvent datasets and their attribution to the scores used in this assessment.

Table B.24: Definition of pedigree scores for reliability

Score	Definition
1	Verified data based on measurements
2	Verified data partly based on assumptions or non-verified data based on measurements
3	Non-verified data partly based on qualified estimates
4	Qualified estimate (e.g. by industrial expert); data derived from theoretical information
5	Non-qualified estimate

Table B.25: Reliability of individual products (where reliability is based on ILCD scores in this table it is calculated as average between the ILCD scores “Methodological appropriateness and consistency” and “Precision / uncertainty”)

Product	Source	Country of LCA data	Score	Comments
Apples				
Apples	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Fresh Fruits				
Pear	(ecoinvent, 2016)	Switzerland	3	see Table B.26
Grapes	(ecoinvent, 2016)	Spain	2	see Table B.26
Apricots	(WFLDB, 2015)	France	1	ILCD data quality rating at dataset level
Peach	(WFLDB, 2015)	CH-Import mix	3	ILCD data quality rating at dataset level
Berries, exotic, citrus fruits				
Kiwi	(ecoinvent, 2016)	GLO	3	see Table B.26
Strawberry	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Avocado	(ecoinvent, 2016)	Israel	3	see Table B.26
Banana	(ecoinvent, 2016)	Colombia	3	see Table B.26
Citrus	(ecoinvent, 2016)	Italia	3	see Table B.26
Papaya	(ecoinvent, 2016)	Brazil	3	see Table B.26
Pineapple	(ecoinvent, 2016)	Costa Rica	3	see Table B.26
Mandarin	(WFLDB, 2015)	Spain	3	ILCD data quality rating at dataset level
Orange fresh ES	(WFLDB, 2015)	Spain	2	ILCD data quality rating at dataset level
Orange processed	(WFLDB, 2015)	Spain	2	ILCD data quality rating at dataset level
Canned Fruits				
Pear	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Grape	(ecoinvent, 2016)	Spain	3	see Table B.26
Pineapple	(ecoinvent, 2016)	Costa Rica	3	see Table B.26
Apricot	(WFLDB, 2015)	France	1	ILCD data quality rating at dataset level
Peach	(WFLDB, 2015)	CH-Import mix	4	ILCD data quality rating at dataset level
Potatoes				
Potato organic & Potato	(ecoinvent, 2016)	Switzerland	3	see Table B.26
Fresh Vegetables				
Aubergine	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Broccoli	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Cauliflower	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Celery	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Cucumber	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Fennel	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Green asparagus	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Green bell Pepper	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Iceberg lettuce	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Lettuce Greenhouse	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Lettuce field	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Melon	(ecoinvent, 2016)	France	3	see Table B.26
Radish	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Spinach	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Tomato	(ecoinvent, 2016)	Switzerland	2	see Table B.26
White asparagus	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Zucchini	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Storable Vegetables				
Fava bean organic	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Fava bean	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Cabbage red	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Cabbage white	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Carrot	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Onion	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Vanilla	(WFLDB, 2015)	Madagascar	5	ILCD data quality rating: no information
Processed Vegetables				
Fava bean organic	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Fava bean	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Carrot	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Spinach	(ecoinvent, 2016)	Switzerland	2	see Table B.26

Bread Wheat				
Barley Grain extensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Barley Grain intensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Rye Grain extensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Rye Grain intensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Wheat grain organic	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Wheat grain extensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Wheat grain intensive	(ecoinvent, 2016)	Switzerland	4	see Table B.26
Oat	(WFLDB, 2015)	Canada and Finland	2	ILCD data quality rating at dataset level1
Durum Wheat				
Durum Wheat	(WFLDB, 2015)	Italia	2	ILCD data quality rating at dataset level[1]
Rice				
Rice	(ecoinvent, 2016)	China and India	4	see Table B.26
Corn				
Maize grain organic	(ecoinvent, 2016)	USA, Argentina and Brazil	4	see Table B.26
Maize grain	(ecoinvent, 2016)	USA, Argentina and Brazil	4	see Table B.26
Sugar				
Sugar from Beet	(ecoinvent, 2016)	Switzerland	1	see Table B.26
Sugar from Cane	(ecoinvent, 2016)	Brazil	1	see Table B.26
Oils, fats, nuts, seeds				
Palm oil	(ecoinvent, 2016)	Malaysia and Indonesia	4	see Table B.26
Rape oil	(ecoinvent, 2016)	Switzerland	2	see Table B.26
Margarine	(WFLDB, 2015)	Spain	2	ILCD data quality rating at dataset level[1]
Olive oil	(WFLDB, 2015)	Spain and Italy	2	ILCD data quality rating at dataset level[1]
Sunflower oil	(WFLDB, 2015)	Hungary, France and Ukraine	2	ILCD data quality rating at dataset level[1]
Coconut	(ecoinvent, 2016)	Philippines	5	see Table B.26
Tofu	(ecoinvent, 2016)	Canada	1	see Table B.26
Almonds	(WFLDB, 2015)	USA and China	2	ILCD data quality rating at dataset level[1]
Peanut	(WFLDB, 2015)	India and Argentina	2	ILCD data quality rating at dataset level[1]
Olives org	(Schwab et al., 2014)	Italy	2	
Dairy, Cheese and Butter				
Milk IP	(Wettstein, 2016)	Switzerland	3	
Milk org	(Wettstein, 2016)	Switzerland	3	
Beef IP	(Wettstein, 2016)	Switzerland	3	
Veal IP	(Wettstein, 2016)	Switzerland	3	
Veal org	(Wettstein, 2016)	Switzerland	3	
Eggs				
Eggs NL	(Agri-Footprint, 2014)	Netherlands	3	based on one reference
Eggs average FR	(Colomb et al., 2015), (Colomb, 2016)	France	2	The Agribalyse V 1.2 documentation of datasets shows the results of an ILCD quality assessment:; “Precision / uncertainty = 2 (good) Methodological appropriateness / consistency = 2 (good)”
Pork				
Pigs	(Agri-Footprint, 2014)	Netherlands	3	“… checked by industry experts”
Pork	(WFLDB, 2015)	Germany, Canada and Spain	3	ILCD data quality rating at dataset level[1]
Poultry				
Broilers NL AF	(Agri-Footprint, 2014)	Netherlands	3	“…checked by industry experts”
Chicken BR WF	(WFLDB, 2015)	Brazil	3	ILCD data quality rating at dataset level[1]
Chicken US WF	(WFLDB, 2015)	USA	3	ILCD data quality rating at dataset level[1]
Beef				
Beef GLO	(WFLDB, 2015)	Brazil, Australia and USA	3	ILCD data quality rating at dataset level[1]
Beef IP	(Wettstein, 2016)	Switzerland	3	
Beef org	(Wettstein, 2016)	Switzerland	3	
Horse	(Wettstein, 2016)	Switzerland	3	
Veal	(Wettstein, 2016)	Switzerland	3	
Fish				
Large trout	(Colomb et al., 2015)	France	3	Agribalyse V 1.2 documentation of datasets : “ILCD-Quality: (detailed evaluation not performed) => final note = 2,6 (i.e.: basic quality)”
Sea bass	(Colomb et al., 2015)	France	3	
Small trout	(Colomb et al., 2015)	France	3	
Coffee, Tea, Chocolate				
Coffee	(WFLDB, 2015)	Brazil, Vietnam and Indonesia	2	ILCD data quality rating at dataset level[1]
Dark chocolate	(WFLDB, 2015)	Canary Islands, Indonesia and Ghana	3	ILCD data quality rating at dataset level[1]
Milk chocolate	(WFLDB, 2015)	Canary Islands, Indonesia and Ghana	3	ILCD data quality rating at dataset level[1]
Tea	(WFLDB, 2015)	Kenia	3	ILCD data quality rating at dataset level[1]

Table B.26: Attribution of pedigree scores to ecoinvent datasets (the description of data quality is adapted from the documentation of ecoinvent data)

Score	ecoinvent description of data quality
1	Sampling procedure: Data is from producer in CH, industrial data.
2	Sampling procedure: The LCI is based on production cost tables from Switzerland which is well representative for an Integrated Production in Switzerland. Most probably it is representative for productions in industrialized countries or farms which produces similarly.
3	Sampling procedure: The LCI is based on production information from different sources (peer reviewed journals, books, extension leaflets, personal information) and is well representative for a conventional production in their main production countries. Most probably it is representative for productions in other countries or farms which produce similarly.
4	Sampling procedure: Data were compiled from statistics, pilot network, fertilising recommendations, documents from extension services, information provided by retailers and expert knowledge. The production data was verified and adjusted by a group of experts.
5	Extrapolations: This dataset has been extrapolated from year 1995 to the year of the calculation (2014). The uncertainty has been adjusted accordingly.

B.17.1.4 Further Technological Correlation

We used the similarity of fertilizer application in the main producing country of a product and the country the LCI dataset is based on as an indicator for further technological correlation. Table B.27 shows of the definition of the pedigree scores, Table B.28 the scores attributed to the individual datasets. Fertilizer application is based on Actualix (2016).

Table B.27: Definition of pedigree scores for technological correlation

Score	Definition
1	Same practices in fertilizer application (0-10% difference of the modeled country from the main producing country)
2	Similar practices in fertilizer application (10-30% difference of the modeled country from the main producing country)
3	Rather similar practices in fertilizer application (30-50% difference of the modeled country from the main producing country)
4	Rather different practices in fertilizer application (50-70% difference of the modeled country from the main producing country)
5	Different practices in fertilizer application (more than 70% difference of the modeled country from the main producing country)

Table B.28: Technological correlation of individual products

Product	Main producing country	Amount of soil fertilizer applied [kg/ha arable land]	Country of LCA data	Amount of soil fertilizer applied [kg/ha arable land]	Difference [%]	Score
		= a		= b	= |(a-b)| / a	
Apples						
Apples	Switzerland	209	Switzerland	209	0	1
Fresh Fruits						
Peach and Pear	Switzerland	209	Switzerland	209	0	1
Grapes	Italy	151	Spain	124	18	2
Apricots	Switzerland	209	France	137	34	3
Berries, exotic, citrus fruits						
Kiwi	Italy	151	Italy	151	0	1
Strawberry	Spain	124	Switzerland	209	69	4
Avocado	Peru	104	Israel	269	159	5
Banana	Colombia	649	Colombia	649	0	1
Citrus	New Zealand	1486	Italia	151	90	5
Papaya	Brazil	182	Brazil	182	0	1
Pineapple	Costa Rica	700	Costa Rica	700	0	1
Mandarin	Spain	124	Spain	124	0	1
Orange ES	Spain	124	Spain	124	0	1
Orange CH	Brazil	182	Spain	124	32	3
Canned Fruits						
Pear and Peach	Switzerland	209	Switzerland	209	0	1
Grape	Italy	151	Spain	124	18	2
Pineapple	Costa Rica	700	Costa Rica	700	0	1
Apricot	Switzerland	209	France	137	34	3
Potatoes						
Potato organic & Potato	Switzerland	209	Switzerland	209	0	1
Fresh Vegetables						
Aubergine	Switzerland	209	Switzerland	209	0	1
Broccoli	Switzerland	209	Switzerland	209	0	1
Cauliflower	Switzerland	209	Switzerland	209	0	1
Celery	Switzerland	209	Switzerland	209	0	1
Cucumber	Switzerland	209	Switzerland	209	0	1
Fennel	Switzerland	209	Switzerland	209	0	1
Green asparagus	Mexico	72	Switzerland	209	190	5
Green bell Pepper	Vietnam	297	Switzerland	209	30	3
Iceberg lettuce	Switzerland	209	Switzerland	209	0	1
Lettuce Greenhouse	Switzerland	209	Switzerland	209	0	1
Lettuce field	Switzerland	209	Switzerland	209	0	1
Melon	Spain	124	France	137	10	2
Radish	Switzerland	209	Switzerland	209	0	1
Spinach	Switzerland	209	Switzerland	209	0	1
Tomato	Italy	151	Switzerland	209	38	3
White asparagus	Mexico	72	Switzerland	209	190	5
Zucchini	Spain	124	Switzerland	209	69	4
Storable Vegetables						
Fava bean organic	Switzerland	209	Switzerland	209	0	1
Fava bean	Switzerland	209	Switzerland	209	0	1
Cabbage red	Switzerland	209	Switzerland	209	0	1
Cabbage white	Switzerland	209	Switzerland	209	0	1
Carrot	Switzerland	209	Switzerland	209	0	1
Onion	Switzerland	209	Switzerland	209	0	1
Vanilla	Madagascar	4	Madagascar	4	0	1
Processed Vegetables						
Fava bean organic	Switzerland	209	Switzerland	209	0	1
Fava bean	Switzerland	209	Switzerland	209	0	1
Carrot	Switzerland	209	Switzerland	209	0	1
Spinach	Switzerland	209	Switzerland	209	0	1
Bread Wheat						
Barley Grain extensive	Germany	199	Switzerland	209	5	1
Barley Grain intensive	Germany	199	Switzerland	209	5	1

Rye Grain extensive	Switzerland	209	Switzerland	209	0	1
Rye Grain intensive	Switzerland	209	Switzerland	209	0	1
Wheat grain organic	Switzerland	209	Switzerland	209	0	1
Wheat grain extensive	Switzerland	209	Switzerland	209	0	1
Wheat grain intensive	Switzerland	209	Switzerland	209	0	1
Oat	Finland	168	Canada and Finland	168	0	1
Durum Wheat						
Durum Wheat	Switzerland	209	Italy	151	28	2
Rice						
Rice	Italy	151	China and India	364	141	5
Corn						
Maize grain organic	Italy	151	USA, Argentina and Brazil	182	21	2
Maize grain	Italy	151	USA, Argentina and Brazil	182	21	2
Sugar						
Sugar from Beet	Germany	199	Switzerland	209	5	1
Sugar from Cane	Brazil	182	Brazil	182	0	1
Oils, fats, nuts, seeds						
Palm oil	Malaysia	1727	Malaysia and Indonesia	1727	0	1
Rape oil	Switzerland	209	Switzerland	209	0	1
Margarine	Germany	199	Spain	124	38	3
Olive oil	Italy	151	Spain and Italy	151	0	1
Sunflower oil	Tanzania	4	Hungary, France and Ukraine	137	3325	5
Coconut	Cote d'Ivoire	36	Philippines	72	100	5
Tofu	Brazil	182	Canada	88	52	4
Almonds	USA	131	USA and China	131	0	1
Peanut	Egypt	636	India and Argentina	158	75	5
Olives org	Italy	151	Italy	151	0	1
Dairy, Cheese and Butter						
milk IP	Switzerland	209	Switzerland	209	0	1
Milk org	Switzerland	209	Switzerland	209	0	1
Beef IP	Switzerland	209	Switzerland	209	0	1
veal IP	Switzerland	209	Switzerland	209	0	1
Veal org	Switzerland	209	Switzerland	209	0	1
Eggs						
Eggs NL	Switzerland	209	Netherlands	231	11	2
Eggs average FR	Switzerland	209	France	137	34	3
Pork						
Pigs	Switzerland	209	Netherlands	231	11	2
Pork	Switzerland	209	Germany, Canada and Spain	199	5	1
Poultry						
Broilers NL AF	Switzerland	209	Netherlands	231	11	2
Chicken BR WF	Switzerland	209	Brazil	182	13	2
Beef						
Beef GLO	Switzerland	209	Brazil, Australia and USA	182	13	2
Beef IP	Switzerland	209	Switzerland	209	0	1
Beef org	Switzerland	209	Switzerland	209	0	1
Horse	Canada	88	Switzerland	209	138	5
Veal	Switzerland	209	Switzerland	209	0	1
Fish						
Large trout	Turkey	114	France	137	20	2
Sea bass	France	137	France	137	0	1
Small trout	Turkey	114	France	137	20	2
Coffee, Tea, Chocolate						
Coffee	Brazil	182	Brazil, Vietnam and Indonesia	182	0	1
Dark chocolate	Ghana	36	Canary Islands, Indonesia and Ghana	36	0	1
Milk chocolate	Ghana	36	Canary Islands, Indonesia and Ghana	36	0	1
Tea	Brazil	182	Kenia	53	71	5

B.17.1.5 Completeness

Completeness is an indicator for the quantitative percentage of products consumed in a product category that is represented by LCI datasets referring to these SPECIFIC or to SIMILAR products.

Example 1: Strawberries and kiwi are assumed to have similarities to all other berries, so with these two products 100% of berry consumption is represented by LCI datasets of a similar product -> completeness = 1.

Example 2: For processed vegetables only data for beans, carrots, and spinach was available; these products may have little similarities to a group of processed vegetables (peas, rhubarbs…) -> completeness = 3.

B.17.1.6 Sample size

Sample size is an indicator for the quantitative percentage of products consumed in a product category that is represented by LCI datasets referring to these SPECIFIC products (e.g. datasets for strawberry and kiwi represent berry consumption with 65% of total berry consumption -> sample size = 2; datasets for beans, carrots, and spinach represent processed vegebles with 40-50% -> smple size = 3).

B.18 DISCUSSION OF UNCERTAINTIES

Swiss food consumption

- The MFA and EFA in this publication are based on food consumption at retail level reported by SBV (2014) and Swissfruit (2015). In their statistics food which is wasted before its official quantification as *"available food production"* is not included in food consumption. However, potentially edible food which is wasted in later stages of the FVC (processing and trade industry) is still included in the reported consumption at retail level, if it is not officially quantified for the use as feed for livestock, seed or industrial non-food product (SBV, 2013). This may lead to an **overestimation of actual food consumption at retail level.** Nevertheless, we used **consumption at retail level as reference for our MFA**, because it was not possible to identify the losses which are still included in the consumption reported by SBV (2014) and Swissfruit (2015). Furthermore, final consumption (consumption at retail level minus FW in households and food services) is consistent with calorie consumption estimated by nutrition experts (Table B.29).

Quantification of food waste

- **Household FW** in this study is based on UK numbers by Quested and Johnson (2009), because their methodology is judged as most reliable. Between 2009 and 2012 a large FW campaign was accomplished in the UK (Quested et al., 2013). However, since no comparable FW campaign has taken place in Switzerland, we use the UK numbers from before the campaign and adopt them to the Swiss food basket.
- The **allocation** of the reported FW amounts **to agriculture, trade, and the processing industry** is based on case studies. However, the stage of the FVC where sorting and storage takes place may vary from case to case, so some of the losses may not be attributed to the appropriate stage of the FVC.
- **FW from agricultural production** is **variable** depending on the type of product, the region, the season, the method of production, external influences (weather, diseases…), and the demand. The estimations in this study are partly based on literature, partly on case studies, and completed with rough assumptions, implying considerable uncertainty.
- The amount of **FW of individual food categories sent to different methods of treatment** is rather uncertain. However, the influence on overall impacts may be relatively small, since FW treatment has significantly lower impacts than the cumulated impacts of the FVC and since products with high calorific content generally create higher environmental credits for all methods of FW treatment.
- The uncertainty of FW amounts that are based on Beretta et al. (2013) is documented in their SI for each product and each stage of the FVC with a pedigree analysis.
- Since data on country-specific imports does not differentiate between table and wine grapes, the consumption of table grapes modelled in the biodiversity assessment is uncertain and may over-estimate actual consumption (-> Fig. 4 in the manuscript).

Life cycle assessment

- The impacts of the FVC are allocated proportionally to the metabolizable energy of the food and FW. However, it can be argued that **some** of these **impacts cannot be reduced by FW prevention** and should therefore only be allocated to the consumed food. For example, it can be argued that if consumers avoid FW they reduce the amount they buy, but not the frequency of shopping. Similarly, if cooking smaller portions the energy for cooking decreases under-proportionally to the amount of food being cooked. On the other hand, FW prevention often requires optimized planning which can save resources, e.g. by reducing stocks and the need for refrigeration capacities.
- The allocation of environmental impacts proportionally to the metabolizable energy of the food and FW implies that **a calorie of food** of a specific food category **can be replaced by a calorie of avoidable FW of the same food category**.
- Differences between **system boundaries of different databases** used for the life cycle inventory may provide some inconsistencies. Explicitly datasets from Agri-footprint 2015 (www.agri-footprint.com) for pork, poultry, and eggs do not include agricultural equipment and the production of pesticides and manure.
- The **environmental credits from the substitution** of electricity, heat, fertilizer, peat, and feed depend on the present system and the exact products that are actually replaced. These credits can vary substantially depending on the individual case and on future developments. For example, the credits from heat will decrease dramatically in a future scenario with renewable energy instead of natural gas as marginal technology. Similarly, the credits from feeding are higher in a system where soy is imported from tropical areas than in an extensive, grassland based production system.
- The **environmental impacts of fruits**, which are **not harvested**, are not analyzed in this study because of high uncertainties in their amounts. The impacts of the production of these fruits are expected to be relatively low, especially if the fruit trees are not cultivated. However, if imported fruits are substituted, the potential of saving impacts may be relevant.

B.19 COMPARISON WITH LITERATURE

Table B.29: Comparison of key parameters of this study with values from literature. The numbers relate to food consumption, FW quantification, and the corresponding life cycle impacts. Deviations below ±20% are marked with green background, above ±50% with red and in between with yellow background.

Source		Parameter	Unit		This study		Comments
	Country and year			Value	Value	Comparison	
Food consumption		*Final energy intake*					
SBV, 2014	Switzerland, 2012	Estimation by nutrition experts	kcal/p/d (low estimation)	2151	2290	106%	Final energy intake accodring to our study does not include alcoholic beverages (about 5% of total energy intake according to SBV, 2014). Thus, the numbers are similar.
			kcal/p/d (high estimation)	2390	2290	96%	
Food waste quantification		*Amount of avoidable food waste*					
Gustavsson, 2011	Europe, 2007	Agriculture	% of edible food at harvest time	9.7%	6.0%	62%	Large variations between years, product categories, and companies may explain differences. Our estimation lies **between the reported values** for Europe and Norway.
Hanssen and Møller, 2013	Norway, 2010	Agriculture	% of edible food at harvest time	4.8%	6.0%	126%	
	Norway, 2009	Wholesale (Trade)	% of revenue (assumed proportional to mass)	0.26%	1.2%	477%	Sorting of products is done at different stages of the food chain (agricultural production, trade, processing). This may explain differences between countries and studies. Compared to other stages of the food chain, **both numbers are relatively low**.
		Retail	% of sold food (revenue)	3.5%	3.1%	87%	The value of this study relates to mass. The numbers are consistent.
Hamilton et al., 2015	Norway, 2009-11	Retail	% of sold food (dry matter)	3.2%	3.1%	95%	
		Processing	% of sold food at retail level (dry matter)	3.7%	11.3%	308%	Hamilton et al. **do not consider cereals** in their study. Cereals sorted out for animal feed are dominant in our study and may explain most of the difference. Additionally, vegetable waste has a lower influence on average total waste when **expressed as dry matter**, compared to wet weight.
Hanssen and Møller, 2013	Norway, 2009	Households & food service (without drinks)	% of purchases	10.2%	18.2%	178%	Different **methodologies** (consumer self reporting via web panel).
Hanssen et al., 2016	Norway, 2011		kg/p/a	46.3	116	250%	Different **methodologies** (possibly avoidable food waste is not or only partly considered and food waste fed to animals or disposed of in the sewer is neglected).
Quested and Johnson, 2009	UK, 2007	Households (without drinks)	% of purchases	21.3%	19.1%	89%	Household food waste in this study is based on Quested and Johnson, because their methodology is judged most reliable; the slight differences are due to different consumer baskets of Swiss and UK households.
			kg/p/a	112	116	119%	
Schneider et al., 2012	Austria, 2009		kg/p/a (minimum)	28.5	116	406%	Besides cultural aspects, different **classification** of avoidable FW, large variations of municipal biowaste between different regions in Austria, and **uncertainties** of the broad estimations from surveys for home composting, pet feeding and disposal in the sewer may explain the large differences.
			kg/p/a (maximum)	46.4	116	249%	
Kranert et al., 2012	Germany, 2010		kg/p/a (minimum)	46	116	252%	Besides cultural aspects, different **methodologies** and classiffications and the **lack of data** on pet feeding, home composting, and disposal in the sewer may explain the differences.
			kg/p/a (maximum)	60	116	193%	
Rosenbauer, 2011	Germany, 2010		% of purchases	12%	19%	154%	Besides cultural aspects, different **classification** of avoidable FW (deviation including unavoidable FW is lower) and different **methodologies** (online diaries with consumers' self-reporting) may explain the differences.
			% of purchases incl. unavoidable FW	21%	24%	113%	
Life cycle assessment		*Environmental impact of* ***food consumption***					
Jungbluth et al., 2011	Switzerland, 2005	Carbon footprint	t CO_2-eq/p/a	2	2.0	96%	The eco-points in this study are calculated with Environmental Scarcity 2013. The results are quite consistent.
		Environmental Scarcity 2006	mio UBP (eco-points)	5.6	4.8	85%	
Eberle and Fels, 2015	Germany, 2010	Carbon footprint	t CO_2-eq/p/a	3	2.0	67%	The German **electricity mix** has higher climate impact than the Swiss electricity mix and may explain some of the difference.
		Carbon footprint of agriculture and consumption	% of total food chain impact	94%	92%	98%	Similarly to Eberle and Fels also in this study food production is dominant (1.8 kg CO_2-eq/kg), followed by consumer shopping (0.4 kg CO2-eq/kg) and storage and preparation (0.1 kg CO2-eq/kg).
		Agricultural land use	m^2a/p/a	4266	3829	90%	
Life cycle assessment		*Environmental impact of* ***food waste***					
FAO, 2013	Europe, 2007	Carbon footprint	kg CO_2-eq/p/a	700	537	77%	The carbon footprint in the FAO study is probably mainly higher than in this study because in Europe a considerable amount of food waste is sent to **landfill**. Additionally, the FAO study also includes impacts of the production of inedible parts of food and does not consider benefits from food waste treatment.
Hamilton et al., 2015	Norway, 2009-11	Net process energy	% of process energy for total food supply	16%	22%	140%	Hamilton et al. do **not include food waste from agriculture** and they use lower estimates of waste amounts from processing and final consumers.
Schott and Cánovas, 2015	Europe, USA…	Carbon footprint	kg CO_2-eq/kg of food waste (minimum)	0.8	1.0	119%	The carbon footprint in our study (the minimum relates to food waste from agriculture, the maximum to household food waste) is **in the same range** as the values reported by literature. For individual products, the variation is larger.
			kg CO_2-eq/kg of food waste (maximum)	4.4	2.2	50%	
Eberle and Fels, 2015	Germany, 2010	Carbon footprint	% of total consumption and losses	21%	25%	119%	Compared to this study, Eberle and Fels base their analyses on **lower food loss amounts** by Kranert et al. (2012) (see above).
Abeliotis et al., 2015	Greece, 2009	Carbon footprint of food waste treatment	% of the cumulated supply chain impacts of food waste	75%	-8%	-11%	The main reasons, why food waste treatment has the dominant climate impact in Greece, may be the following: 1) In Greece **98%** of food waste is sent to **landfill** which has high methane emissions (about 20x higher than composting). 2) Abeliotis et al. include the impacts of the **treatment of unavoidable food waste** from households, which makes up 70% of total household food waste (Abeliotis et al., 2015).

Additional information to the political target in the ETH Zurich energy strategy "1t CO_2-eq/cap":

The Swiss Federal climate targets are 20% reduction compared to 1990 by 2020, i.e. resulting in about 5 t CO_2/cap (this figure only refers to domestic emissions, not to the overall Swiss footprint). One ton CO_2/cap is much lower and refers to the amount of emissions that globally could be released without surpassing the 2-degree target; 1t CO_2/cap has been promoted as a political target in the ETH's energy strategy, and has been widely adopted as a vision. Boulouchos et al. (2008) write "(…) Thus, under optimal conditions, the goal of a "1t CO_2 per capita per annum" society is achieved, meaning that by the end of the 21st century, no more than 10 Gt CO_2/year are being produced — assuming a world population of 9 to 10 billion and a global prosperity level in 2100 similar to that of Switzerland today."

B.20 Inventory of Food Losses and Impacts

Table B.30a: Food waste of all products at each stage of the FVC in % of input, by mass, differentiated for avoidable (AFW) and unavoidable (UFW) food waste and for the various methods of treatment. Final consumption and total avoidable losses are expressed in tonnes per year, kg per person per year, and in mass-% of agricultural production as well as in kcal per person per day and in energy-% of agricultural production. For food outputs and avoidable losses the metabolisable energy contents (E) are shown in kcal/100g, based on Yazio.de (2015) and SBV (2014). This is an updated version of the inventory by Beretta et al. (2013). The composition of donations and FW flows to different treatment methods is uncertain and mainly based on own assumptions.

Mass Flow Analysis		Table apples			Apple juice			Other fresh table fruits			Other fresh fruit juices		
		AFW	E	UFW	AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
Agricultural Production	Food Output	98%	52.5		98%	52.5		94%	51.7		94%	51.7	
	Donations	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Field Composting	0.0%	52.5	2.5%	0.0%	52.5	2.5%	0.0%	51.7	6.0%	0.0%	51.7	6.0%
	Anaerobic Digestion	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Sewer	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	SUM	0.0%		2.5%	0.0%		2.5%	0.0%		6.0%	0.0%		6.0%
Trade	Food Output	99%	52.5		100%	52.5		98%	51.7		100%	51.7	
	Donations	0.00%	52.5	0.0%	0.00%	52.5	0.0%	0.00%	51.7	0.0%	0.00%	51.7	0.0%
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Composting	0.0%	52.5	0.8%	0.0%	52.5	0.0%	0.0%	51.7	2.0%	0.0%	51.7	0.0%
	Anaerobic Digestion	0.3%	52.5	0.0%	0.0%	52.5	0.0%	0.3%	51.7	0.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Sewer	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	SUM	0.3%		0.8%	0.0%		0.0%	0.3%		2.0%	0.0%		0.0%
Processing	Food Output	100%	52.5		76%	46.0		100%	51.7		75%	49.6	
	Donations	0.00%	52.5	0.0%	0.00%	46.0	0.0%	0.00%	51.7	0.0%	0.00%	49.6	0.0%
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Composting	0.0%	52.5	0.0%	0.0%	52.5	0.8%	0.0%	51.7	0.0%	0.0%	51.7	16.0%
	Anaerobic Digestion	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	23.0%	0.0%	51.7	0.0%	0.0%	51.7	9.0%
	Sewer	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	SUM	0.0%		0.0%	0.0%		23.8%	0.0%		0.0%	0.0%		25.0%
Food service	Food Output	67%	52.5		96%	46.0		31%	51.7		86%	49.6	
	Donations	0.56%	52.5	0.0%	0.56%	52.5	0.0%	0.56%	51.7	0.0%	0.56%	51.7	0.0%
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Composting	3.3%	52.5	12.1%	0.0%	52.5	0.0%	10.4%	51.7	0.0%	0.0%	51.7	0.0%
	Anaerobic Digestion	17.0%	52.5	0.0%	0.0%	52.5	0.0%	3.2%	51.7	55.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Sewer	0.0%	52.5	0.0%	3.4%	46.0	0.0%	0.0%	51.7	0.0%	13.6%	49.6	0.0%
	SUM	20.2%		12.1%	3.4%		0.0%	13.6%		55.0%	13.6%		0.0%
Retail	Food Output	97%	52.5		99%	46.0		94%	51.7		99%	49.6	
	Donations	0.17%	52.5	0.0%	0.17%	52.5	0.0%	0.17%	51.7	0.0%	0.17%	51.7	0.0%
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Composting	1.5%	52.5	0.0%	0.0%	52.5	0.0%	2.8%	51.7	0.0%	0.0%	51.7	0.0%
	Anaerobic Digestion	1.5%	52.5	0.0%	0.0%	52.5	0.0%	2.8%	51.7	0.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Sewer	0.0%	52.5	0.0%	1.1%	46.0	0.0%	0.0%	51.7	0.0%	0.8%	49.6	0.0%
	SUM	3.1%		0.0%	1.1%		0.0%	5.7%		0.0%	0.8%		0.0%
Households	Food Output	60%	52.5		93%	46.0		54%	51.7		93%	49.6	
food losses:	Incineration	0.0%	52.5	0.0%	0.0%	52.5	0.0%	11.0%	51.7	0.0%	0.0%	51.7	0.0%
	Composting	24.0%	63.0	4.4%	0.0%	52.5	0.0%	0.0%	51.7	5.0%	0.0%	51.7	0.0%
	Anaerobic Digestion	12.0%	52.5	0.0%	0.0%	52.5	0.0%	30.0%	51.7	0.0%	0.0%	51.7	0.0%
	Feeding	0.0%	52.5	0.0%	0.0%	52.5	0.0%	0.0%	51.7	0.0%	0.0%	51.7	0.0%
	Sewer	0.0%	52.5	0.0%	7.0%	46.0	0.0%	0.0%	51.7	0.0%	7.0%	49.6	0.0%
	SUM	36.0%		4.4%	7.0%		0.0%	41.0%		5.0%	7.0%		0.0%
Donations	Food Output	100%	52.5		100%	52.5		100%	51.7		100%	51.7	

Mass Flow Analysis		Berries			Exotic and citrus table fruits			Exotic and citrus fruit juices			Canned fruits		
		AFW	E	UFW	AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
Agricultural Production	Food Output	81%	37.6		76%	32.9		76%	32.9		95%	52.1	
	Donations	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
food losses:	Incineration	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Field Composting	12.0%	37.6	7.5%	16.3%	32.9	8.1%	16.3%	32.9	8.1%	0.0%	52.1	5.0%
	Anaerobic Digestion	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	SUM	12.0%		7.5%	16.3%		8.1%	16.3%		8.1%	0.0%		5.0%
Trade	Food Output	98%	37.6		98%	32.9		100%	32.9		100%	52.1	
	Donations	0.00%	37.6	0.0%	0.00%	32.9	0.0%	0.00%	32.9	0.0%	0.00%	52.1	0.0%
food losses:	Incineration	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Composting	0.0%	37.6	1.3%	0.0%	32.9	1.3%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Anaerobic Digestion	0.3%	37.6	0.0%	0.3%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	SUM	0.3%		1.3%	0.3%		1.3%	0.0%		0.0%	0.0%		0.0%
Processing	Food Output	100%	37.6		100%	32.9		69%	34.5		21%	171.8	
	Donations	0.00%	37.6	0.0%	0.00%	32.9	0.0%	0.00%	34.5	0.0%	0.00%	171.8	0.0%
food losses:	Incineration	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Composting	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	31.4%	0.0%	52.1	79.1%
	Anaerobic Digestion	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	SUM	0.0%		0.0%	0.0%		0.0%	0.0%		31.4%	0.0%		79.1%
Food service	Food Output	70%	37.6		82%	32.9		96%	34.5		88%	171.8	
	Donations	0.56%	37.6	0.0%	0.00%	32.9	0.0%	0.56%	32.9	0.0%	0.23%	171.8	0.0%
food losses:	Incineration	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Composting	12.7%	37.6	0.0%	5.6%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Anaerobic Digestion	11.6%	37.6	5.5%	6.9%	32.9	5.5%	0.0%	32.9	0.0%	11.6%	171.8	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	3.4%	49.6	0.0%	0.0%	52.1	0.0%
	SUM	24.3%		5.5%	12.5%		5.5%	3.4%		0.0%	11.6%		0.0%
Retail	Food Output	92%	37.6		94%	32.9		99%	34.5		100%	171.8	
	Donations	0.17%	37.6	0.0%	0.26%	32.9	0.0%	0.17%	32.9	0.0%	0.07%	171.8	0.0%
food losses:	Incineration	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Composting	0.0%	37.6	0.0%	2.5%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Anaerobic Digestion	7.9%	37.6	0.0%	3.0%	32.9	0.0%	0.0%	32.9	0.0%	0.4%	171.8	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.8%	49.6	0.0%	0.0%	52.1	0.0%
	SUM	7.9%		0.0%	5.5%		0.0%	0.8%		0.0%	0.4%		0.0%
Households	Food Output	71%	37.6		54%	32.9		93%	34.5		84%	171.8	
food losses:	Incineration	15.0%	37.6	0.0%	12.4%	32.9	0.0%	0.0%	32.9	0.0%	15.8%	171.8	0.0%
	Composting	0.0%	37.6	2.0%	0.0%	32.9	21.8%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Anaerobic Digestion	12.0%	37.6	0.0%	12.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Feeding	0.0%	37.6	0.0%	0.0%	32.9	0.0%	0.0%	32.9	0.0%	0.0%	52.1	0.0%
	Sewer	0.0%	37.6	0.0%	0.0%	32.9	0.0%	7.0%	49.6	0.0%	0.0%	52.1	0.0%
	SUM	27.0%		2.0%	24.4%		21.8%	7.0%		0.0%	15.8%		0.0%
Donations	Food Output	100%	37.6		100%	32.9		100%	32.9		100%	171.8	

Mass Flow Analysis		Potatoes			Fresh vegetables			Legumes			Other storable vegetables		
		AFW	E	UFW	AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
Agricultural Production	Food Output	80%	55.6		68%	19.0		80%	43.6		80%	19.0	
	Donations	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
food losses:	Incineration	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Field Composting	0.0%	55.6	2.5%	25.0%	19.0	5.0%	12.5%	43.6	5.0%	12.5%	19.0	5.0%
	Anaerobic Digestion	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Feeding	17.5%	55.6	0.0%	2.0%	19.0	0.0%	2.5%	43.6	0.0%	2.5%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	17.5%		2.5%	27.0%		5.0%	15.0%		5.0%	15.0%		5.0%
Trade	Food Output	87%	55.6		96%	19.0		99%	43.6		86%	19.0	
	Donations	0.00%	55.6	0.0%	0.05%	19.0	0.0%	0.05%	43.6	0.0%	0.05%	19.0	0.0%
food losses:	Incineration	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Composting	0.0%	55.6	0.0%	3.5%	19.0	0.0%	0.0%	43.6	0.0%	3.5%	19.0	0.0%
	Anaerobic Digestion	0.0%	55.6	2.8%	0.3%	19.0	0.0%	1.0%	43.6	0.0%	10.0%	19.0	0.0%
	Feeding	10.6%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	10.6%		2.8%	3.8%		0.0%	1.0%		0.0%	13.5%		0.0%
Processing	Food Output	91%	55.6		100%	19.0		100%	43.6		100%	19.0	
	Donations	0.00%	55.6	0.0%	0.00%	19.0	0.0%	0.00%	43.6	0.0%	0.00%	19.0	0.0%
food losses:	Incineration	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Composting	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Anaerobic Digestion	1.3%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Feeding	2.8%	55.6	5.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	4.1%		5.0%	0.0%		0.0%	0.0%		0.0%	0.0%		0.0%
Food service	Food Output	62%	55.6		49%	19.0		52%	43.6		53%	19.0	
	Donations	0.00%	55.6	0.0%	0.56%	19.0	0.0%	0.00%	43.6	0.0%	0.00%	36.5	0.0%
food losses:	Incineration	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	7.9%	19.0	0.0%
	Composting	3.7%	55.6	0.0%	7.9%	19.0	0.0%	0.0%	43.6	0.0%	10.6%	19.0	0.0%
	Anaerobic Digestion	9.4%	55.6	24.8%	15.9%	19.0	24.8%	23.1%	43.6	24.8%	4.0%	19.0	24.8%
	Feeding	0.0%	55.6	0.0%	2.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	13.1%		24.8%	25.8%		24.8%	23.1%		24.8%	22.5%		24.8%
Retail	Food Output	97%	55.6		90%	19.0		93%	43.6		93%	19.0	
	Donations	0.13%	55.6	0.0%	0.17%	19.0	0.0%	0.26%	43.6	0.0%	0.17%	36.5	0.0%
food losses:	Incineration	1.4%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Composting	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Anaerobic Digestion	1.4%	55.6	0.0%	9.7%	19.0	0.0%	6.5%	43.6	0.0%	6.5%	19.0	0.0%
	Feeding	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	2.8%		0.0%	9.7%		0.0%	6.5%		0.0%	6.5%		0.0%
Households	Food Output	75%	55.6		53%	19.0		60%	43.6		60%	19.0	
food losses:	Incineration	15.0%	55.6	9.0%	23.0%	19.0	0.0%	24.0%	43.6	0.0%	24.0%	19.0	0.0%
	Composting	0.0%	55.6	0.0%	9.0%	19.0	9.0%	0.0%	43.6	9.0%	7.0%	19.0	9.0%
	Anaerobic Digestion	0.0%	55.6	0.0%	6.0%	19.0	0.0%	7.0%	43.6	0.0%	0.0%	19.0	0.0%
	Feeding	0.8%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	Sewer	0.0%	55.6	0.0%	0.0%	19.0	0.0%	0.0%	43.6	0.0%	0.0%	19.0	0.0%
	SUM	15.8%		9.0%	38.0%		9.0%	31.0%		9.0%	31.0%		9.0%
Donations	Food Output	100%	55.6		100%	19.0		100%	43.6		100%	32.5	

Mass Flow Analysis		Processed vegetables			Bread and pastries			Pasta			Rice		
		AFW	E	UFW	AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
Agricultural Production	Food Output	88%	47.6		90%	285.4		90%	264.0		90%	347.4	
	Donations	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
food losses:	Incineration	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Field Composting	5.0%	47.6	5.0%	0.0%	285.4	10.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Feeding	2.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	10.0%	0.0%	347.4	10.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	7.0%		5.0%	0.0%		10.0%	0.0%		10.0%	0.0%		10.0%
Trade	Food Output	100%	47.6		99%	285.4		99%	264.0		99%	347.4	
	Donations	0.00%	47.6	0.0%	0.00%	285.4	0.0%	0.00%	264.0	0.0%	0.00%	347.4	0.0%
food losses:	Incineration	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Composting	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	0.3%	47.6	0.0%	0.0%	285.4	1.0%	0.0%	264.0	1.0%	0.0%	347.4	1.0%
	Feeding	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	0.3%		0.0%	0.0%		1.0%	0.0%		1.0%	0.0%		1.0%
Processing	Food Output	41%	71.8		70%	315.8		61%	308.5		80%	347.4	
	Donations	0.00%	71.8	0.0%	0.00%	315.8	0.0%	0.14%	308.5	0.0%	0.00%	347.4	0.0%
food losses:	Incineration	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Composting	4.3%	71.8	25.5%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	0.0%	47.6	25.5%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Feeding	4.3%	71.8	0.0%	28.1%	315.8	2.0%	35.5%	308.5	3.2%	8.6%	347.4	11.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	8.5%		51.0%	28.1%		2.0%	35.5%		3.2%	8.6%		11.0%
Food service	Food Output	85%	71.8		75%	315.8		60%	308.5		60%	347.4	
	Donations	0.56%	71.8	0.0%	0.50%	315.8	0.0%	0.23%	308.5	0.0%	0.23%	347.4	0.0%
food losses:	Incineration	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	24.5%	347.4	0.0%
	Composting	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	14.5%	71.8	0.0%	24.2%	315.8	0.0%	39.5%	308.5	0.0%	15.1%	347.4	0.0%
	Feeding	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	14.5%		0.0%	24.2%		0.0%	39.5%		0.0%	39.6%		0.0%
Retail	Food Output	100%	71.8		95%	315.8		99%	308.5		100%	347.4	
	Donations	0.17%	71.8	0.0%	0.15%	315.8	0.0%	0.07%	308.5	0.0%	0.07%	347.4	0.0%
food losses:	Incineration	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Composting	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	0.2%	71.8	0.0%	1.4%	315.8	0.0%	0.7%	308.5	0.0%	0.3%	347.4	0.0%
	Feeding	0.0%	47.6	0.0%	3.0%	315.8	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	0.2%		0.0%	4.4%		0.0%	0.7%		0.0%	0.3%		0.0%
Households	Food Output	86%	71.8		61%	315.8		68%	308.5		68%	347.4	
food losses:	Incineration	7.0%	71.8	0.0%	31.5%	315.8	0.0%	29.0%	308.5	0.0%	29.0%	347.4	0.0%
	Composting	7.0%	71.8	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Anaerobic Digestion	0.0%	47.6	0.0%	5.5%	315.8	0.0%	3.0%	308.5	0.0%	3.0%	347.4	0.0%
	Feeding	0.0%	47.6	0.0%	2.0%	315.8	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	Sewer	0.0%	47.6	0.0%	0.0%	285.4	0.0%	0.0%	264.0	0.0%	0.0%	347.4	0.0%
	SUM	14.0%		0.0%	39.0%		0.0%	32.0%		0.0%	32.0%		0.0%
Donations	Food Output	100%	71.8		100%	315.8		100%	308.5		100%	347.4	

	Table apples		Apple juice		Other fresh table fruits		Other fresh fruit juices	
Mass Flow Analysis	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]
Final Consumption	83'487	57%	59'359	69%	40'672	44%	14'002	64%
Total avoidable losses	50'003	34%	4'657	5%	33'804	37%	1'322	6%
Agricultural Production	0	0%	0	0%	0	0%	0	0%
Trade	427	0%	0	0%	260	0%	0	0%
Processing	0	0%	0	0%	0	0%	0	0%
Food service	4'313	3%	330	0%	1'742	2%	315	1%
Retail	3'674	3%	572	1%	4'071	4%	105	0%
Households	41'590	28%	3'756	4%	27'731	30%	901	4%
Incineration	0	0%	0	0%	7'440	8%	0	0%
Field Composting	0	0%	0	0%	0	0%	0	0%
Composting	19'171	13%	0	0%	3'365	4%	0	0%
Home Composting	11'091	8%	0	0%	0	0%	0	0%
Anaerobic Digestion	19'742	14%	0	0%	23'000	25%	0	0%
Feeding	0	0%	0	0%	0	0%	0	0%
Sewer	0	0%	4'657	5%	0	0%	1'322	6%
Mass Flow Analysis	[kg/p/a]		[kg/p/a]		[kg/p/a]		[kg/p/a]	
Final Consumption	10.5		7.5		5.1		1.8	
Total avoidable losses	6.3		0.6		4.2		0.2	
Agricultural Production	0.0		0.0		0.0		0.0	
Trade	0.1		0.0		0.0		0.0	
Processing	0.0		0.0		0.0		0.0	
Food service	0.5		0.0		0.2		0.0	
Retail	0.5		0.1		0.5		0.0	
Households	5.2		0.5		3.5		0.1	
Energy Flow Analysis	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]
Final Consumption	15.1	57%	9.4	60%	7.2	44%	2.4	62%
Total avoidable losses	10.0	38%	0.7	5%	6.0	37%	0.2	6%
Agricultural Production	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Trade	0.1	0%	0.0	0%	0.0	0%	0.0	0%
Processing	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Food service	0.8	3%	0.1	0%	0.3	2%	0.1	1%
Retail	0.7	3%	0.1	1%	0.7	4%	0.0	0%
Households	8.5	32%	0.6	4%	4.9	30%	0.2	4%

	Berries		Exotic and citrus table fruits		Exotic and citrus fruit juices		Canned fruits	
Mass Flow Analysis	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]
Final Consumption	35'339	52%	201'881	41%	87'216	48%	5'992	17%
Total avoidable losses	25'023	37%	174'695	36%	36'031	20%	1'094	3%
Agricultural Production	8'084	12%	79'138	16%	29'390	16%	0	0%
Trade	163	0%	1'105	0%	0	0%	0	0%
Processing	0	0%	0	0%	0	0%	0	0%
Food service	1'967	3%	6'854	1%	477	0%	124	0%
Retail	3'558	5%	16'812	3%	645	0%	24	0%
Households	11'250	17%	70'786	15%	5'520	3%	945	3%
Incineration	6'250	9%	35'980	7%	0	0%	945	3%
Field Composting	8'084	12%	79'138	16%	29'390	16%	0	0%
Composting	1'029	2%	10'669	2%	0	0%	0	0%
Home Composting	0	0%	0	0%	0	0%	0	0%
Anaerobic Digestion	9'660	14%	48'908	10%	0	0%	149	0%
Feeding	0	0%	0	0%	0	0%	0	0%
Sewer	0	0%	0	0%	6'641	4%	0	0%
Mass Flow Analysis	[kg/p/a]		[kg/p/a]		[kg/p/a]		[kg/p/a]	
Final Consumption	4.4		25.4		11.0		0.8	
Total avoidable losses	3.1		22.0		4.5		0.1	
Agricultural Production	1.0		9.9		3.7		0.0	
Trade	0.0		0.1		0.0		0.0	
Processing	0.0		0.0		0.0		0.0	
Food service	0.2		0.9		0.1		0.0	
Retail	0.4		2.1		0.1		0.0	
Households	1.4		8.9		0.7		0.1	
Energy Flow Analysis	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]
Final Consumption	4.6	52%	22.9	41%	10.4	51%	3.5	55%
Total avoidable losses	3.2	37%	19.8	36%	4.5	22%	0.6	10%
Agricultural Production	1.0	12%	9.0	16%	3.3	16%	0.0	0%
Trade	0.0	0%	0.1	0%	0.0	0%	0.0	0%
Processing	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Food service	0.3	3%	0.8	1%	0.1	0%	0.1	1%
Retail	0.5	5%	1.9	3%	0.1	1%	0.0	0%
Households	1.5	17%	8.0	15%	0.9	5%	0.6	9%

	Potatoes		Fresh vegetables		Legumes		Other storable vegetables	
Mass Flow Analysis	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]
Final Consumption	266'153	45%	310'793	31%	15'110	44%	69'614	39%
Total avoidable losses	235'482	40%	562'819	57%	14'615	43%	88'855	49%
Agricultural Production	103'623	18%	266'577	27%	5'130	15%	27'034	15%
Trade	50'370	9%	25'512	3%	274	1%	19'464	11%
Processing	16'731	3%	0	0%	0	0%	0	0%
Food service	7'392	1%	18'606	2%	698	2%	3'134	2%
Retail	8'957	2%	55'728	6%	1'558	5%	7'174	4%
Households	48'409	8%	196'396	20%	6'955	20%	32'048	18%
Incineration	50'395	9%	118'871	12%	5'385	16%	25'917	14%
Field Composting	0	0%	246'830	25%	4'275	13%	22'528	13%
Composting	2'098	0%	57'130	6%	0	0%	10'862	6%
Home Composting	0	0%	18'606	2%	0	0%	2'895	2%
Anaerobic Digestion	14'974	3%	100'195	10%	4'100	12%	22'148	12%
Feeding	168'016	28%	21'186	2%	855	3%	4'506	3%
Sewer	0	0%	0	0%	0	0%	0	0%
Mass Flow Analysis	[kg/p/a]		[kg/p/a]		[kg/p/a]		[kg/p/a]	
Final Consumption	33.5		39.1		1.9		8.8	
Total avoidable losses	29.6		70.8		1.8		11.2	
Agricultural Production	13.0		33.5		0.6		3.4	
Trade	6.3		3.2		0.0		2.4	
Processing	2.1		0.0		0.0		0.0	
Food service	0.9		2.3		0.1		0.4	
Retail	1.1		7.0		0.2		0.9	
Households	6.1		24.7		0.9		4.0	
Energy Flow Analysis	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]
Final Consumption	51.0	45%	20.3	31%	2.3	44%	4.6	39%
Total avoidable losses	45.1	40%	36.8	57%	2.2	43%	5.8	49%
Agricultural Production	19.9	18%	17.4	27%	0.8	15%	1.8	15%
Trade	9.7	9%	1.7	3%	0.0	1%	1.3	11%
Processing	3.2	3%	0.0	0%	0.0	0%	0.0	0%
Food service	1.4	1%	1.2	2%	0.1	2%	0.2	2%
Retail	1.7	2%	3.6	6%	0.2	5%	0.5	4%
Households	9.3	8%	12.8	20%	1.0	20%	2.1	18%

	Processed vegetables		Bread and pastries		Pasta		Rice	
Mass Flow Analysis	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]	[t/a]	[% of agr]
Final Consumption	45'624	30%	261'054	38%	78'177	36%	30'338	48%
Total avoidable losses	29'614	20%	339'083	49%	107'481	50%	20'021	32%
Agricultural Production	10'478	7%	0	0%	0	0%	0	0%
Trade	395	0%	0	0%	0	0%	0	0%
Processing	11'162	7%	172'343	25%	68'164	32%	4'866	8%
Food service	2'333	2%	15'654	2%	7'016	3%	2'727	4%
Retail	60	0%	15'971	2%	727	0%	125	0%
Households	5'185	3%	135'114	20%	31'574	15%	12'304	19%
Incineration	2'593	2%	109'131	16%	28'614	13%	12'838	20%
Field Composting	7'484	5%	0	0%	0	0%	0	0%
Composting	7'137	5%	0	0%	0	0%	0	0%
Home Composting	1'037	1%	0	0%	0	0%	0	0%
Anaerobic Digestion	2'788	2%	39'791	6%	10'703	5%	2'317	4%
Feeding	8'575	6%	190'161	28%	68'164	32%	4'866	8%
Sewer	0	0%	0	0%	0	0%	0	0%
Mass Flow Analysis	[kg/p/a]		[kg/p/a]		[kg/p/a]		[kg/p/a]	
Final Consumption	5.7		32.8		9.8		3.8	
Total avoidable losses	3.7		42.6		13.5		2.5	
Agricultural Production	1.3		0.0		0.0		0.0	
Trade	0.0		0.0		0.0		0.0	
Processing	1.4		21.7		8.6		0.6	
Food service	0.3		2.0		0.9		0.3	
Retail	0.0		2.0		0.1		0.0	
Households	0.7		17.0		4.0		1.5	
Energy Flow Analysis	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]	[kcal/p/d]	[% of agr]
Final Consumption	11.3	46%	284.0	42%	83.1	42%	36.3	48%
Total avoidable losses	6.4	26%	368.8	55%	114.2	58%	24.0	32%
Agricultural Production	1.7	7%	0.0	0%	0.0	0%	0.0	0%
Trade	0.1	0%	0.0	0%	0.0	0%	0.0	0%
Processing	2.8	11%	187.5	28%	72.4	37%	5.8	8%
Food service	0.6	2%	17.0	3%	7.5	4%	3.3	4%
Retail	0.0	0%	17.4	3%	0.8	0%	0.1	0%
Households	1.3	5%	147.0	22%	33.5	17%	14.7	19%

Inventory of food losses and impacts

Maize			Sugar			Vegetal oils and fats		
AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
90%	240.9		100%	84.5		90%	635.0	
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	6.8%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	10.0%	0.0%	84.5	0.0%	2.9%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%		10.0%	0.0%		0.0%	9.7%		0.0%
99%	240.9		100%	84.5		99%	635.0	
0.00%	240.9	0.0%	0.10%	84.5	0.0%	0.00%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	1.0%	0.4%	84.5	0.0%	1.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%		1.0%	0.4%		0.0%	1.0%		0.0%
61%	240.9		17%	396.4		44%	895.5	
0.00%	240.9	0.0%	0.00%	396.4	0.0%	0.00%	895.5	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	45.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	42.3%
0.0%	240.9	39.0%	0.0%	84.5	28.0%	9.0%	428.9	4.3%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%		39.0%	0.0%		83.0%	9.0%		46.5%
41%	240.9		89%	396.4		83%	895.5	
0.23%	240.9	0.0%	0.23%	396.4	0.0%	0.23%	895.5	0.0%
26.1%	240.9	0.0%	4.7%	396.4	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
13.2%	240.9	19.3%	5.7%	396.4	0.0%	13.3%	895.5	3.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
39.3%		19.3%	10.3%		0.0%	13.3%		3.0%
100%	240.9		97%	396.4		99%	895.5	
0.07%	240.9	0.0%	0.07%	396.4	0.0%	0.07%	895.5	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.3%	240.9	0.0%	3.2%	396.4	0.0%	0.8%	895.5	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.3%		0.0%	3.2%		0.0%	0.8%		0.0%
76%	240.9		88%	396.4		83%	895.5	
14.0%	240.9	0.0%	8.0%	396.4	0.0%	0.0%	635.0	0.0%
0.0%	240.9	7.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
3.0%	240.9	0.0%	4.0%	396.4	0.0%	3.7%	895.5	1.1%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	0.0%	635.0	0.0%
0.0%	240.9	0.0%	0.0%	84.5	0.0%	11.9%	895.5	0.0%
17.0%		7.0%	12.0%		0.0%	15.6%		1.1%
100%	240.9		100%	317.8		100%	895.5	
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]		[% of agr]
13'235		38%	293'937		15%	112'480		33%
3'864		11%	56'176		3%	85'031		25%
0		0%	0		0%	33'168		10%
0		0%	8'042		0%	2'995		1%
0		0%	0		0%	27'383		8%
1'117		3%	5'311		0%	2'729		1%
52		0%	9'345		0%	933		0%
2'695		8%	33'479		2%	17'823		5%
2'962		9%	24'718		1%	0		0%
0		0%	0		0%	23'217		7%
0		0%	0		0%	0		0%
0		0%	0		0%	0		0%
902		3%	31'458		2%	10'884		3%
0		0%	0		0%	37'334		11%
0		0%	0		0%	13'596		4%
[kg/p/a]			[kg/p/a]			[kg/p/a]		
1.7			37.0			14.1		
0.5			7.1			10.7		
0.0			0.0			4.2		
0.0			1.0			0.4		
0.0			0.0			3.4		
0.1			0.7			0.3		
0.0			1.2			0.1		
0.3			4.2			2.2		
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]
11.0		38%	399.1		68%	346.9		46%
3.2		11%	68.1		12%	185.8		25%
0.0		0%	0.0		0%	72.5		10%
0.0		0%	2.3		0%	6.5		1%
0.0		0%	0.0		0%	40.5		5%
0.9		3%	7.2		1%	8.4		1%
0.0		0%	12.8		2%	2.9		0%
2.2		8%	45.7		8%	55.0		7%

Nuts, seeds, oleiferous fruits			Milk, other dairy			Meat co-product from milk		
AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
90%	300.5		99%	66.9		43%	110.0	
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	19.0%
7.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	13.0%
3.0%	300.5	0.0%	0.5%	66.9	0.0%	0.0%	110.0	8.0%
0.0%	300.5	0.0%	0.0%	66.9	1.0%	0.0%	110.0	11.0%
10.0%		0.0%	0.5%		1.0%	0.0%		57.0%
99%	300.5		100%	66.9		99%	110.0	
0.00%	300.5	0.0%	0.00%	66.9	0.0%	0.00%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.7%	167.1	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
1.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.5%	0.0%	110.0	0.0%
1.0%		0.0%	0.0%		0.5%	0.7%		0.0%
45%	601.0		100%	66.9		95%	167.1	
0.00%	601.0	0.0%	0.00%	66.9	0.0%	0.00%	167.1	0.0%
0.0%	300.5	50.0%	0.0%	66.9	0.0%	2.5%	167.1	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
5.0%	601.0	0.0%	0.0%	66.9	0.0%	0.0%	110.0	2.5%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
5.0%		50.0%	0.0%		0.0%	2.5%		2.5%
83%	601.0		94%	66.9		72%	167.1	
0.00%	300.5	0.0%	0.20%	66.9	0.0%	0.20%	167.1	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	13.8%	167.1	13.8%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
14.3%	601.0	3.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	5.5%	66.9	0.0%	0.0%	110.0	0.0%
14.3%		3.0%	5.5%		0.0%	13.8%		13.8%
98%	601.0		99%	66.9		98%	167.1	
0.13%	601.0	0.0%	0.06%	66.9	0.0%	0.06%	167.1	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	1.8%	167.1	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
1.6%	601.0	0.0%	0.9%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
1.6%		0.0%	0.9%		0.0%	1.8%		0.0%
83%	601.0		91%	66.9		83%	167.1	
11.9%	601.0	0.0%	0.0%	66.9	0.0%	4.0%	167.1	5.0%
0.0%	300.5	0.0%	0.0%	66.9	0.0%	0.0%	110.0	0.0%
3.7%	601.0	1.1%	0.0%	66.9	0.0%	7.9%	167.1	0.0%
0.0%	300.5	0.0%	2.0%	66.9	0.0%	0.0%	110.0	0.0%
0.0%	300.5	0.0%	7.0%	66.9	0.0%	0.0%	110.0	0.0%
15.6%		1.1%	9.0%		0.0%	11.9%		5.0%
100%	601.0		100%	66.9		100%	167.1	
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]		[% of agr]
36'783		33%	715'477		89%	4'441		33%
24'577		22%	76'039		9%	935		7%
11'177		10%	4'018		1%	0		0%
1'006		1%	0		0%	41		0%
4'979		4%	0		0%	146		1%
971		1%	6'507		1%	116		1%
616		1%	5'951		1%	84		1%
5'828		5%	59'564		7%	549		4%
4'446		4%	0		0%	571		4%
7'824		7%	0		0%	0		0%
0		0%	0		0%	0		0%
0		0%	0		0%	0		0%
8'954		8%	5'951		1%	364		3%
3'353		3%	17'254		2%	0		0%
0		0%	52'834		7%	0		0%
[kg/p/a]			[kg/p/a]			[kg/p/a]		
4.6			89.9			0.6		
3.1			9.6			0.1		
1.4			0.5			0.0		
0.1			0.0			0.0		
0.6			0.0			0.0		
0.1			0.8			0.0		
0.1			0.7			0.0		
0.7			7.5			0.1		
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]
76.1		66%	164.8		89%	2.6		49%
38.3		33%	17.5		9%	0.5		10%
11.6		10%	0.9		1%	0.0		0%
1.0		1%	0.0		0%	0.0		0%
10.3		9%	0.0		0%	0.1		2%
2.0		2%	1.5		1%	0.1		1%
1.3		1%	1.4		1%	0.0		1%
12.1		10%	13.7		7%	0.3		6%

Cheese, whey			Meat co-product from cheese			Butter, buttermilk, skimmed milk		
AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
99%	67.0		43%	110.0		99%	66.9	
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	19.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	13.0%	0.0%	66.9	0.0%
0.5%	67.0	0.0%	0.0%	110.0	8.0%	0.5%	66.9	0.0%
0.0%	67.0	1.0%	0.0%	110.0	11.0%	0.0%	66.9	1.0%
0.5%		1.0%	0.0%		57.0%	0.5%		1.0%
100%	67.0		99%	110.0		100%	66.9	
0.00%	67.0	0.0%	0.00%	110.0	0.0%	0.00%	66.9	0.0%
0.0%	67.0	0.0%	0.7%	167.1	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.5%	0.0%	110.0	0.0%	0.0%	66.9	0.5%
0.0%		0.5%	0.7%		0.0%	0.0%		0.5%
33%	135.3		95%	167.1		92%	69.6	
0.00%	135.3	0.0%	0.00%	167.1	0.0%	0.00%	69.6	0.0%
0.0%	67.0	0.0%	2.5%	167.1	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	2.5%	0.0%	66.9	0.0%
20.7%	63.3	14.2%	0.0%	110.0	0.0%	6.9%	35.4	0.0%
0.0%	67.0	32.6%	0.0%	110.0	0.0%	0.9%	37.8	0.0%
20.7%		46.8%	2.5%		2.5%	7.8%		0.0%
84%	135.3		72%	167.1		94%	69.6	
0.20%	135.3	0.0%	0.00%	110.0	0.0%	0.20%	69.6	0.0%
0.8%	135.3	0.0%	13.8%	167.1	13.8%	1.7%	69.6	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
6.6%	135.3	8.3%	0.2%	167.1	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	3.8%	69.6	0.0%
7.4%		8.3%	14.0%		13.8%	5.5%		0.0%
99%	135.3		98%	167.1		100%	69.6	
0.06%	135.3	0.0%	0.06%	167.1	0.0%	0.06%	69.6	0.0%
0.0%	67.0	0.0%	1.8%	167.1	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
1.3%	135.3	0.0%	0.0%	110.0	0.0%	0.4%	69.6	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
1.3%		0.0%	1.8%		0.0%	0.4%		0.0%
83%	135.3		83%	167.1		92%	69.6	
0.0%	67.0	0.0%	0.0%	110.0	5.0%	4.3%	66.9	0.0%
0.0%	67.0	3.0%	4.0%	167.1	0.0%	0.0%	66.9	0.0%
10.0%	135.3	0.0%	7.9%	167.1	0.0%	3.7%	69.6	0.0%
4.0%	135.3	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
0.0%	67.0	0.0%	0.0%	110.0	0.0%	0.0%	66.9	0.0%
14.0%		3.0%	11.9%		5.0%	8.0%		0.0%
100%	135.3		100%	167.1		100%	69.6	
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]		[% of agr]
327'467		26%	6'891		33%	776'859		83%
314'205		25%	1'454		7%	142'778		15%
6'236		1%	0		0%	4'668		1%
0		0%	64		0%	0		0%
252'491		20%	226		1%	71'512		8%
4'478		0%	183		1%	6'981		1%
4'374		0%	130		1%	2'608		0%
46'626		4%	852		4%	57'009		6%
503		0%	600		3%	32'808		4%
0		0%	0		0%	0		0%
0		0%	172		1%	0		0%
0		0%	114		1%	0		0%
41'654		3%	568		3%	28'974		3%
272'049		22%	0		0%	68'232		7%
0		0%	0		0%	12'764		1%
[kg/p/a]			[kg/p/a]			[kg/p/a]		
41.2			0.9			97.7		
39.5			0.2			17.9		
0.8			0.0			0.6		
0.0			0.0			0.0		
31.7			0.0			9.0		
0.6			0.0			0.9		
0.5			0.0			0.3		
5.9			0.1			7.2		
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]
152.6		53%	4.0		49%	186.2		87%
82.3		29%	0.8		10%	25.5		12%
1.4		1%	0.0		0%	1.1		1%
0.0		0%	0.0		0%	0.0		0%
55.0		19%	0.1		2%	8.8		4%
2.1		1%	0.1		1%	1.7		1%
2.0		1%	0.1		1%	0.6		0%
21.7		8%	0.5		6%	13.4		6%

Meat co-product from butter			Eggs without co-product poultry			Meat from laying hens		
AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
43%	110.0		99%	122.1		39%	103.8	
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	19.0%	0.0%	122.1	1.0%	0.0%	103.8	42.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	13.0%	0.3%	122.1	0.0%	16.8%	105.0	0.0%
0.0%	110.0	8.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	11.0%	0.0%	122.1	0.0%	0.0%	103.8	2.0%
0.0%		57.0%	0.3%		1.0%	16.8%		44.0%
99%	110.0		100%	122.1		99%	103.8	
0.00%	110.0	0.0%	0.00%	122.1	0.0%	0.00%	103.8	0.0%
0.7%	167.1	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.5%	0.7%	127.0	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.7%		0.0%	0.0%		0.5%	0.7%		0.0%
95%	167.1		99%	122.1		95%	127.1	
0.00%	167.1	0.0%	0.00%	122.1	0.0%	0.00%	127.1	0.0%
2.5%	167.1	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	2.5%	0.0%	122.1	1.2%	2.5%	127.0	2.5%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
2.5%		2.5%	0.0%		1.2%	2.5%		2.5%
72%	167.1		43%	122.1		62%	127.1	
0.00%	110.0	0.0%	0.20%	122.1	0.0%	0.00%	103.8	0.0%
13.8%	167.1	13.8%	7.2%	122.1	49.5%	7.4%	127.0	25.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.2%	167.1	0.0%	0.0%	122.1	0.0%	5.7%	127.0	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
14.0%		13.8%	7.2%		49.5%	13.1%		25.0%
98%	167.1		98%	122.1		99%	127.1	
0.06%	167.1	0.0%	0.06%	122.1	0.0%	0.06%	127.0	0.0%
1.8%	167.1	0.0%	1.6%	122.1	0.0%	1.1%	127.0	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
1.8%		0.0%	1.6%		0.0%	1.1%		0.0%
83%	167.1		73%	122.1		59%	127.1	
0.0%	110.0	5.0%	0.0%	122.1	6.0%	0.0%	103.8	25.0%
4.0%	167.1	0.0%	6.0%	122.1	6.0%	2.0%	127.0	0.0%
7.9%	167.1	0.0%	3.0%	122.1	6.0%	10.8%	127.0	3.7%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
0.0%	110.0	0.0%	0.0%	122.1	0.0%	0.0%	103.8	0.0%
11.9%		5.0%	9.0%		18.0%	12.8%		28.7%
100%	167.1		100%	122.1		100%	127.0	
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]		[% of agr]
5'158		33%	56'826		65%	1'923		22%
1'088		7%	8'663		10%	2'056		23%
0		0%	275		0%	1'495		17%
48		0%	0		0%	24		0%
169		1%	0		0%	87		1%
137		1%	913		1%	66		1%
97		1%	1'157		1%	32		0%
637		4%	6'320		7%	353		4%
449		3%	2'069		2%	69		1%
0		0%	0		0%	0		0%
129		1%	2'528		3%	33		0%
86		1%	1'685		2%	22		0%
425		3%	2'381		3%	1'932		22%
0		0%	0		0%	0		0%
0		0%	0		0%	0		0%
[kg/p/a]			[kg/p/a]			[kg/p/a]		
0.6			7.1			0.2		
0.1			1.1			0.3		
0.0			0.0			0.2		
0.0			0.0			0.0		
0.0			0.0			0.0		
0.0			0.1			0.0		
0.0			0.1			0.0		
0.1			0.8			0.0		
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]
3.0		49%	23.9		65%	0.8		26%
0.6		10%	3.6		10%	0.8		25%
0.0		0%	0.1		0%	0.5		17%
0.0		0%	0.0		0%	0.0		0%
0.1		2%	0.0		0%	0.0		1%
0.1		1%	0.4		1%	0.0		1%
0.1		1%	0.5		1%	0.0		0%
0.4		6%	2.7		7%	0.2		5%

Pork			Poultry			Beef, horse, veal		
AFW	E	UFW	AFW	E	UFW	AFW	E	UFW
69%	229.0		61%	132.0		43%	110.0	
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	22.0%	0.0%	132.0	37.0%	0.0%	110.0	19.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	13.0%
0.0%	229.0	3.0%	0.0%	132.0	0.0%	0.0%	110.0	8.0%
2.3%	10.0	2.4%	0.0%	132.0	2.0%	0.0%	110.0	11.0%
2.3%		29.2%	0.0%		39.0%	0.0%		57.0%
99%	229.0		99%	132.0		99%	110.0	
0.00%	229.0	0.0%	0.00%	132.0	0.0%	0.00%	110.0	0.0%
0.7%	284.5	0.0%	0.0%	132.0	0.0%	0.7%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.7%	161.7	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.7%		0.0%	0.7%		0.0%	0.7%		0.0%
95%	284.5		95%	161.7		95%	167.1	
0.00%	284.5	0.0%	0.00%	161.7	0.0%	0.00%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	2.5%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
2.5%	284.5	2.5%	2.5%	161.7	2.5%	0.0%	110.0	2.5%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
2.5%		2.5%	2.5%		2.5%	2.5%		2.5%
76%	284.5		62%	161.7		67%	167.1	
0.20%	284.5	0.0%	0.20%	161.7	0.0%	0.20%	167.1	0.0%
2.4%	284.5	13.8%	13.1%	161.7	25.0%	0.0%	110.0	13.8%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
7.9%	284.5	0.0%	0.0%	132.0	0.0%	19.4%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
10.3%		13.8%	13.1%		25.0%	19.4%		13.8%
98%	284.5		99%	161.7		98%	167.1	
0.06%	284.5	0.0%	0.06%	132.0	0.0%	0.06%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
1.5%	284.5	0.0%	1.3%	161.7	0.0%	1.9%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
1.5%		0.0%	1.3%		0.0%	1.9%		0.0%
78%	284.5		59%	161.7		83%	167.1	
16.8%	284.5	5.0%	2.8%	161.7	25.0%	9.9%	167.1	5.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	8.0%	161.7	3.7%	0.0%	110.0	0.0%
0.0%	229.0	0.0%	2.0%	161.7	0.0%	2.0%	167.1	0.0%
0.0%	229.0	0.0%	0.0%	132.0	0.0%	0.0%	110.0	0.0%
16.8%		5.0%	12.8%		28.7%	11.9%		5.0%
100%	284.5		100%	154.8		100%	153.7	
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]		[% of agr]
153'683		50%	44'800		34%	86'494		32%
47'493		15%	13'180		10%	19'476		7%
6'958		2%	0		0%	0		0%
1'484		0%	569		0%	810		0%
5'263		2%	2'019		2%	2'871		1%
3'126		1%	1'528		1%	3'202		1%
2'611		1%	843		1%	1'799		1%
28'052		9%	8'220		6%	10'795		4%
30'262		10%	3'326		2%	12'661		5%
0		0%	0		0%	0		0%
0		0%	0		0%	0		0%
0		0%	0		0%	0		0%
10'273		3%	8'570		6%	5'001		2%
0		0%	1'284		1%	1'814		1%
6'958		2%	0		0%	0		0%
[kg/p/a]			[kg/p/a]			[kg/p/a]		
19.3			5.6			10.9		
6.0			1.7			2.4		
0.9			0.0			0.0		
0.2			0.1			0.1		
0.7			0.3			0.4		
0.4			0.2			0.4		
0.3			0.1			0.2		
3.5			1.0			1.4		
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]
150.6		62%	24.9		41%	49.8		49%
40.0		16%	7.3		12%	11.2		11%
0.2		0%	0.0		0%	0.0		0%
1.5		1%	0.3		1%	0.5		0%
5.2		2%	1.1		2%	1.7		2%
3.1		1%	0.9		1%	1.8		2%
2.6		1%	0.5		1%	1.0		1%
27.5		11%	4.6		8%	6.2		6%

Fish, shellfish			Cocoa, coffee, tea			All food categories	
AFW	E	UFW	AFW	E	UFW	AFW	UFW
65%	114.0		95%	370.4		88%	0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	1.7%
0.0%	114.0	0.0%	4.9%	370.4	0.0%	4.1%	2.1%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	0.4%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	1.5%	0.6%
35.0%	114.0	0.0%	0.0%	370.4	0.0%	0.4%	0.7%
35.0%		0.0%	4.9%		0.0%	6.0%	5.8%
100%	114.0		98%	370.4		98%	0%
0.00%	114.0	0.0%	0.00%	370.4	0.0%	0.0%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	0.0%
0.5%	114.0	0.0%	2.2%	370.4	0.0%	0.3%	0.1%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.3%	0.2%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.5%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	0.2%
0.5%		0.0%	2.2%		0.0%	1.2%	0.5%
94%	114.0		95%	370.4		64%	0%
0.00%	114.0	0.0%	0.00%	370.4	0.0%	0.0%	0.0%
0.0%	114.0	3.0%	0.4%	370.4	0.0%	0.0%	0.6%
0.0%	114.0	0.0%	0.6%	370.4	3.8%	0.1%	11.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.2%	1.9%
3.0%	114.0	0.0%	0.0%	370.4	0.0%	6.6%	9.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.1%	4.3%
3.0%		3.0%	1.0%		3.8%	7.0%	29.1%
59%	114.0		92%	370.4		78%	0%
0.20%	114.0	0.0%	0.23%	370.4	0.0%	0.26%	0.0%
10.9%	114.0	23.6%	4.7%	370.4	0.0%	1.6%	2.1%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	1.8%	0.3%
6.4%	114.0	0.0%	2.6%	370.4	0.9%	8.2%	6.1%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.2%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	1.4%	0.0%
17.2%		23.6%	7.3%		0.9%	13.2%	8.6%
96%	114.0		100%	370.4		97%	0%
0.06%	114.0	0.0%	0.07%	370.4	0.0%	0.11%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.1%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.2%	0.0%
3.6%	114.0	0.0%	0.4%	370.4	0.0%	2.5%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.2%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	0.0%	0.0%
3.6%		0.0%	0.4%		0.0%	3.1%	0.0%
78%	114.0		94%	370.4		76%	0%
0.0%	114.0	8.6%	5.6%	370.4	0.0%	10.4%	1.4%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	1.8%	3.0%
10.5%	114.0	0.0%	0.0%	370.4	0.3%	4.6%	0.2%
3.0%	114.0	0.0%	0.0%	370.4	0.0%	0.8%	0.0%
0.0%	114.0	0.0%	0.0%	370.4	0.0%	1.5%	0.0%
13.5%		8.6%	5.6%		0.3%	19.1%	4.6%
100%	114.0		100%	370.4		100%	0%
[t/a]		[% of agr]	[t/a]		[% of agr]	[t/a]	[% of agr]
45'655		44%	84'683		83%	4'371'607	41%
49'024		47%	13'610		13%	2'584'250	24%
36'171		35%	5'020		5%	638'638	6%
336		0%	2'109		2%	115'496	1%
2'005		2%	904		1%	643'324	6%
1'640		2%	1'001		1%	113'686	1%
1'942		2%	303		0%	152'636	1%
6'930		7%	4'274		4%	920'470	9%
1'035		1%	5'275		5%	526'111	5%
0		0%	5'020		5%	433'791	4%
336		0%	2'651		3%	117'307	1%
0		0%	0		0%	35'536	0%
7'937		8%	664		1%	465'367	4%
3'545		3%	0		0%	871'195	8%
36'171		35%	0		0%	134'943	1%
[kg/p/a]			[kg/p/a]			[kg/p/a]	
5.7			10.6			549.6	
6.2			1.7			324.9	
4.5			0.6			80.3	
0.0			0.3			14.5	
0.3			0.1			80.9	
0.2			0.1			14.3	
0.2			0.0			19.2	
0.9			0.5			115.7	
[kcal/p/d]		[% of agr]	[kcal/p/d]		[% of agr]	[kcal/p/d]	[% of agr]
17.9		44%	108.0		83%	2'290.4	56%
19.2		47%	17.4		13%	1'170.7	28%
14.2		35%	6.4		5%	163.9	4%
0.1		0%	2.7		2%	28.1	1%
0.8		2%	1.2		1%	396.5	10%
0.6		2%	1.3		1%	65.8	2%
0.8		2%	0.4		0%	55.2	1%
2.7		7%	5.5		4%	461.2	11%

Table B.30b: Climate change impacts of final consumption and avoidable food losses expressed in kg CO_2-eq per person per year and in % of total impacts. The same values are shown for the aggregated LCIA methods recipe (mPt) and ecological scarcity 2013 (ecopoints) as well as for global biodiversity impacts from land use and from water use (gPDF-eq/p/a).

	Table apples		Apple juice		Other fresh table fruits		Other fresh fruit juices		Berries		Exotic and citrus table fruits		Exotic and citrus fruit juices		Canned fruits	
Climate Change Impacts	[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]	
Final Consumption	**7.64**	67%	**6.30**	93%	**3.89**	63%	**1.46**	91%	**3.18**	70%	**36.54**	69%	**9.49**	87%	**0.36**	85%
Total avoidable losses	**3.78**	33%	**0.51**	7%	**2.28**	37%	**0.15**	9%	**1.36**	30%	**16.71**	31%	**1.40**	13%	**0.07**	15%
Agricultural Production	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.24	5%	1.90	4%	0.34	3%	0.00	0%
Trade	0.01	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.08	0%	0.00	0%	0.00	0%
Processing	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Food service	0.38	3%	0.04	1%	0.28	4%	0.04	2%	0.15	3%	0.99	2%	0.09	1%	0.01	1%
Retail	0.07	1%	0.04	1%	0.05	1%	0.01	0%	0.08	2%	1.33	2%	0.07	1%	-0.00	0%
Households	3.32	29%	0.43	6%	1.94	31%	0.10	6%	0.90	20%	12.41	23%	0.90	8%	0.06	14%
Recipe	[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]	
Final Consumption	**880**	64%	**715**	93%	**463**	60%	**170**	91%	**362**	68%	**4'175**	68%	**1'241**	87%	**89**	85%
Total avoidable losses	**491**	36%	**57**	7%	**305**	40%	**17**	9%	**166**	32%	**1'979**	32%	**180**	13%	**16**	15%
Agricultural Production	0	0%	0	0%	0	0%	0	0%	26	5%	216	4%	43	3%	0	0%
Trade	1	0%	0	0%	1	0%	0	0%	0	0%	10	0%	0	0%	0	0%
Processing	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Food service	52	4%	5	1%	39	5%	5	3%	21	4%	124	2%	12	1%	2	2%
Retail	13	1%	5	1%	13	2%	1	0%	12	2%	172	3%	9	1%	0	0%
Households	425	31%	48	6%	252	33%	12	6%	107	20%	1'457	24%	116	8%	14	13%
Ecological Scarcity 2013	[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]	
Final Consumption	**19.44**	62%	**15.86**	93%	**11.93**	58%	**3.44**	91%	**8.52**	65%	**89.14**	63%	**32.21**	82%	**3.83**	85%
Total avoidable losses	**11.89**	38%	**1.24**	7%	**8.71**	42%	**0.35**	9%	**4.67**	35%	**51.78**	37%	**7.28**	18%	**0.70**	15%
Agricultural Production	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.95	7%	12.91	9%	3.78	10%	0.00	0%
Trade	0.05	0%	0.00	0%	0.04	0%	0.00	0%	0.02	0%	0.27	0%	0.00	0%	0.00	0%
Processing	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%	0.00	0%
Food service	1.47	5%	0.12	1%	1.25	6%	0.11	3%	0.64	5%	3.11	2%	0.32	1%	0.09	2%
Retail	0.49	2%	0.11	1%	0.64	3%	0.02	0%	0.52	4%	4.45	3%	0.28	1%	0.01	0%
Households	9.88	32%	1.01	6%	6.78	33%	0.22	6%	2.54	19%	31.03	22%	2.89	7%	0.60	13%
Biodiversity impacts from land use	[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
Final Consumption	**6.3E-15**	60%	**5.7E-15**	93%	**8.0E-14**	56%	**3.1E-14**	91%	**2.3E-14**	59%	**5.8E-14**	56%	**2.9E-14**	74%	**4.7E-14**	85%
Total avoidable losses	**4.1E-15**	40%	**4.5E-16**	7%	**6.3E-14**	44%	**2.9E-15**	9%	**1.6E-14**	41%	**4.6E-14**	44%	**1.0E-14**	26%	**8.5E-15**	15%
Biodiversity impacts from water use	[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
Final Consumption	**1.1E-17**	60%	**1.0E-17**	93%	**2.2E-14**	56%	**8.3E-15**	91%	**1.6E-15**	59%	**1.3E-14**	56%	**6.3E-15**	74%	**1.3E-14**	85%
Total avoidable losses	**7.2E-18**	40%	**7.8E-19**	7%	**1.7E-14**	44%	**7.8E-16**	9%	**1.1E-15**	41%	**1.0E-14**	44%	**2.2E-15**	26%	**2.3E-15**	15%

	Potatoes		Fresh vegetables		Legumes		Other storable vegetables		Processed vegetables		Bread and pastries		Pasta		Rice	
Climate Change Impacts	[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]	
Final Consumption	**22.82**	84%	**89.12**	43%	**2.26**	59%	**7.78**	57%	**5.98**	77%	**43.97**	60%	**16.19**	52%	**12.13**	62%
Total avoidable losses	**4.37**	16%	**119.81**	57%	**1.59**	41%	**5.81**	43%	**1.75**	23%	**29.73**	40%	**14.83**	48%	**7.37**	38%
Agricultural Production	-0.43	-2%	44.59	21%	0.34	9%	1.18	9%	0.29	4%	0.00	0%	0.00	0%	0.00	0%
Trade	-0.07	0%	4.39	2%	0.02	0%	0.45	3%	0.01	0%	0.00	0%	0.00	0%	0.00	0%
Processing	0.07	0%	0.00	0%	0.00	0%	0.00	0%	0.54	7%	6.72	9%	6.91	22%	1.34	7%
Food service	0.61	2%	6.09	3%	0.12	3%	0.40	3%	0.28	4%	2.23	3%	1.37	4%	1.10	6%
Retail	0.19	1%	10.61	5%	0.11	3%	0.25	2%	0.00	0%	1.18	2%	0.10	0%	0.04	0%
Households	4.00	15%	54.14	26%	1.01	26%	3.53	26%	0.63	8%	19.60	27%	6.44	21%	4.88	25%
Recipe	[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]	
Final Consumption	**2'643**	83%	**8'774**	43%	**240**	59%	**881**	56%	**686**	77%	**4'989**	61%	**1'950**	52%	**1'000**	63%
Total avoidable losses	**539**	17%	**11'493**	57%	**168**	41%	**688**	44%	**209**	23%	**3'226**	39%	**1'803**	48%	**587**	37%
Agricultural Production	-42	-1%	4'001	20%	32	8%	127	8%	27	3%	0	0%	0	0%	0	0%
Trade	-2	0%	443	2%	2	0%	71	5%	1	0%	0	0%	0	0%	0	0%
Processing	13	0%	0	0%	0	0%	0	0%	72	8%	614	7%	836	22%	88	6%
Food service	85	3%	630	3%	13	3%	51	3%	35	4%	252	3%	174	5%	93	6%
Retail	25	1%	1'036	5%	12	3%	34	2%	0	0%	123	2%	13	0%	3	0%
Households	461	14%	5'383	27%	109	27%	405	26%	75	8%	2'237	27%	780	21%	402	25%
Ecological Scarcity 2013	[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]	
Final Consumption	**69.55**	72%	**120.35**	44%	**9.45**	55%	**16.20**	54%	**24.08**	71%	**167.97**	55%	**71.64**	49%	**24.32**	63%
Total avoidable losses	**27.18**	28%	**155.89**	56%	**7.86**	45%	**13.80**	46%	**9.96**	29%	**136.49**	45%	**75.44**	51%	**14.06**	37%
Agricultural Production	6.30	7%	52.25	19%	2.19	13%	2.59	9%	1.72	5%	0.00	0%	0.00	0%	0.00	0%
Trade	3.41	4%	5.97	2%	0.12	1%	1.94	6%	0.07	0%	0.00	0%	0.00	0%	0.00	0%
Processing	1.53	2%	0.00	0%	0.00	0%	0.00	0%	4.15	12%	39.13	13%	39.25	27%	1.82	5%
Food service	2.96	3%	10.38	4%	0.59	3%	1.20	4%	1.37	4%	10.74	4%	6.94	5%	2.41	6%
Retail	1.30	1%	14.28	5%	0.73	4%	0.86	3%	0.03	0%	5.95	2%	0.60	0%	0.09	0%
Households	11.67	12%	73.01	26%	4.23	24%	7.21	24%	2.62	8%	80.67	26%	28.65	19%	9.75	25%
Biodiversity impacts from land use	[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
Final Consumption	**1.5E-14**	56%	**1.1E-13**	37%	**5.3E-15**	52%	**2.4E-14**	46%	**2.9E-14**	65%	**1.3E-13**	43%	**4.1E-14**	42%	**5.3E-14**	60%
Total avoidable losses	**1.2E-14**	44%	**1.8E-13**	63%	**4.8E-15**	48%	**2.9E-14**	54%	**1.5E-14**	35%	**1.7E-13**	57%	**5.6E-14**	58%	**3.5E-14**	40%
Biodiversity impacts from water use	[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
Final Consumption	**7.6E-16**	56%	**5.3E-15**	37%	**5.2E-16**	52%	**3.1E-15**	46%	**3.7E-15**	65%	**2.7E-15**	43%	**8.2E-16**	42%	**3.5E-16**	60%
Total avoidable losses	**5.9E-16**	44%	**8.9E-15**	63%	**4.8E-16**	48%	**3.7E-15**	54%	**2.0E-15**	35%	**3.5E-15**	57%	**1.1E-15**	58%	**2.3E-16**	40%

Table B.30c: Climate change impacts of final consumption, avoidable food losses, and food waste treatment expressed in kg CO_2-eq per kg of food or food waste.

	Table apples	Apple juice	Other fresh table fruits	Other fresh fruit juices	Berries	Exotic and citrus table fruits	Exotic and citrus fruit juices	Canned fruits	Potatoes	Fresh vegetables	Legumes	Other storable vegetables	Processed vegetables	Bread and pastries	Pasta	Rice
Climate Change Impacts	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]
Final Consumption	**0.73**	**0.84**	**0.76**	**0.83**	**0.72**	**1.44**	**0.87**	**0.48**	**0.68**	**2.28**	**1.19**	**0.89**	**1.04**	**1.34**	**1.65**	**3.18**
Total avoidable losses	**0.60**	**0.87**	**0.54**	**0.89**	**0.43**	**0.76**	**0.31**	**0.47**	**0.15**	**1.69**	**0.87**	**0.52**	**0.47**	**0.70**	**1.10**	**2.93**
Incineration			0.04		0.04	0.04		0.03	0.01	0.06	0.06	0.06	0.05	-0.12	0.01	0.01
Field Composting					-0.02	-0.02	-0.02			-0.02	-0.02	-0.02	-0.02			
(Home) Composting	-0.14		-0.06		-0.02	-0.13			-0.04	-0.20		-0.12	-0.10			
Anaerobic Digestion	-0.18		-0.18		-0.18	-0.18		-0.18	-0.21	-0.19	-0.19	-0.19	-0.19	-0.31	-0.20	-0.20
Feeding									-0.13	-0.05	-0.11	-0.05	-0.18	-0.44	-0.42	-0.57
Sewer		0.08		0.08			0.08									

Maize		Sugar		Vegetal oils and fats		Nuts, seeds, oleiferous fruits		Milk, other dairy		Meat co-product from milk	
[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]	
1.20	77%	**39.82**	90%	**47.68**	71%	**6.82**	76%	**152.25**	91%	**12.99**	83%
0.35	23%	**4.47**	10%	**19.18**	29%	**2.18**	24%	**15.56**	9%	**2.72**	17%
0.00	0%	0.00	0%	5.39	8%	0.96	11%	0.52	0%	0.00	0%
0.00	0%	-0.29	-1%	0.43	1%	0.04	0%	0.00	0%	0.16	1%
0.00	0%	0.00	0%	4.80	7%	0.34	4%	0.00	0%	0.39	2%
0.12	8%	0.63	1%	1.04	2%	0.14	2%	1.53	1%	0.37	2%
0.00	0%	0.46	1%	0.29	0%	0.05	1%	0.86	1%	0.23	1%
0.23	15%	3.66	8%	7.23	11%	0.65	7%	12.64	8%	1.57	10%
[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]	
121	77%	**4'263**	90%	**4'738**	72%	**918**	76%	**15'032**	91%	**1'202**	83%
37	23%	**463**	10%	**1'820**	28%	**290**	24%	**1'529**	9%	**252**	17%
0	0%	0	0%	484	7%	111	9%	47	0%	0	0%
0	0%	-35	-1%	37	1%	5	0%	0	0%	15	1%
0	0%	0	0%	466	7%	50	4%	0	0%	36	2%
13	8%	68	1%	98	2%	18	1%	155	1%	34	2%
0	0%	41	1%	26	0%	7	1%	84	1%	21	1%
23	15%	388	8%	708	11%	99	8%	1'243	8%	145	10%
[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]	
4.10	76%	**78.03**	88%	**174.60**	70%	**32.79**	70%	**269.19**	91%	**22.32**	83%
1.32	24%	**10.64**	12%	**75.48**	30%	**14.27**	30%	**26.95**	9%	**4.69**	17%
0.00	0%	0.00	0%	21.73	9%	4.40	9%	0.81	0%	0.00	0%
0.00	0%	-0.10	0%	1.96	1%	0.36	1%	0.00	0%	0.28	1%
0.00	0%	0.00	0%	19.14	8%	3.52	7%	0.00	0%	0.67	2%
0.51	9%	1.70	2%	4.34	2%	0.89	2%	3.08	1%	0.64	2%
0.01	0%	1.34	2%	1.29	1%	0.45	1%	1.69	1%	0.39	1%
0.80	15%	7.70	9%	27.02	11%	4.65	10%	21.37	7%	2.71	10%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
6.3E-15	77%	**1.2E-13**	86%	**2.8E-13**	68%	**2.4E-13**	67%	**1.8E-13**	90%	**6.1E-14**	83%
1.9E-15	23%	**2.0E-14**	14%	**1.3E-13**	32%	**1.2E-13**	33%	**1.9E-14**	10%	**1.3E-14**	17%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
2.5E-16	77%	**7.9E-15**	86%	**1.1E-14**	68%	**1.3E-13**	67%	**4.4E-15**	90%	**4.7E-16**	83%
7.6E-17	23%	**1.3E-15**	14%	**4.9E-15**	32%	**6.3E-14**	33%	**4.7E-16**	10%	**9.9E-17**	17%

Cheese, whey		Meat co-product from cheese		Butter, buttermilk, skimmed milk		Meat co-product from butter		Eggs without co-product poultry		Meat from laying hens	
[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]	
142.72	69%	**20.16**	83%	**209.51**	90%	**15.09**	83%	**46.65**	87%	**2.12**	57%
63.35	31%	**4.23**	17%	**22.46**	10%	**3.17**	17%	**6.78**	13%	**1.61**	43%
0.89	0%	0.00	0%	0.61	0%	0.00	0%	0.15	0%	1.05	28%
0.00	0%	0.25	1%	0.00	0%	0.19	1%	0.00	0%	0.02	1%
40.10	19%	0.61	2%	7.03	3%	0.45	2%	0.00	0%	0.06	2%
1.99	1%	0.58	2%	1.85	1%	0.44	2%	1.18	2%	0.07	2%
1.54	1%	0.35	1%	0.52	0%	0.26	1%	0.69	1%	0.02	1%
18.84	9%	2.44	10%	12.45	5%	1.82	10%	4.76	9%	0.38	10%
[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]	
13'620	70%	**1'865**	83%	**20'642**	90%	**1'396**	83%	**4'736**	87%	**192**	57%
5'829	30%	**391**	17%	**2'182**	10%	**293**	17%	**693**	13%	**144**	43%
80	0%	0	0%	55	0%	0	0%	15	0%	94	28%
0	0%	23	1%	0	0%	17	1%	0	0%	2	1%
3'607	19%	56	2%	652	3%	42	2%	0	0%	6	2%
194	1%	54	2%	185	1%	40	2%	121	2%	6	2%
145	1%	32	1%	51	0%	24	1%	69	1%	2	1%
1'803	9%	226	10%	1'239	5%	169	10%	488	9%	35	10%
[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]	
247.53	71%	**34.63**	83%	**384.10**	90%	**25.92**	83%	**108.66**	87%	**4.61**	56%
102.28	29%	**7.30**	17%	**42.47**	10%	**5.46**	17%	**16.12**	13%	**3.61**	44%
1.36	0%	0.00	0%	0.94	0%	0.00	0%	0.37	0%	2.37	29%
0.00	0%	0.43	1%	0.00	0%	0.33	1%	0.00	0%	0.05	1%
61.70	18%	1.04	2%	11.95	3%	0.78	2%	0.00	0%	0.14	2%
3.88	1%	1.01	2%	3.88	1%	0.76	2%	2.83	2%	0.16	2%
2.77	1%	0.60	1%	1.05	0%	0.45	1%	1.62	1%	0.05	1%
32.56	9%	4.21	10%	24.66	6%	3.15	10%	11.29	9%	0.84	10%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
2.1E-13	66%	**9.4E-14**	83%	**2.1E-13**	88%	**7.0E-14**	83%	**4.4E-14**	87%	**3.1E-15**	55%
1.1E-13	34%	**2.0E-14**	17%	**2.8E-14**	12%	**1.5E-14**	17%	**6.6E-15**	13%	**2.5E-15**	45%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
5.0E-15	66%	**7.2E-16**	83%	**5.0E-15**	88%	**5.4E-16**	83%	**1.8E-15**	87%	**1.4E-16**	55%
2.6E-15	34%	**1.5E-16**	17%	**6.9E-16**	12%	**1.2E-16**	17%	**2.7E-16**	13%	**1.1E-16**	45%

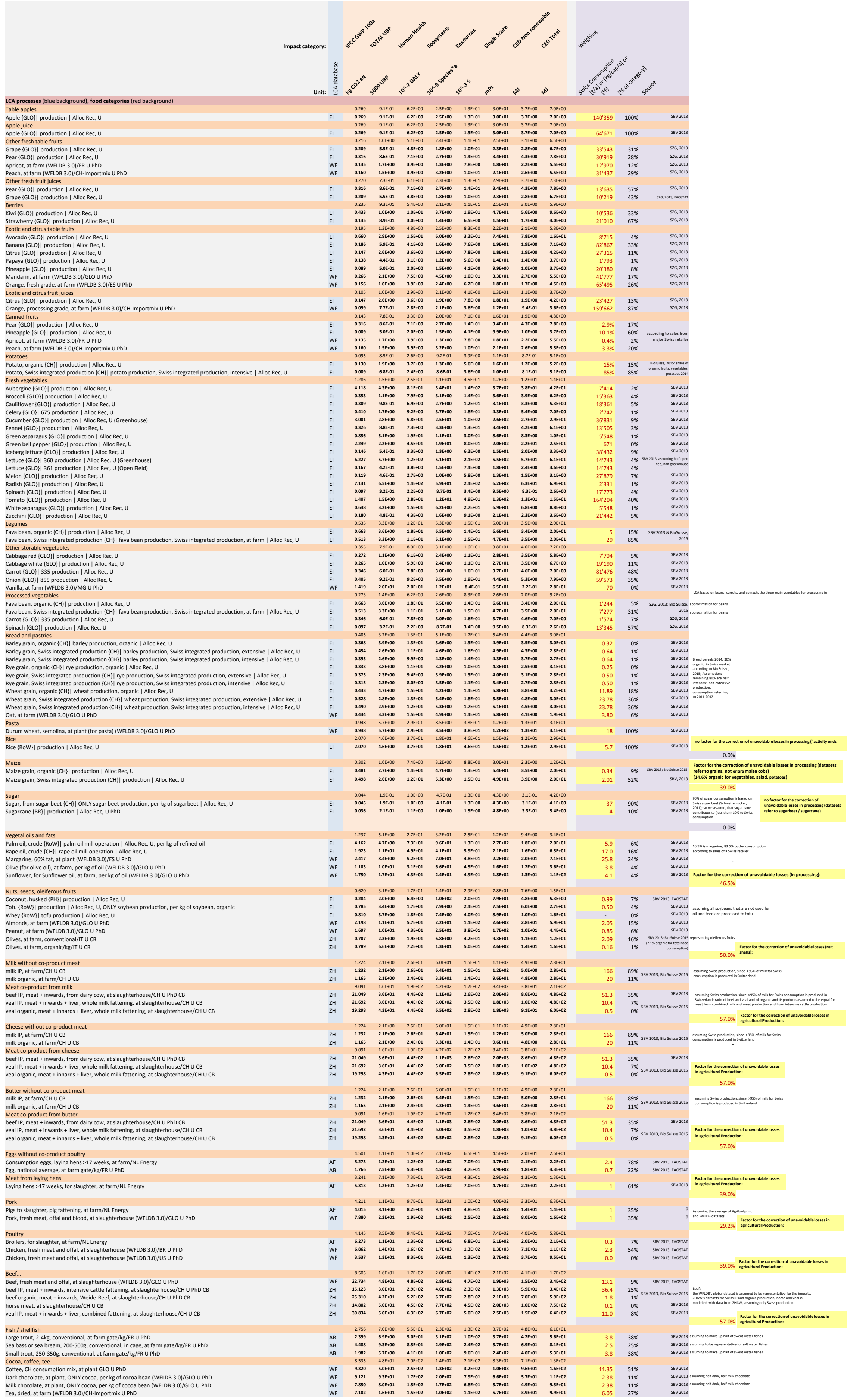
Pork		Poultry		Beef, horse, veal		Fish, shellfish		Cocoa, coffee, tea		All food categories	
[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]		[kg CO_2-eq/p/a]	
137.14	80%	**57.60**	79%	**236.62**	82%	**21.11**	54%	**101.18**	87%	**1'519.74**	75%
35.02	20%	**15.27**	21%	**53.08**	18%	**17.99**	46%	**15.30**	13%	**494.23**	25%
0.23	0%	0.00	0%	0.00	0%	12.88	33%	5.38	5%	76.51	4%
1.40	1%	0.58	1%	3.01	1%	0.11	0%	2.24	2%	13.03	1%
3.98	2%	1.71	2%	7.20	2%	0.58	1%	1.01	1%	83.84	4%
3.01	2%	1.90	3%	9.49	3%	0.89	2%	1.22	1%	40.64	2%
2.00	1%	0.72	1%	4.49	2%	0.67	2%	0.36	0%	27.65	1%
24.41	14%	10.35	14%	28.89	10%	2.86	7%	5.08	4%	252.57	13%
[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]		[mPt/p/a]	
13'347	80%	**10'059**	79%	**19'820**	82%	**2'782**	54%	**9'957**	87%	**153'951**	75%
3'405	20%	**2'711**	21%	**4'437**	18%	**2'417**	46%	**1'496**	13%	**50'312**	25%
22	0%	0	0%	0	0%	1'718	33%	521	5%	7'576	4%
134	1%	105	1%	250	1%	15	0%	222	2%	1'318	1%
385	2%	310	2%	598	2%	84	2%	99	1%	8'012	4%
296	2%	332	3%	798	3%	119	2%	120	1%	4'244	2%
194	1%	130	1%	374	2%	92	2%	34	0%	2'799	1%
2'374	14%	1'834	14%	2'417	10%	389	7%	500	4%	26'363	13%
[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]		[1'000 ecopoints/p/a]	
346.66	79%	**118.29**	79%	**449.42**	82%	**51.94**	53%	**548.98**	87%	**3'589.7**	75%
89.66	21%	**31.77**	21%	**101.20**	18%	**45.83**	47%	**85.28**	13%	**1'191.6**	25%
0.59	0%	0.00	0%	0.00	0%	32.51	33%	30.49	5%	178.3	4%
3.60	1%	1.22	1%	5.72	1%	0.30	0%	12.88	2%	38.9	1%
10.51	2%	3.61	2%	13.69	2%	1.56	2%	5.74	1%	219.9	5%
7.91	2%	4.03	3%	18.36	3%	2.34	2%	6.61	1%	106.6	2%
5.26	1%	1.52	1%	8.60	2%	1.79	2%	1.94	0%	61.2	1%
61.77	14%	21.40	14%	54.83	10%	7.33	7%	27.62	4%	586.7	12%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
1.6E-13	79%	**6.5E-14**	78%	**1.2E-12**	81%	**3.2E-14**	51%	**2.9E-12**	86%	**6.5E-12**	77%
4.2E-14	21%	**1.8E-14**	22%	**2.7E-13**	19%	**3.0E-14**	49%	**4.5E-13**	14%	**2.0E-12**	23%
[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]		[gPDF-eq/p/a]	
1.9E-15	79%	**3.0E-15**	78%	**9.1E-15**	81%	**2.7E-15**	51%	**1.3E-13**	86%	**3.9E-13**	72%
4.9E-16	21%	**8.2E-16**	22%	**2.1E-15**	19%	**2.6E-15**	49%	**2.1E-14**	14%	**1.5E-13**	28%

Maize	Sugar	Vegetal oils and fats	Nuts, seeds, oleiferous fruits	Milk, other dairy	Meat co-product from milk	Cheese, whey	Meat co-product from cheese	Butter, buttermilk, skimmed milk
[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]
0.72	**1.08**	**3.37**	**1.47**	**1.69**	**23.27**	**3.47**	**23.27**	**2.15**
0.72	**0.63**	**1.79**	**0.71**	**1.63**	**23.14**	**1.60**	**23.13**	**1.25**
0.01	-0.12		-0.58		-0.05	-0.25	-0.05	-0.47
		0.09	0.09					
							-0.002	
-0.20	-0.34	-0.49	-0.49	-0.20	-0.21	-0.20	-0.21	-0.20
				-0.20		-0.11		-0.12
				0.08				

Meat co-product from butter	Eggs without co-product poultry	Meat from laying hens	Pork	Poultry	Beef, horse, veal	Fish, shellfish	Cocoa, coffee, tea	All food categories
[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]	[kg CO_2-eq/kg]
23.27	**6.53**	**8.75**	**7.10**	**10.23**	**21.76**	**3.68**	**9.50**	**2.77**
23.13	**6.23**	**6.22**	**5.87**	**9.22**	**21.68**	**2.92**	**8.94**	**1.52**
-0.05	0.03	-0.05	-0.05	-0.05	-0.05	-0.05	-0.03	-0.04
							-0.002	-0.01
-0.002	-0.03	-0.0005				-0.01	-0.05	-0.22
-0.21	-0.20	-0.21	-0.21	-0.21	-0.21	-0.21	0.23	-0.22
				-0.80	-0.82	-0.56		-0.21
						0.08		0.06

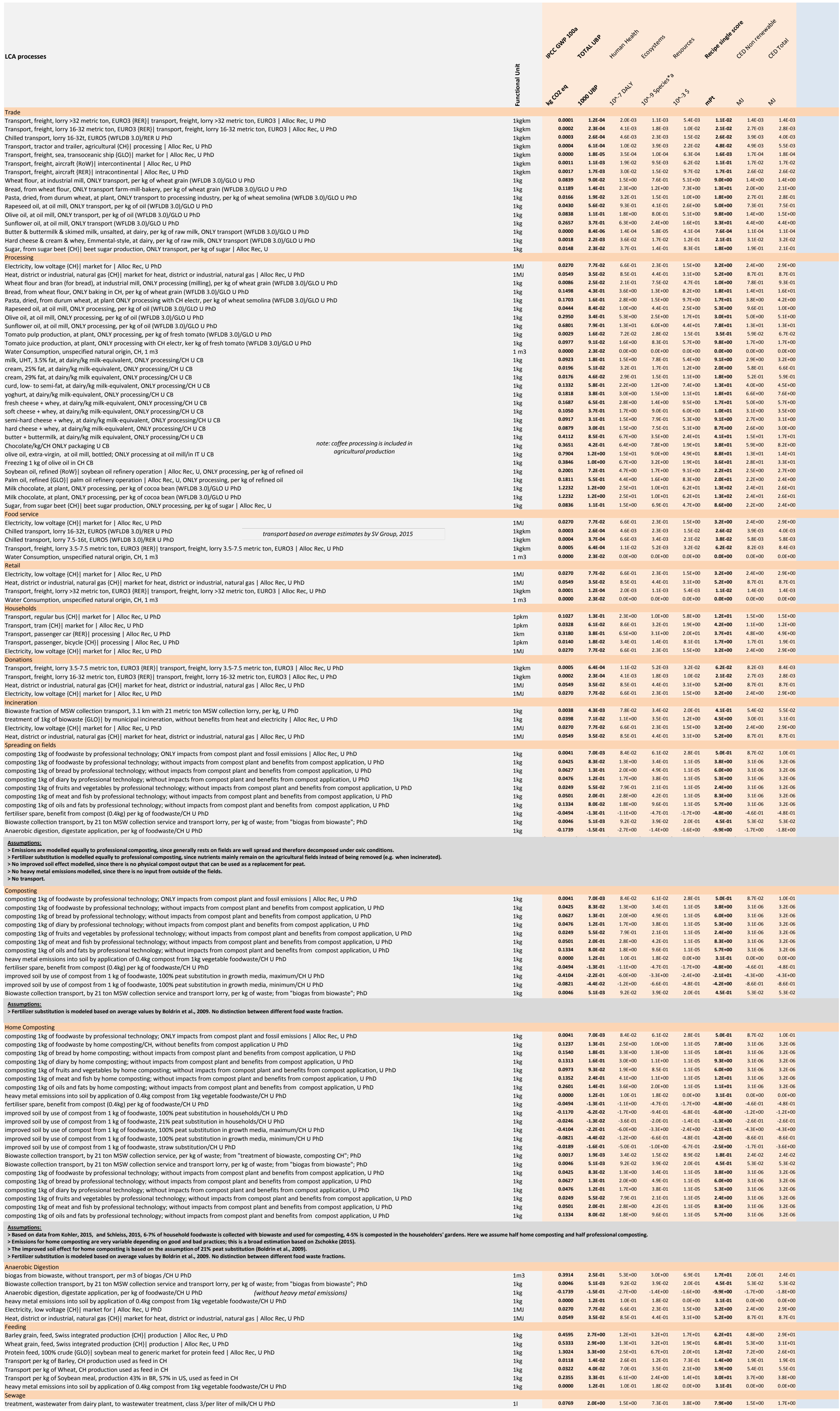
B.21 LCI Unit Processes and Factor Matrix

Table B.31: Food LCI unit processes. Defines for each food category which LCI processes are used and how they are weighted based on the Swiss consumption mix. Impacts per kg of food; the aggregated values for food categories are defined per kg of food at agricultural level (including inedible parts). (for abbrevitions of databases see Table B.34)



Impact category:		IPCC GWP 100a	TOTAL UBP	Human Health	Ecosystems	Resources	Single Score	CED Non renewable	CED Total	Weighting			
Unit:	LCA database	kg CO2 eq	1000 UBP	10^-7 DALY	10^-9 Species*a	10^-3 $	mPt	MJ	MJ	Swiss Consumption [t/a] or [kg/cap/a] or [%]	[% of category]	Source	
LCA processes (blue background**), food categories** (red background)													
Table apples		0.269	9.1E-01	6.2E+00	2.5E+00	1.3E+01	3.0E+01	3.7E+00	7.0E+00				
Apple {GLO}| production | Alloc Rec, U	EI	0.269	9.1E-01	6.2E+00	2.5E+00	1.3E+01	3.0E+01	3.7E+00	7.0E+00	140'359	100%	SBV 2013	
Apple juice		0.269	9.1E-01	6.2E+00	2.5E+00	1.3E+01	3.0E+01	3.7E+00	7.0E+00				
Apple {GLO}| production | Alloc Rec, U	EI	0.269	9.1E-01	6.2E+00	2.5E+00	1.3E+01	3.0E+01	3.7E+00	7.0E+00	64'671	100%	SBV 2013	
Other fresh table fruits		0.216	1.0E+00	5.1E+00	2.4E+00	1.1E+01	2.5E+01	3.1E+00	6.5E+00				
Grape {GLO}| production | Alloc Rec, U	EI	0.209	5.5E-01	4.8E+00	1.8E+00	1.0E+01	2.3E+01	2.8E+00	6.7E+00	33'543	31%	SZG, 2013	
Pear {GLO}| production | Alloc Rec, U	EI	0.316	8.6E-01	7.1E+00	2.7E+00	1.4E+01	3.4E+01	4.3E+00	7.8E+00	30'919	28%	SZG, 2013	
Apricot, at farm (WFLDB 3.0)/FR U PhD	WF	0.135	1.7E+00	3.9E+00	1.3E+00	7.8E+00	1.8E+01	2.2E+00	5.5E+00	12'970	12%	SZG, 2013	
Peach, at farm (WFLDB 3.0)/CH-Importmix U PhD	WF	0.160	1.5E+00	3.9E+00	3.2E+00	1.0E+01	2.1E+01	2.6E+00	5.5E+00	31'437	29%	SZG, 2013	
Other fresh fruit juices		0.270	7.3E-01	6.1E+00	2.3E+00	1.3E+01	2.9E+01	3.7E+00	7.3E+00				
Pear {GLO}| production | Alloc Rec, U	EI	0.316	8.6E-01	7.1E+00	2.7E+00	1.4E+01	3.4E+01	4.3E+00	7.8E+00	13'635	57%	SZG, 2013	
Grape {GLO}| production | Alloc Rec, U	EI	0.209	5.5E-01	4.8E+00	1.8E+00	1.0E+01	2.3E+01	2.8E+00	6.7E+00	10'219	43%	SZG, 2013; FAOSTAT	
Berries		0.235	9.3E-01	5.4E+00	2.1E+00	1.1E+01	2.5E+01	3.0E+00	5.9E+00				
Kiwi {GLO}| production | Alloc Rec, U	EI	0.433	1.0E+00	1.0E+01	3.7E+00	1.9E+01	4.7E+01	5.6E+00	9.6E+00	10'536	33%	SZG, 2013	
Strawberry {GLO}| production | Alloc Rec, U	EI	0.135	8.9E-01	3.0E+00	1.4E+00	6.5E+00	1.5E+01	1.7E+00	4.0E+00	21'010	67%	SZG, 2013	
Exotic and citrus table fruits		0.195	1.3E+00	4.8E+00	2.5E+00	8.3E+00	2.2E+01	2.1E+00	5.8E+00				
Avocado {GLO}| production | Alloc Rec, U	EI	0.660	2.9E+00	1.5E+01	6.0E+00	3.2E+01	7.4E+01	7.8E+00	1.6E+01	8'715	4%	SZG, 2013	
Banana {GLO}| production | Alloc Rec, U	EI	0.186	5.9E-01	4.1E+00	1.6E+00	7.6E+00	1.9E+01	1.9E+00	7.1E+00	82'867	33%	SZG, 2013	
Citrus {GLO}| production | Alloc Rec, U	EI	0.147	2.6E+00	3.6E+00	1.9E+00	7.8E+00	1.8E+01	1.9E+00	4.2E+00	27'315	11%	SZG, 2013	
Papaya {GLO}| production | Alloc Rec, U	EI	0.138	4.4E-01	3.1E+00	1.2E+00	5.6E+00	1.4E+01	1.4E+00	3.7E+00	1'793	1%	SZG, 2013	
Pineapple {GLO}| production | Alloc Rec, U	EI	0.089	5.0E-01	2.0E+00	1.5E+00	4.1E+00	9.9E+00	1.0E+00	3.7E+00	20'380	8%	SZG, 2013	
Mandarin, at farm (WFLDB 3.0)/GLO U PhD	WF	0.266	2.1E+00	7.5E+00	4.5E+00	1.0E+01	3.3E+01	2.7E+00	5.5E+00	41'777	17%	SZG, 2013	
Orange, fresh grade, at farm (WFLDB 3.0)/ES U PhD	WF	0.156	1.0E+00	3.9E+00	2.4E+00	6.2E+00	1.8E+01	1.7E+00	4.5E+00	65'495	26%	SZG, 2013	
Exotic and citrus fruit juices		0.105	1.0E+00	2.9E+00	2.1E+00	4.1E+00	1.3E+01	1.1E+00	3.7E+00				
Citrus {GLO}| production | Alloc Rec, U	EI	0.147	2.6E+00	3.6E+00	1.9E+00	7.8E+00	1.8E+01	1.9E+00	4.2E+00	23'427	13%	SZG, 2013	
Orange, processing grade, at farm (WFLDB 3.0)/CH-Importmix U PhD	WF	0.099	7.7E-01	2.8E+00	2.1E+00	3.6E+00	1.2E+01	9.4E-01	3.6E+00	159'662	87%	SZG, 2013	
Canned fruits		0.143	7.8E-01	3.3E+00	2.0E+00	7.1E+00	1.6E+01	1.9E+00	4.8E+00				
Pear {GLO}| production | Alloc Rec, U	EI	0.316	8.6E-01	7.1E+00	2.7E+00	1.4E+01	3.4E+01	4.3E+00	7.8E+00	2.9%	17%		
Pineapple {GLO}| production | Alloc Rec, U	EI	0.089	5.0E-01	2.0E+00	1.5E+00	4.1E+00	9.9E+00	1.0E+00	3.7E+00	10.1%	60%	according to sales from major Swiss retailer	
Apricot, at farm (WFLDB 3.0)/FR U PhD	WF	0.135	1.7E+00	3.9E+00	1.3E+00	7.8E+00	1.8E+01	2.2E+00	5.5E+00	0.4%	2%		
Peach, at farm (WFLDB 3.0)/CH-Importmix U PhD	WF	0.160	1.5E+00	3.9E+00	3.2E+00	1.0E+01	2.1E+01	2.6E+00	5.5E+00	3.3%	20%		
Potatoes		0.095	8.5E-01	2.6E+00	9.2E-01	3.9E+00	1.1E+01	8.7E-01	5.1E+00				
Potato, organic {CH}| production | Alloc Rec, U	EI	0.130	1.9E+00	3.7E+00	1.3E+00	5.6E+00	1.6E+01	1.2E+00	5.2E+00	15%	15%	Biosuisse, 2015: share of organic fruits, vegetables, potatoes 2014	
Potato, Swiss integrated production {CH}| potato production, Swiss integrated production, intensive | Alloc Rec, U	EI	0.089	6.8E-01	2.4E+00	8.6E-01	3.6E+00	1.0E+01	8.1E-01	5.1E+00	85%	85%		
Fresh vegetables		1.286	1.5E+00	2.5E+01	1.1E+01	4.5E+01	1.2E+02	1.2E+01	1.4E+01				
Aubergine {GLO}| production | Alloc Rec, U	EI	4.118	4.3E+00	8.1E+01	3.4E+01	1.4E+02	3.7E+02	3.8E+01	4.2E+01	7'414	2%	SBV 2013	
Broccoli {GLO}| production | Alloc Rec, U	EI	0.353	1.1E+00	7.9E+00	3.1E+00	1.4E+01	3.6E+01	3.9E+00	6.2E+00	15'363	4%	SBV 2013	
Cauliflower {GLO}| production | Alloc Rec, U	EI	0.309	9.8E-01	6.9E+00	2.7E+00	1.2E+01	3.1E+01	3.3E+00	5.3E+00	18'361	5%	SBV 2013	
Celery {GLO}| 675 production | Alloc Rec, U	EI	0.410	1.7E+00	9.2E+00	3.7E+00	1.8E+01	4.3E+01	5.4E+00	7.0E+00	2'742	1%	SBV 2013	
Cucumber {GLO}| production | Alloc Rec, U (Greenhouse)	EI	3.001	2.8E+00	5.8E+01	2.5E+01	1.0E+02	2.6E+02	2.7E+01	2.9E+01	36'831	9%	SBV 2013	
Fennel {GLO}| production | Alloc Rec, U	EI	0.326	8.8E-01	7.3E+00	3.3E+00	1.3E+01	3.4E+01	4.2E+00	6.1E+00	13'505	3%	SBV 2013	
Green asparagus {GLO}| production | Alloc Rec, U	EI	0.856	5.1E+00	1.9E+01	1.1E+01	3.0E+01	8.6E+01	8.3E+00	1.0E+01	5'548	1%	SBV 2013	
Green bell pepper {GLO}| production | Alloc Rec, U	EI	2.249	2.2E+00	4.5E+01	1.9E+01	8.0E+01	2.0E+02	2.2E+01	2.5E+01	671	0%	SBV 2013	
Iceberg lettuce {GLO}| production | Alloc Rec, U	EI	0.146	5.4E-01	3.3E+00	1.3E+00	6.2E+00	1.5E+01	2.0E+00	3.3E+00	38'432	9%	SBV 2013	
Lettuce {GLO}| 360 production | Alloc Rec, U (Greenhouse)	EI	6.227	5.7E+00	1.2E+02	5.1E+01	2.1E+02	5.5E+02	5.7E+01	6.1E+01	14'743	4%	SBV 2013, assuming half open fied, half greenhouse	
Lettuce {GLO}| 361 production | Alloc Rec, U (Open Field)	EI	0.167	4.2E-01	3.8E+00	1.5E+00	7.4E+00	1.8E+01	2.4E+00	3.6E+00	14'743	4%		
Melon {GLO}| production | Alloc Rec, U	EI	0.119	4.6E-01	2.7E+00	1.0E+00	5.8E+00	1.3E+01	1.5E+00	3.1E+00	27'879	7%	SBV 2013	
Radish {GLO}| production | Alloc Rec, U	EI	7.131	6.5E+00	1.4E+02	5.9E+01	2.4E+02	6.2E+02	6.3E+01	6.9E+01	2'331	1%	SBV 2013	
Spinach {GLO}| production | Alloc Rec, U	EI	0.097	3.2E-01	2.2E+00	8.7E-01	3.4E+00	9.5E+00	8.3E-01	2.6E+00	17'773	4%	SBV 2013	
Tomato {GLO}| production | Alloc Rec, U	EI	1.407	1.5E+00	2.8E+01	1.2E+01	4.9E+01	1.3E+02	1.3E+01	1.5E+01	164'204	40%	SBV 2013	
White asparagus {GLO}| production | Alloc Rec, U	EI	0.648	3.2E+00	1.5E+01	6.2E+00	2.7E+01	6.9E+01	6.8E+00	8.8E+00	5'548	1%	SBV 2013	
Zucchini {GLO}| production | Alloc Rec, U	EI	0.180	4.8E-01	4.3E+00	1.6E+00	9.1E+00	2.1E+01	2.3E+00	3.6E+00	21'442	5%	SBV 2013	
Legumes		0.535	3.3E+00	1.2E+01	5.3E+00	1.5E+01	5.0E+01	3.5E+00	2.0E+01				
Fava bean, organic {CH}| production | Alloc Rec, U	EI	0.663	3.6E+00	1.8E+01	6.5E+00	1.4E+01	6.6E+01	3.4E+00	2.0E+01	5	15%	SBV 2013 & BioSuisse, 2015	
Fava bean, Swiss integrated production {CH}| fava bean production, Swiss integrated production, at farm | Alloc Rec, U	EI	0.513	3.3E+00	1.1E+01	5.1E+00	1.5E+01	4.7E+01	3.5E+00	2.0E+01	29	85%		
Other storable vegetables		0.355	7.9E-01	8.0E+00	3.1E+00	1.6E+01	3.8E+01	4.6E+00	7.2E+00				
Cabbage red {GLO}| production | Alloc Rec, U	EI	0.272	1.1E+00	6.1E+00	2.4E+00	1.1E+01	2.8E+01	3.5E+00	5.8E+00	7'704	5%	SBV 2013	
Cabbage white {GLO}| production | Alloc Rec, U	EI	0.265	1.0E+00	5.9E+00	2.4E+00	1.1E+01	2.7E+01	3.5E+00	6.7E+00	19'190	11%	SBV 2013	
Carrot {GLO}| 335 production | Alloc Rec, U	EI	0.346	6.0E-01	7.8E+00	3.0E+00	1.6E+01	3.7E+01	4.6E+00	7.0E+00	81'476	48%	SBV 2013	
Onion {GLO}| 855 production | Alloc Rec, U	EI	0.405	9.2E-01	9.2E+00	3.5E+00	1.9E+01	4.4E+01	5.3E+00	7.9E+00	59'573	35%	SBV 2013	
Vanilla, at farm (WFLDB 3.0)/MG U PhD	WF	1.419	2.0E+01	2.0E+01	1.2E+01	8.4E-01	6.5E+01	2.2E-01	2.8E+01	70	0%	SBV 2013	
Processed vegetables		0.273	1.4E+00	6.2E+00	2.6E+00	8.3E+00	2.6E+01	2.0E+00	9.2E+00				LCA based on beans, carrots, and spinach, the three main vegetables for processing in
Fava bean, organic {CH}| production | Alloc Rec, U	EI	0.663	3.6E+00	1.8E+01	6.5E+00	1.4E+01	6.6E+01	3.4E+00	2.0E+01	1'244	5%	SZG, 2013; Bio Suisse, 2015	approximation for beans
Fava bean, Swiss integrated production {CH}| fava bean production, Swiss integrated production, at farm | Alloc Rec, U	EI	0.513	3.3E+00	1.1E+01	5.1E+00	1.5E+01	4.7E+01	3.5E+00	2.0E+01	7'277	31%		approximation for beans
Carrot {GLO}| 335 production | Alloc Rec, U	EI	0.346	6.0E-01	7.8E+00	3.0E+00	1.6E+01	3.7E+01	4.6E+00	7.0E+00	1'574	7%	SZG, 2013	
Spinach {GLO}| production | Alloc Rec, U	EI	0.097	3.2E-01	2.2E+00	8.7E-01	3.4E+00	9.5E+00	8.3E-01	2.6E+00	13'345	57%	SZG, 2013	
Bread and pastries		0.485	3.2E+00	1.3E+01	5.1E+00	1.7E+01	5.4E+01	4.4E+00	3.0E+01				
Barley grain, organic {CH}| barley production, organic | Alloc Rec, U	EI	0.368	3.9E+00	1.3E+01	3.6E+00	1.3E+01	4.9E+01	3.5E+00	3.0E+01	0.32	0%	SBV 2013	
Barley grain, Swiss integrated production {CH}| barley production, Swiss integrated production, extensive | Alloc Rec, U	EI	0.454	2.6E+00	1.1E+01	4.6E+00	1.6E+01	4.9E+01	4.3E+00	2.8E+01	0.64	1%	SBV 2013	
Barley grain, Swiss integrated production {CH}| barley production, Swiss integrated production, intensive | Alloc Rec, U	EI	0.395	2.6E+00	9.9E+00	4.3E+00	1.4E+01	4.3E+01	3.7E+00	2.7E+01	0.64	1%	SBV 2013	Bread cereals 2014: 20% organic in Swiss market according to Bio Suisse, 2015; Assumption: remaining 80% are half intensive, half extensive production; consumption referring to 2011-2012
Rye grain, organic {CH}| rye production, organic | Alloc Rec, U	EI	0.333	3.8E+00	1.1E+01	3.2E+00	1.0E+01	4.3E+01	2.5E+00	3.1E+01	0.25	0%	SBV 2013	
Rye grain, Swiss integrated production {CH}| rye production, Swiss integrated production, extensive | Alloc Rec, U	EI	0.375	2.3E+00	9.4E+00	3.9E+00	1.3E+01	4.0E+01	3.1E+00	2.8E+01	0.50	1%	SBV 2013	
Rye grain, Swiss integrated production {CH}| rye production, Swiss integrated production, intensive | Alloc Rec, U	EI	0.315	2.3E+00	8.0E+00	3.5E+00	1.1E+01	3.4E+01	2.7E+00	2.8E+01	0.50	1%	SBV 2013	
Wheat grain, organic {CH}| wheat production, organic | Alloc Rec, U	EI	0.433	4.7E+00	1.5E+01	4.2E+00	1.4E+01	5.8E+01	3.8E+00	3.2E+01	11.89	18%	SBV 2013	
Wheat grain, Swiss integrated production {CH}| wheat production, Swiss integrated production, extensive | Alloc Rec, U	EI	0.528	2.8E+00	1.3E+01	5.4E+00	1.8E+01	5.5E+01	4.8E+00	3.0E+01	23.78	36%	SBV 2013	
Wheat grain, Swiss integrated production {CH}| wheat production, Swiss integrated production, intensive | Alloc Rec, U	EI	0.490	2.9E+00	1.2E+01	5.3E+00	1.7E+01	5.1E+01	4.5E+00	3.0E+01	23.78	36%	SBV 2013	
Oat, at farm (WFLDB 3.0)/GLO U PhD	WF	0.434	3.3E+00	1.5E+01	4.9E+00	1.4E+01	5.8E+01	4.1E+00	1.9E+01	3.80	6%	SBV 2013	
Pasta		0.948	5.7E+00	2.9E+01	8.5E+00	3.8E+01	1.2E+02	1.3E+01	3.1E+01				
Durum wheat, semolina, at plant (for pasta) (WFLDB 3.0)/GLO U PhD	WF	0.948	5.7E+00	2.9E+01	8.5E+00	3.8E+01	1.2E+02	1.3E+01	3.1E+01	18	100%	SBV 2013	
Rice		2.070	4.6E+00	3.7E+01	1.8E+01	4.6E+01	1.5E+02	1.2E+01	2.9E+01				**no factor for the correction of unavoidable losses in processing ("activity ends**
Rice {RoW}| production | Alloc Rec, U	EI	2.070	4.6E+00	3.7E+01	1.8E+01	4.6E+01	1.5E+02	1.2E+01	2.9E+01	5.7	100%	SBV 2013	
													0.0%
Maize		0.302	1.6E+00	7.4E+00	3.2E+00	8.8E+00	3.0E+01	2.3E+00	1.2E+01				
Maize grain, organic {CH}| production | Alloc Rec, U	EI	0.481	2.7E+00	1.4E+01	4.7E+00	1.3E+01	5.4E+01	3.5E+00	2.0E+01	0.34	9%	SBV 2013; Bio Suisse 2015	**Factor for the correction of unavoidable losses in processing (datasets refer to grains, not entire maize cobs) (14.6% organic for vegetables, salad, potatoes)**
Maize grain, Swiss integrated production {CH}| production | Alloc Rec, U	EI	0.498	2.6E+00	1.2E+01	5.3E+00	1.5E+01	4.9E+01	3.9E+00	2.0E+01	2.01	52%	SBV, 2013	
													39.0%
Sugar		0.044	1.9E-01	1.0E+00	4.7E-01	1.3E+00	4.3E+00	3.1E-01	4.2E+00				
Sugar, from sugar beet {CH}| ONLY sugar beet production, per kg of sugarbeet | Alloc Rec, U	EI	0.045	1.9E-01	1.0E+00	4.1E-01	1.3E+00	4.3E+00	3.1E-01	4.1E+00	37	90%	SBV 2013	90% of sugar consumption is based on Swiss sugar beet (Schweizerzucker, 2011); so we assume, that sugar cane contributes to (less than) 10% to Swiss consumption **no factor for the correction of unavoidable losses in processing (datasets refer to sugarbeet / sugarcane)**
Sugarcane {BR}| production | Alloc Rec, U PhD	EI	0.036	2.1E-01	1.1E+00	1.0E+00	1.5E+00	4.8E+00	3.3E-01	5.4E+00	4	10%	SBV 2013	
													0.0%
Vegetal oils and fats		1.237	5.1E+00	2.7E+01	3.2E+01	2.5E+01	1.2E+02	9.4E+00	3.4E+01				
Palm oil, crude {RoW}| palm oil mill operation | Alloc Rec, U, per kg of refined oil	EI	4.162	4.7E+00	7.3E+01	9.6E+01	1.3E+01	2.7E+02	1.8E+01	2.0E+01	5.9	6%	SBV 2013	16.5% is margarine, 83.5% butter consumption according to sales of a Swiss retailer
Rape oil, crude {CH}| rape oil mill operation | Alloc Rec, U	EI	1.923	1.1E+01	4.9E+01	4.1E+01	5.9E+01	2.1E+02	1.6E+01	6.5E+01	17.0	16%	SBV 2013	
Margarine, 60% fat, at plant (WFLDB 3.0)/ES U PhD	WF	2.417	8.4E+00	5.2E+01	7.0E+01	4.8E+01	2.2E+02	2.0E+01	7.1E+01	25.8	24%	SBV 2013	-
Olive (for olive oil), at farm, per kg of oil (WFLDB 3.0)/GLO U PhD	WF	1.103	1.0E+01	3.1E+01	6.6E+01	4.5E+01	1.6E+02	1.2E+01	3.6E+01	3.8	4%	SBV 2013	
Sunflower, for Sunflower oil, at farm, per kg of oil (WFLDB 3.0)/GLO U PhD	WF	1.750	1.7E+01	4.3E+01	2.4E+01	4.9E+01	1.8E+02	1.3E+01	1.1E+02	4.1	4%	SBV 2013	**Factor for the correction of unavoidable losses (in processing):**
													46.5%
Nuts, seeds, oleiferous fruits		0.620	3.1E+00	1.7E+01	1.4E+01	2.9E+01	7.8E+01	7.6E+00	1.5E+01				
Coconut, husked {PH}| production | Alloc Rec, U	EI	0.284	2.0E+00	6.4E+00	1.0E+02	2.0E+01	7.9E+01	4.8E+00	5.3E+00	0.99	7%	SBV 2013, FAOSTAT	
Tofu {RoW}| production | Alloc Rec, U, ONLY soybean production, per kg of soybean, organic	EI	0.785	3.4E+00	1.7E+01	7.9E+00	2.4E+01	7.5E+01	6.0E+00	2.7E+01	0.50	4%	SBV 2013	assuming all soybeans that are not used for oil and feed are processed to tofu
Whey {RoW}| tofu production | Alloc Rec, U	EI	0.810	3.7E+00	1.8E+01	7.4E+00	4.0E+01	8.9E+01	1.0E+01	1.6E+01	-	0%	SBV 2013	
Almonds, at farm (WFLDB 3.0)/GLO U PhD	WF	2.198	1.1E+01	5.7E+01	2.2E+01	1.1E+02	2.6E+02	2.8E+01	5.9E+01	2.05	15%	SBV 2013	
Peanut, at farm (WFLDB 3.0)/GLO U PhD	WF	1.697	1.0E+01	4.3E+01	2.5E+01	3.8E+01	1.7E+02	1.0E+01	4.4E+01	0.85	6%	SBV 2013	
Olives, at farm, conventional/IT U CB	ZH	0.707	2.3E+00	1.9E+01	6.8E+00	4.2E+01	9.3E+01	1.1E+01	1.2E+01	2.09	16%	SBV 2013; Bio Suisse 2015 (7.1% organic for total food consumption)	representing oleiferous fruits
Olives, at farm, organic/kg/IT U CB	ZH	0.789	6.6E+00	7.2E+01	1.3E+01	5.0E+01	2.6E+02	1.4E+01	1.6E+01	0.16	1%		**Factor for the correction of unavoidable losses (nut shells):**
													50.0%
Milk without co-product meat		1.224	2.1E+00	2.6E+01	6.0E+01	1.5E+01	1.1E+02	4.9E+00	2.8E+01				
milk IP, at farm/CH U CB	ZH	1.232	2.1E+00	2.6E+01	6.4E+01	1.5E+01	1.2E+02	5.0E+00	2.8E+01	166	89%	SBV 2013, Bio Suisse 2015	assuming Swiss production, since >95% of milk for Swiss consumption is produced in Switzerland
milk organic, at farm/CH U CB	ZH	1.165	2.1E+00	2.4E+01	3.3E+01	1.4E+01	9.6E+01	4.8E+00	2.8E+01	20	11%		
Meat co-product from milk		9.091	1.6E+01	1.9E+02	4.2E+02	1.2E+02	8.4E+02	3.8E+01	2.1E+02				
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U PhD CB	ZH	21.049	3.6E+01	4.4E+02	1.1E+03	2.6E+02	2.0E+03	8.6E+01	4.8E+02	51.3	35%	SBV 2013	assuming Swiss production, since >95% of milk for Swiss consumption is produced in Switzerland; ratio of beef and veal and of organic and IP products assumed to be equal for meat from combined milk and meat production and from intensive cattle production
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	21.692	3.6E+01	4.4E+02	5.0E+02	3.5E+02	1.8E+03	1.0E+02	4.8E+02	10.4	7%	SBV 2013, Bio Suisse 2015	
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	19.298	4.3E+01	4.4E+02	6.5E+02	2.8E+02	1.8E+03	9.1E+01	6.0E+02	0.5	0%		
													57.0% **Factor for the correction of unavoidable losses in agricultural Production:**
Cheese without co-product meat		1.224	2.1E+00	2.6E+01	6.0E+01	1.5E+01	1.1E+02	4.9E+00	2.8E+01				
milk IP, at farm/CH U CB	ZH	1.232	2.1E+00	2.6E+01	6.4E+01	1.5E+01	1.2E+02	5.0E+00	2.8E+01	166	89%	SBV 2013, Bio Suisse 2015	assuming Swiss production, since >95% of milk for Swiss consumption is produced in Switzerland
milk organic, at farm/CH U CB	ZH	1.165	2.1E+00	2.4E+01	3.3E+01	1.4E+01	9.6E+01	4.8E+00	2.8E+01	20	11%		-
Meat co-product from cheese		9.091	1.6E+01	1.9E+02	4.2E+02	1.2E+02	8.4E+02	3.8E+01	2.1E+02				
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U PhD CB	ZH	21.049	3.6E+01	4.4E+02	1.1E+03	2.6E+02	2.0E+03	8.6E+01	4.8E+02	51.3	35%	SBV 2013	
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	21.692	3.6E+01	4.4E+02	5.0E+02	3.5E+02	1.8E+03	1.0E+02	4.8E+02	10.4	7%	SBV 2013, Bio Suisse 2015	**Factor for the correction of unavoidable losses in agricultural Production:**
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	19.298	4.3E+01	4.4E+02	6.5E+02	2.8E+02	1.8E+03	9.1E+01	6.0E+02	0.5	0%		
													57.0%
Butter without co-product meat		1.224	2.1E+00	2.6E+01	6.0E+01	1.5E+01	1.1E+02	4.9E+00	2.8E+01				
milk IP, at farm/CH U CB	ZH	1.232	2.1E+00	2.6E+01	6.4E+01	1.5E+01	1.2E+02	5.0E+00	2.8E+01	166	89%	SBV 2013, Bio Suisse 2015	assuming Swiss production, since >95% of milk for Swiss consumption is produced in Switzerland
milk organic, at farm/CH U CB	ZH	1.165	2.1E+00	2.4E+01	3.3E+01	1.4E+01	9.6E+01	4.8E+00	2.8E+01	20	11%		
Meat co-product from butter		9.091	1.6E+01	1.9E+02	4.2E+02	1.2E+02	8.4E+02	3.8E+01	2.1E+02				
beef IP, meat + inwards, from dairy cow, at slaughterhouse/CH U PhD CB	ZH	21.049	3.6E+01	4.4E+02	1.1E+03	2.6E+02	2.0E+03	8.6E+01	4.8E+02	51.3	35%	SBV 2013	
veal IP, meat + inwards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	21.692	3.6E+01	4.4E+02	5.0E+02	3.5E+02	1.8E+03	1.0E+02	4.8E+02	10.4	7%	SBV 2013, Bio Suisse 2015	**Factor for the correction of unavoidable losses in agricultural Production:**
veal organic, meat + innards + liver, whole milk fattening, at slaughterhouse/CH U CB	ZH	19.298	4.3E+01	4.4E+02	6.5E+02	2.8E+02	1.8E+03	9.1E+01	6.0E+02	0.5	0%		
													57.0%
Eggs without co-product poultry		4.501	1.1E+01	1.0E+02	2.1E+02	6.5E+01	4.5E+02	2.0E+01	2.6E+01				
Consumption eggs, laying hens >17 weeks, at farm/NL Energy	AF	5.273	1.2E+01	1.2E+02	1.4E+02	7.0E+01	4.7E+02	2.1E+01	2.2E+01	2.4	78%	SBV 2013, FAOSTAT	
Egg, national average, at farm gate/kg/FR U PhD	AB	1.766	7.5E+00	5.3E+01	4.5E+02	4.7E+01	3.9E+02	1.8E+01	4.3E+01	0.7	22%	SBV 2013, FAOSTAT	
Meat from laying hens		3.241	7.1E+00	7.3E+01	8.7E+01	4.3E+01	2.9E+02	1.3E+01	1.3E+01				**Factor for the correction of unavoidable losses in agricultural Production:**
Laying hens >17 weeks, for slaughter, at farm/NL Energy	AF	5.313	1.2E+01	1.2E+02	1.4E+02	7.0E+01	4.7E+02	2.1E+01	2.2E+01	1	61%	SBV 2013	
													39.0%
Pork		4.211	1.1E+01	9.7E+01	8.2E+01	1.0E+02	4.0E+02	3.3E+01	6.3E+01				
Pigs to slaughter, pig fattening, at farm/NL Energy	AF	4.015	8.1E+00	8.2E+01	9.7E+01	4.8E+01	3.2E+02	1.4E+01	1.4E+01	1	35%	0	Assuming the average of Agrifootprint and WFLDB datasets
Pork, fresh meat, offal and blood, at slaughterhouse (WFLDB 3.0)/GLO U PhD	WF	7.880	2.2E+01	1.9E+02	1.3E+02	2.5E+02	8.2E+02	8.0E+01	1.6E+02	1	35%	0	**Factor for the correction of unavoidable losses in agricultural Production:**
													29.2%
Poultry		4.145	8.5E+00	9.4E+01	9.2E+02	7.6E+01	7.4E+02	4.0E+01	5.8E+01				
Broilers, for slaughter, at farm/NL Energy	AF	6.273	1.1E+01	1.3E+02	1.9E+02	6.8E+01	5.1E+02	2.0E+01	2.1E+01	0.3	7%	SBV 2013, FAOSTAT	
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/BR U PhD	WF	6.862	1.4E+01	1.6E+02	1.7E+03	1.3E+02	1.3E+03	7.1E+01	1.1E+02	2.3	54%	SBV 2013, FAOSTAT	
Chicken, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/US U PhD	WF	3.537	1.3E+01	8.3E+01	3.6E+01	1.3E+02	3.7E+02	3.7E+01	9.5E+01	0.0	0%	SBV 2013, FAOSTAT	
													39.0% **Factor for the correction of unavoidable losses in agricultural Production:**
Beef…		8.505	1.6E+01	1.7E+02	2.0E+02	1.4E+02	7.1E+02	4.1E+01	1.7E+02				
Beef, fresh meat and offal, at slaughterhouse (WFLDB 3.0)/GLO U PhD	WF	22.734	4.8E+01	4.8E+02	2.8E+02	4.7E+02	1.9E+03	1.5E+02	3.4E+02	13.1	9%	SBV 2013, FAOSTAT	
beef IP, meat + inwards, intensive cattle fattening, at slaughterhouse/CH U PhD CB	ZH	15.123	3.0E+01	2.9E+02	4.6E+02	2.3E+02	1.3E+03	5.9E+01	3.4E+02	36.4	25%	SBV 2013, Bio Suisse 2015	Beef: the WFLDB's global dataset is assumed to be representative for the imports, ZHAW's datasets for Swiss IP and organic production; horse and veal is modelled with data from ZHAW, assuming only Swiss production
beef organic, meat + inwards, Weide-Beef, at slaughterhouse/CH U PhD CB	ZH	25.310	4.2E+01	5.2E+02	6.7E+02	2.8E+02	2.1E+03	7.0E+01	5.9E+02	1.8	1%		
horse meat, at slaughterhouse/CH U CB	ZH	14.802	5.0E+01	4.5E+02	7.7E+02	4.5E+02	2.0E+03	1.0E+02	7.5E+02	0.1	0%	SBV 2013	
veal IP, meat + inwards + liver, combined fattening, at slaughterhouse/CH U CB	ZH	30.834	5.0E+01	6.3E+02	6.7E+02	5.0E+02	2.5E+03	1.5E+02	6.4E+02	11.0	8%	SBV 2013	
													57.0% **Factor for the correction of unavoidable losses in agricultural Production:**
Fish / shellfish		2.756	7.0E+00	5.5E+01	2.3E+02	1.3E+02	3.7E+02	4.8E+01	6.1E+01				
Large trout, 2-4kg, conventional, at farm gate/kg/FR U PhD	AB	2.399	6.9E+00	5.0E+01	3.1E+02	1.0E+02	3.7E+02	4.2E+01	5.6E+01	3.8	38%	SBV 2013	assuming to make up half of sweat water fishes
Sea bass or sea bream, 200-500g, conventional, in cage, at farm gate/kg/FR U PhD	AB	4.488	9.3E+00	8.5E+01	2.9E+02	2.4E+02	5.7E+02	6.9E+01	8.1E+01	2.5	25%	SBV 2013	assuming to be representative for salt water fishes
Small trout, 250-350g, conventional, at farm gate/kg/FR U PhD	AB	1.982	5.7E+00	4.1E+01	1.0E+02	9.6E+01	2.4E+02	4.0E+01	5.3E+01	3.8	38%	SBV 2013	assuming to make up half of sweat water fishes
Cocoa, coffee, tee		8.535	4.8E+01	2.0E+02	1.4E+02	2.1E+02	8.3E+02	7.1E+01	1.3E+02				
Coffee, CH consumption mix, at plant GLO U PhD	WF	9.320	5.0E+01	2.5E+02	1.3E+02	3.2E+02	1.0E+03	9.6E+01	1.6E+02	11.35	51%	SBV 2013	
Dark chocolate, at plant, ONLY cocoa, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	WF	9.121	9.3E+01	1.7E+02	2.0E+02	7.9E+01	6.6E+02	5.7E+01	1.1E+02	2.38	11%	SBV 2013	assuming half dark, half milk chocolate
Milk chocolate, at plant, ONLY cocoa, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	WF	7.850	8.0E+01	1.5E+02	1.7E+02	6.8E+01	5.7E+02	4.9E+01	9.5E+01	2.38	11%	SBV 2013	assuming half dark, half milk chocolate
Tea, dried, at farm (WFLDB 3.0)/CH-Importmix U PhD	WF	7.102	1.6E+01	1.5E+02	1.0E+02	1.1E+02	5.7E+02	3.9E+01	9.9E+01	6.05	27%	SBV 2013	

Table B.32: Unit impacts of the processes of the FVC (without agricultural production).



LCA processes		IPCC GWP 100a	TOTAL UBP	Human Health	Ecosystems	Resources	Recipe single score	CED Non renewable	CED Total
	Functional Unit	kg CO2 eq	1000 UBP	10^-7 DALY	10^-9 Species*a	10^-3 $	mPt	MJ	MJ
Trade									
Transport, freight, lorry >32 metric ton, EURO3 {RER}| transport, freight, lorry >32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0001	1.2E-04	2.0E-03	1.1E-03	5.4E-03	1.1E-02	1.4E-03	1.4E-03
Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0002	2.3E-04	4.1E-03	1.8E-03	1.0E-02	2.1E-02	2.7E-03	2.8E-03
Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U PhD	1kgkm	0.0003	2.6E-04	4.6E-03	2.3E-03	1.5E-02	2.6E-02	3.9E-03	4.0E-03
Transport, tractor and trailer, agricultural {CH}| processing | Alloc Rec, U PhD	1kgkm	0.0004	6.1E-04	1.0E-02	3.9E-03	2.2E-02	4.8E-02	4.9E-03	5.5E-03
Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U PhD	1kgkm	0.0000	1.8E-05	3.5E-04	1.0E-04	6.3E-04	1.6E-03	1.7E-04	1.8E-04
Transport, freight, aircraft {RoW}| intercontinental | Alloc Rec, U PhD	1kgkm	0.0011	1.1E-03	1.9E-02	9.5E-03	6.2E-02	1.1E-01	1.7E-02	1.7E-02
Transport, freight, aircraft {RER}| intracontinental | Alloc Rec, U PhD	1kgkm	0.0017	1.7E-03	3.0E-02	1.5E-02	9.7E-02	1.7E-01	2.6E-02	2.6E-02
Wheat flour, at industrial mill, ONLY transport, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	0.0839	9.0E-02	1.5E+00	7.6E-01	5.1E+00	9.0E+00	1.4E+00	1.4E+00
Bread, from wheat flour, ONLY transport farm-mill-bakery, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	0.1189	1.4E-01	2.3E+00	1.2E+00	7.3E+00	1.3E+01	2.0E+00	2.1E+00
Pasta, dried, from durum wheat, at plant, ONLY transport to processing industry, per kg of wheat semolina (WFLDB 3.0)/GLO U PhD	1kg	0.0166	1.9E-02	3.2E-01	1.5E-01	1.0E+00	1.8E+00	2.7E-01	2.8E-01
Rapeseed oil, at oil mill, ONLY transport, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	0.0430	5.6E-02	9.3E-01	4.1E-01	2.6E+00	5.0E+00	7.3E-01	7.5E-01
Olive oil, at oil mill, ONLY transport, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	0.0838	1.1E-01	1.8E+00	8.0E-01	5.1E+00	9.8E+00	1.4E+00	1.5E+00
Sunflower oil, at oil mill, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	0.2657	3.7E-01	6.3E+00	2.4E+00	1.6E+01	3.3E+01	4.4E+00	4.4E+00
Butter & buttermilk & skimed milk, unsalted, at dairy, per kg of raw milk, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	0.0000	8.4E-06	1.4E-04	5.8E-05	4.1E-04	7.6E-04	1.1E-04	1.1E-04
Hard cheese & cream & whey, Emmental-style, at dairy, per kg of raw milk, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	0.0018	2.2E-03	3.6E-02	1.7E-02	1.2E-01	2.1E-01	3.1E-02	3.2E-02
Sugar, from sugar beet {CH}| beet sugar production, ONLY transport, per kg of sugar | Alloc Rec, U	1kg	0.0148	2.3E-02	3.7E-01	1.4E-01	8.3E-01	1.8E+00	1.9E-01	2.1E-01
Processing									
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	0.0549	3.5E-02	8.5E-01	4.4E-01	3.1E+00	5.2E+00	8.7E-01	8.7E-01
Wheat flour and bran (for bread), at industrial mill, ONLY processing (milling), per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	0.0086	2.5E-02	2.1E-01	7.5E-02	4.7E-01	1.0E+00	7.8E-01	9.3E-01
Bread, from wheat flour, ONLY baking in CH, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	0.1498	4.3E-01	3.6E+00	1.3E+00	8.2E+00	1.8E+01	1.4E+01	1.6E+01
Pasta, dried, from durum wheat, at plant ONLY processing with CH electr, per kg of wheat semolina (WFLDB 3.0)/GLO U PhD	1kg	0.1703	1.6E-01	2.8E+00	1.5E+00	9.7E+00	1.7E+01	3.8E+00	4.2E+00
Rapeseed oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	0.0444	8.4E-02	1.0E+00	4.4E-01	2.5E+00	5.3E+00	9.6E-01	1.0E+00
Olive oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	0.2950	3.4E-01	5.3E+00	2.5E+00	1.7E+01	3.0E+01	5.0E+00	5.1E+00
Sunflower oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	0.6801	7.9E-01	1.3E+01	6.0E+00	4.4E+01	7.8E+01	1.3E+01	1.3E+01
Tomato pulp production, at plant, ONLY processing, per kg of fresh tomato (WFLDB 3.0)/GLO U PhD	1kg	0.0029	1.6E-02	7.2E-02	2.8E-02	1.5E-01	3.5E-01	5.9E-02	6.7E-02
Tomato juice production, at plant, ONLY processing with CH electr, ker kg of fresh tomato (WFLDB 3.0)/GLO U PhD	1kg	0.0977	9.1E-02	1.6E+00	8.3E-01	5.7E+00	9.8E+00	1.7E+00	1.7E+00
Water Consumption, unspecified natural origin, CH, 1 m3	1 m3	0.0000	2.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
milk, UHT, 3.5% fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.0923	1.8E-01	1.5E+00	7.8E-01	5.4E+00	9.1E+00	2.9E+00	3.2E+00
cream, 25% fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.0196	5.1E-02	3.2E-01	1.7E-01	1.2E+00	2.0E+00	5.8E-01	6.6E-01
cream, 29% fat, at dairy/kg milk equivalent, ONLY processing/CH U CB	1kg	0.0176	4.6E-02	2.9E-01	1.5E-01	1.1E+00	1.8E+00	5.2E-01	5.9E-01
curd, low- to semi-fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.1332	5.8E-01	2.2E+00	1.2E+00	7.4E+00	1.3E+01	4.0E+00	4.5E+00
yoghurt, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.1818	3.8E-01	3.0E+00	1.5E+00	1.1E+01	1.8E+01	6.6E+00	7.6E+00
fresh cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.1687	6.5E-01	2.8E+00	1.4E+00	9.5E+00	1.7E+01	5.0E+00	5.7E+00
soft cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.1050	3.7E-01	1.7E+00	9.0E-01	6.0E+00	1.0E+01	3.1E+00	3.5E+00
semi-hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.0917	3.1E-01	1.5E+00	7.9E-01	5.3E+00	9.1E+00	2.7E+00	3.1E+00
hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	0.0879	3.0E-01	1.5E+00	7.5E-01	5.1E+00	8.7E+00	2.6E+00	3.0E+00
butter + buttermilk, at dairy/kg milk equivalent, ONLY processing/CH U CB	1kg	0.4112	8.5E-01	6.7E+00	3.5E+00	2.4E+01	4.1E+01	1.5E+01	1.7E+01
Chocolate/kg/CH ONLY packaging U CB *note: coffee processing is included in agricultural production*	1kg	0.3651	4.2E-01	6.4E+00	7.8E+00	1.9E+01	3.8E+01	5.9E+00	8.2E+00
olive oil, extra-virgin, at oil mill, bottled; ONLY processing at oil mill/in IT U CB	1kg	0.7904	1.2E+00	1.5E+01	9.0E+00	4.9E+01	8.8E+01	1.3E+01	1.4E+01
Freezing 1 kg of olive oil in CH CB	1kg	0.3846	1.0E+00	6.7E+00	3.2E+00	1.9E+01	3.6E+01	2.8E+01	3.3E+01
Soybean oil, refined {RoW}| soybean oil refinery operation | Alloc Rec, U, ONLY processing, per kg of refined oil	1kg	0.2001	7.2E-01	4.7E+00	1.7E+00	9.1E+00	2.2E+01	2.5E+00	2.7E+00
Palm oil, refined {GLO}| palm oil refinery operation | Alloc Rec, U, ONLY processing, per kg of refined oil	1kg	0.1811	5.5E-01	4.4E+00	1.6E+00	8.3E+00	2.0E+01	2.2E+00	2.4E+00
Milk chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	1kg	1.2232	1.2E+00	2.5E+01	1.0E+01	6.2E+01	1.3E+02	2.4E+01	2.6E+01
Milk chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	1kg	1.2232	1.2E+00	2.5E+01	1.0E+01	6.2E+01	1.3E+02	2.4E+01	2.6E+01
Sugar, from sugar beet {CH}| beet sugar production, ONLY processing, per kg of sugar | Alloc Rec, U	1kg	0.0836	1.1E-01	1.5E+00	6.9E-01	4.7E+00	8.6E+00	2.2E+00	2.4E+00
Food service									
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U PhD *transport based on average estimates by SV Group, 2015*	1kgkm	0.0003	2.6E-04	4.6E-03	2.3E-03	1.5E-02	2.6E-02	3.9E-03	4.0E-03
Chilled transport, lorry 7.5-16t, EURO5 (WFLDB 3.0)/RER U PhD	1kgkm	0.0004	3.7E-04	6.6E-03	3.4E-03	2.1E-02	3.8E-02	5.8E-03	5.8E-03
Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0005	6.4E-04	1.1E-02	5.2E-03	3.2E-02	6.2E-02	8.2E-03	8.4E-03
Water Consumption, unspecified natural origin, CH, 1 m3	1 m3	0.0000	2.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Retail									
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	0.0549	3.5E-02	8.5E-01	4.4E-01	3.1E+00	5.2E+00	8.7E-01	8.7E-01
Transport, freight, lorry >32 metric ton, EURO3 {RER}| transport, freight, lorry >32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0001	1.2E-04	2.0E-03	1.1E-03	5.4E-03	1.1E-02	1.4E-03	1.4E-03
Water Consumption, unspecified natural origin, CH, 1 m3	1 m3	0.0000	2.3E-02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Households									
Transport, regular bus {CH}| market for | Alloc Rec, U PhD	1pkm	0.1027	1.3E-01	2.3E+00	1.0E+00	5.8E+00	1.2E+01	1.5E+00	1.5E+00
Transport, tram {CH}| market for | Alloc Rec, U PhD	1pkm	0.0328	6.1E-02	8.6E-01	3.2E-01	1.9E+00	4.2E+00	1.1E+00	1.2E+00
Transport, passenger car {RER}| processing | Alloc Rec, U PhD	1km	0.3180	3.8E-01	6.5E+00	3.1E+00	2.0E+01	3.7E+01	4.8E+00	4.9E+00
Transport, passenger, bicycle {CH}| processing | Alloc Rec, U PhD	1pkm	0.0140	1.8E-02	3.4E-01	1.4E-01	8.1E-01	1.7E+00	1.7E-01	1.9E-01
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Donations									
Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0005	6.4E-04	1.1E-02	5.2E-03	3.2E-02	6.2E-02	8.2E-03	8.4E-03
Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	0.0002	2.3E-04	4.1E-03	1.8E-03	1.0E-02	2.1E-02	2.7E-03	2.8E-03
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	0.0549	3.5E-02	8.5E-01	4.4E-01	3.1E+00	5.2E+00	8.7E-01	8.7E-01
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Incineration									
Biowaste fraction of MSW collection transport, 3.1 km with 21 metric ton MSW collection lorry, per kg, U PhD	1kg	0.0038	4.3E-03	7.8E-02	3.4E-02	2.0E-01	4.1E-01	5.4E-02	5.5E-02
treatment of 1kg of biowaste {GLO}| by municipal incineration, without benefits from heat and electricity | Alloc Rec, U PhD	1kg	0.0398	7.1E-02	1.1E+00	3.5E-01	1.2E+00	4.5E+00	3.0E-01	3.1E-01
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	0.0549	3.5E-02	8.5E-01	4.4E-01	3.1E+00	5.2E+00	8.7E-01	8.7E-01
Spreading on fields									
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	0.0041	7.0E-03	8.4E-02	6.1E-02	2.8E-01	5.0E-01	8.7E-02	1.0E-01
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0425	8.3E-02	1.3E+00	3.4E-01	1.1E-05	3.8E+00	3.1E-06	3.2E-06
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0627	1.3E-01	2.0E+00	4.9E-01	1.1E-05	6.0E+00	3.1E-06	3.2E-06
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0476	1.2E-01	1.7E+00	3.8E-01	1.1E-05	5.3E+00	3.1E-06	3.2E-06
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0249	5.5E-02	7.9E-01	2.1E-01	1.1E-05	2.4E+00	3.1E-06	3.2E-06
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0501	2.0E-01	2.8E+00	4.2E-01	1.1E-05	8.3E+00	3.1E-06	3.2E-06
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1334	8.0E-02	1.8E+00	9.6E-01	1.1E-05	5.7E+00	3.1E-06	3.2E-06
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	-0.0494	-1.3E-01	-1.1E+00	-4.7E-01	-1.7E+00	-4.8E+00	-4.6E-01	-4.8E-01
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	0.0046	5.1E-03	9.2E-02	3.9E-02	2.0E-01	4.5E-01	5.3E-02	5.3E-02
Anaerobic digestion, digestate application, per kg of foodwaste/CH U PhD	1kg	-0.1739	-1.5E-01	-2.7E+00	-1.4E+00	-1.6E+00	-9.9E+00	-1.7E+00	-1.8E+00
<u>Assumptions:</u> > Emissions are modelled equally to professional composting, since generally rests on fields are well spread and therefore decomposed under oxic conditions. > Fertilizer substitution is modelled equally to professional composting, since nutrients mainly remain on the agricultural fields instead of being removed (e.g. when incinerated). > No improved soil effect modelled, since there is no physical compost output that can be used as a replacement for peat. > No heavy metal emissions modelled, since there is no input from outside of the fields. > No transport.									
Composting									
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	0.0041	7.0E-03	8.4E-02	6.1E-02	2.8E-01	5.0E-01	8.7E-02	1.0E-01
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0425	8.3E-02	1.3E+00	3.4E-01	1.1E-05	3.8E+00	3.1E-06	3.2E-06
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0627	1.3E-01	2.0E+00	4.9E-01	1.1E-05	6.0E+00	3.1E-06	3.2E-06
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0476	1.2E-01	1.7E+00	3.8E-01	1.1E-05	5.3E+00	3.1E-06	3.2E-06
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0249	5.5E-02	7.9E-01	2.1E-01	1.1E-05	2.4E+00	3.1E-06	3.2E-06
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0501	2.0E-01	2.8E+00	4.2E-01	1.1E-05	8.3E+00	3.1E-06	3.2E-06
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1334	8.0E-02	1.8E+00	9.6E-01	1.1E-05	5.7E+00	3.1E-06	3.2E-06
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	0.0000	1.2E-01	1.0E-01	1.8E-02	0.0E+00	3.1E-01	0.0E+00	0.0E+00
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	-0.0494	-1.3E-01	-1.1E+00	-4.7E-01	-1.7E+00	-4.8E+00	-4.6E-01	-4.8E-01
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, maximum/CH U PhD	1kg	-0.4104	-2.2E-01	-6.0E+00	-3.3E+00	-2.4E+00	-2.1E+01	-4.3E+00	-4.3E+00
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, minimum/CH U PhD	1kg	-0.0821	-4.4E-02	-1.2E+00	-6.6E-01	-4.8E-01	-4.2E+00	-8.6E-01	-8.6E-01
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	0.0046	5.1E-03	9.2E-02	3.9E-02	2.0E-01	4.5E-01	5.3E-02	5.3E-02
<u>Assumptions:</u> > Fertilizer substitution is modeled based on average values by Boldrin et al., 2009. No distinction between different food waste fraction.									
Home Composting									
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	0.0041	7.0E-03	8.4E-02	6.1E-02	2.8E-01	5.0E-01	8.7E-02	1.0E-01
composting 1kg of foodwaste by home composting/CH, without benefits from compost application U PhD	1kg	0.1237	1.3E-01	2.5E+00	1.0E+00	1.1E-05	7.8E+00	3.1E-06	3.2E-06
composting 1kg of bread by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1540	1.8E-01	3.3E+00	1.3E+00	1.1E-05	1.0E+01	3.1E-06	3.2E-06
composting 1kg of diary by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1313	1.6E-01	3.0E+00	1.1E+00	1.1E-05	9.3E+00	3.1E-06	3.2E-06
composting 1kg of fruits and vegetables by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0973	9.3E-02	1.9E+00	8.5E-01	1.1E-05	6.0E+00	3.1E-06	3.2E-06
composting 1kg of meat and fish by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1352	2.4E-01	4.1E+00	1.1E+00	1.1E-05	1.2E+01	3.1E-06	3.2E-06
composting 1kg of oils and fats by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.2601	1.4E-01	3.6E+00	2.0E+00	1.1E-05	1.1E+01	3.1E-06	3.2E-06
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	0.0000	1.2E-01	1.0E-01	1.8E-02	0.0E+00	3.1E-01	0.0E+00	0.0E+00
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	-0.0494	-1.3E-01	-1.1E+00	-4.7E-01	-1.7E+00	-4.8E+00	-4.6E-01	-4.8E-01
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in households/CH U PhD	1kg	-0.1170	-6.2E-02	-1.7E+00	-9.4E-01	-6.8E-01	-6.0E+00	-1.2E+00	-1.2E+00
improved soil by use of compost from 1 kg of foodwaste, 21% peat substitution in households/CH U PhD	1kg	-0.0246	-1.3E-02	-3.6E-01	-2.0E-01	-1.4E-01	-1.3E+00	-2.6E-01	-2.6E-01
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, maximum/CH U PhD	1kg	-0.4104	-2.2E-01	-6.0E+00	-3.3E+00	-2.4E+00	-2.1E+01	-4.3E+00	-4.3E+00
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, minimum/CH U PhD	1kg	-0.0821	-4.4E-02	-1.2E+00	-6.6E-01	-4.8E-01	-4.2E+00	-8.6E-01	-8.6E-01
improved soil by use of compost from 1 kg of foodwaste, straw substitution/CH U PhD	1kg	-0.0189	-1.6E-01	-5.0E-01	-1.0E+00	-6.7E-01	-2.5E+00	-1.7E-01	-3.6E+00
Biowaste collection transport, by 21 ton MSW collection service, per kg of waste; from "treatment of biowaste, composting CH"; PhD	1kg	0.0017	1.9E-03	3.4E-02	1.5E-02	8.9E-02	1.8E-01	2.4E-02	2.4E-02
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	0.0046	5.1E-03	9.2E-02	3.9E-02	2.0E-01	4.5E-01	5.3E-02	5.3E-02
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0425	8.3E-02	1.3E+00	3.4E-01	1.1E-05	3.8E+00	3.1E-06	3.2E-06
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0627	1.3E-01	2.0E+00	4.9E-01	1.1E-05	6.0E+00	3.1E-06	3.2E-06
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0476	1.2E-01	1.7E+00	3.8E-01	1.1E-05	5.3E+00	3.1E-06	3.2E-06
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0249	5.5E-02	7.9E-01	2.1E-01	1.1E-05	2.4E+00	3.1E-06	3.2E-06
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.0501	2.0E-01	2.8E+00	4.2E-01	1.1E-05	8.3E+00	3.1E-06	3.2E-06
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	0.1334	8.0E-02	1.8E+00	9.6E-01	1.1E-05	5.7E+00	3.1E-06	3.2E-06
<u>Assumptions:</u> > Based on data from Kohler, 2015, and Schleiss, 2015, 6-7% of household foodwaste is collected with biowaste and used for composting, 4-5% is composted in the householders' gardens. Here we assume half home composting and half professional composting. > Emissions for home composting are very variable depending on good and bad practices; this is a broad estimation based on Zschokke (2015). > The improved soil effect for home composting is based on the assumption of 21% peat substitution (Boldrin et al., 2009). > Fertilizer substitution is modeled based on average values by Boldrin et al., 2009. No distinction between different food waste fractions.									
Anaerobic Digestion									
biogas from biowaste, without transport, per m3 of biogas /CH U PhD	1m3	0.3914	2.5E-01	5.3E+00	3.0E+00	6.9E-01	1.7E+01	2.0E-01	2.4E-01
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	0.0046	5.1E-03	9.2E-02	3.9E-02	2.0E-01	4.5E-01	5.3E-02	5.3E-02
Anaerobic digestion, digestate application, per kg of foodwaste/CH U PhD *(without heavy metal emissions)*	1kg	-0.1739	-1.5E-01	-2.7E+00	-1.4E+00	-1.6E+00	-9.9E+00	-1.7E+00	-1.8E+00
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	0.0000	1.2E-01	1.0E-01	1.8E-02	0.0E+00	3.1E-01	0.0E+00	0.0E+00
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	0.0270	7.7E-02	6.6E-01	2.3E-01	1.5E+00	3.2E+00	2.4E+00	2.9E+00
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	0.0549	3.5E-02	8.5E-01	4.4E-01	3.1E+00	5.2E+00	8.7E-01	8.7E-01
Feeding									
Barley grain, feed, Swiss integrated production {CH}| production | Alloc Rec, U PhD	1kg	0.4595	2.7E+00	1.2E+01	3.2E+01	1.7E+01	6.2E+01	4.8E+00	2.9E+01
Wheat grain, feed, Swiss integrated production {CH}| production | Alloc Rec, U PhD	1kg	0.5333	2.9E+00	1.3E+01	3.2E+01	1.9E+01	6.8E+01	5.3E+00	3.1E+01
Protein feed, 100% crude {GLO}| soybean meal to generic market for protein feed | Alloc Rec, U PhD	1kg	1.3024	3.3E+00	2.5E+01	6.7E+01	2.0E+01	1.2E+02	7.2E+00	2.6E+01
Transport per kg of Barley, CH production used as feed in CH	1kg	0.0118	1.4E-02	2.6E-01	1.2E-01	7.3E-01	1.4E+00	1.9E-01	1.9E-01
Transport per kg of Wheat, CH production used as feed in CH	1kg	0.0322	4.0E-02	7.0E-01	3.5E-01	2.1E+00	3.9E+00	5.4E-01	5.5E-01
Transport per kg of Soybean meal, production 43% in BR, 57% in US, used as feed in CH	1kg	0.2355	3.3E-01	6.1E+00	2.4E+00	1.4E+01	3.0E+01	3.7E+00	3.8E+00
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	0.0000	1.2E-01	1.0E-01	1.8E-02	0.0E+00	3.1E-01	0.0E+00	0.0E+00
Sewage									
treatment, wastewater from dairy plant, to wastewater treatment, class 3/per liter of milk/CH U PhD	1l	0.0769	2.0E+00	1.5E+00	7.3E-01	3.8E+00	7.9E+00	1.5E+00	1.7E+00

Table B.33: Food chain process factor matrix. Defines for each stage of the FVC and for each food category which LCI processes are used and how many times per kg of product at this stage (for abbrevitions of databases see Table B.34). The terms "PhD" and "CB" do not belong to the original database nomenclature and indicate that copies of the original datasets are used.

LCA processes	Functional Unit	Database	Table apples	Apple juice	Other fresh table fruits	Other fresh fruit juices	Berries	Exotic and citrus table fruits	Exotic and citrus fruit juices	Canned fruits	Potatoes	Fresh vegetables	Legumes	Other storable vegetables	Processed vegetables	Bread and pastries	Pasta	Rice	Maize	Sugar	Vegetal oils and fats	Nuts, seeds, oleiferous fruits	Milk...	Meat co-product from milk	Cheese, whey	Meat co-product from cheese	Butter, buttermilk, skimmed milk	Meat co-product from butter	Eggs without co-product poultry	Meat from laying hens	Pork	Poultry	Beef...	Fish, shellfish	Cocoa, coffee, tee
Trade			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Transport, freight, lorry >32 metric ton, EURO3 {RER}| transport, freight, lorry >32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	-	-	-	-	-	40	40	-	-	-	-	-	-	-	-	202	-	-	213	34	-	-	-	-	-	-	-	-	-	-	-	-	858
Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	50	50	50	50	-	571	1'141	100	52.858	526	575	100	53	-	-	879	100	-	690	995	-	-	-	-	-	-	100	-	-	-	-	-	100
Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U PhD	1kgkm	EI	50	50	50	50	100	571	-	-	48.922	526	-	-	49	-	-	-	-	-	-	-	100	100	-	100	-	100	-	100	100	100	100	100	-
Transport, tractor and trailer, agricultural {CH}| processing | Alloc Rec, U PhD	1kgkm	EI	-	-	-	-	-	-	-	-	6.931	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Transport, freight, sea, transoceanic ship {GLO}| market for | Alloc Rec, U PhD	1kgkm	EI	-	-	-	-	-	3'703	3'895	-	118.206	-	-	-	118	-	-	6'909	-	-	8'801	1'968	-	-	-	-	-	-	-	-	-	-	-	-	7'358
Transport, freight, aircraft {RoW}| intercontinental | Alloc Rec, U PhD	1kgkm	EI	-	-	-	-	-	96	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Transport, freight, aircraft {RER}| intracontinental | Alloc Rec, U PhD	1kgkm	EI	-	-	-	-	-	96	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wheat flour, at industrial mill, ONLY transport, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bread, from wheat flour, ONLY transport farm-mill-bakery, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pasta, dried, from durum wheat, at plant, ONLY transport to processing industry, per kg of wheat semolina (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rapeseed oil, at oil mill, ONLY transport, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Olive oil, at oil mill, ONLY transport, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sunflower oil, at oil mill, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.51	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Butter & buttermilk & skimed milk, unsalted, at dairy, per kg of raw milk, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Hard cheese & cream & whey, Emmental-style, at dairy, per kg of raw milk, ONLY transport (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Sugar, from sugar beet {CH}| beet sugar production, ONLY transport, per kg of sugar | Alloc Rec, U	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Processing			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	-	1.18	-	1.18	-	-	1.18	1.18	0.39	-	-	-	0.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	EI	-	0.38	-	0.38	-	-	0.38	0.38	1.01	-	-	-	1.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wheat flour and bran (for bread), at industrial mill, ONLY processing (milling), per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bread, from wheat flour, ONLY baking in CH, per kg of wheat grain (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pasta, dried, from durum wheat, at plant ONLY processing with CH electr, per kg of wheat semolina (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rapeseed oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Olive oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sunflower oil, at oil mill, ONLY processing, per kg of oil (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tomato pulp production, at plant, ONLY processing, per kg of fresh tomato (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tomato juice production, at plant, ONLY processing with CH electr, ker kg of fresh tomato (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water Consumption, unspecified natural origin, CH, 1 m3	1 m³		-	0.004	-	0.004	-	-	0.004	-	0.003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
milk, UHT, 3.5% fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
cream, 25% fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
cream, 29% fat, at dairy/kg milk equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
curd, low- to semi-fat, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
yoghurt, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
fresh cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
soft cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
semi-hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
hard cheese + whey, at dairy/kg milk-equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
butter + buttermilk, at dairy/kg milk equivalent, ONLY processing/CH U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Chocolate/kg/CH ONLY packaging U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
olive oil, extra-virgin, at oil mill, bottled; ONLY processing at oil mill/in IT U CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Freezing 1 kg of olive oil in CH CB	1kg	ZH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soybean oil, refined {RoW}| soybean oil refinery operation | Alloc Rec, U, ONLY processing, per kg of refined oil	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palm oil, refined {GLO}| palm oil refinery operation | Alloc Rec, U, ONLY processing, per kg of refined oil	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milk chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Milk chocolate, at plant, ONLY processing, per kg of cocoa bean (WFLDB 3.0)/GLO U PhD	1kg	WF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sugar, from sugar beet {CH}| beet sugar production, ONLY processing, per kg of sugar | Alloc Rec, U	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Food service			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81
Chilled transport, lorry 16-32t, EURO5 (WFLDB 3.0)/RER U PhD	1kgkm	EI	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
Chilled transport, lorry 7.5-16t, EURO5 (WFLDB 3.0)/RER U PhD	1kgkm	EI	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25
Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25
Water Consumption, unspecified natural origin, CH, 1 m3	1 m³		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Retail			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815	1.815
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	EI	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513	0.513
Transport, freight, lorry >32 metric ton, EURO3 {RER}| transport, freight, lorry >32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Water Consumption, unspecified natural origin, CH, 1 m3	1 m³		0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Households			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Transport, regular bus {CH}| market for | Alloc Rec, U PhD	1pkm	EI	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Transport, tram {CH}| market for | Alloc Rec, U PhD	1pkm	EI	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Transport, passenger car {RER}| processing | Alloc Rec, U PhD	1km	EI	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Transport, passenger, bicycle {CH}| processing | Alloc Rec, U PhD	1pkm	EI	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	3.4	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40
Donations			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3	168.3
Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U PhD	1kgkm	EI	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	EI	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Incineration			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Biowaste fraction of MSW collection transport, 3.1 km with 21 metric ton MSW collection lorry, per kg, U PhD	1kg	EI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
treatment of 1kg of biowaste {GLO}| by municipal incineration, without benefits from heat and electricity | Alloc Rec, U PhD	1kg	EI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	-0.03	-0.07	-0.03	-0.07	-0.03	-0.03	-0.07	-0.07	-0.24	0.15	0.15	0.15	0.08	-1.26	-0.24	-0.24	-0.24	-1.26	-4.90	-4.90	-0.09	-0.73	-2.27	-0.73	-4.01	-0.73	-0.09	-0.73	-0.73	-0.73	-0.73	-0.73	-0.54
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	EI	-0.06	-0.13	-0.06	-0.13	-0.06	-0.06	-0.13	-0.13	-0.44	0.28	0.28	0.28	0.16	-2.33	-0.44	-0.44	-0.44	-2.33	-9.05	-9.05	-0.17	-1.35	-4.18	-1.35	-7.40	-1.35	-0.17	-1.35	-1.35	-1.35	-1.35	-1.35	-1.00
Spreading on fields			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	1	1	1	1	1	-
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	BF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	EI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Anaerobic digestion, digestate application, per kg of foodwaste/CH U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Assumptions:
> Emissions are modelled equally to professional composting, since generally rests on fields are well spread and therefore decomposed under oxic conditions.
> Fertilizer substitution is modelled equally to professional composting, since nutrients mainly remain on the agricultural fields instead of being removed (e.g. when incinerated).
> No improved soil effect modelled, since there is no physical compost output that can be used as a replacement for peat.
> No heavy metal emissions modelled, since there is no input from outside of the fields.

LCA processes	Functional Unit	Database	Table apples	Apple juice	Other fresh table fruits	Other fresh fruit juices	Berries	Exotic and citrus table fruits	Exotic and citrus fruit juices	Canned fruits	Potatoes	Fresh vegetables	Legumes	Other storable vegetables	Processed vegetables	Bread and pastries	Pasta	Rice	Maize	Sugar	Vegetal oils and fats	Nuts, seeds, oleiferous fruits	Milk...	Meat co-product from milk	Cheese, whey	Meat co-product from cheese	Butter, buttermilk, skimmed milk	Meat co-product from butter	Eggs without co-product poultry	Meat from laying hens	Pork	Poultry	Beef...	Fish, shellfish	Cocoa, coffee, tee
Composting			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	BF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	-	-	-	-	-	-	-
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	1	1	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	1	-	1	1	1	1	1	-
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	BF	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	BF	1.00	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, maximum/CH U PhD	1kg	BF	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, minimum/CH U PhD	1kg	BF	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	EI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Assumptions:
> Fertilizer substitution is modeled based on average values by Boldrin et al., 2009. No distinction between different food waste fraction.

LCA processes	Functional Unit	Database	Table apples	Apple juice	Other fresh table fruits	Other fresh fruit juices	Berries	Exotic and citrus table fruits	Exotic and citrus fruit juices	Canned fruits	Potatoes	Fresh vegetables	Legumes	Other storable vegetables	Processed vegetables	Bread and pastries	Pasta	Rice	Maize	Sugar	Vegetal oils and fats	Nuts, seeds, oleiferous fruits	Milk...	Meat co-product from milk	Cheese, whey	Meat co-product from cheese	Butter, buttermilk, skimmed milk	Meat co-product from butter	Eggs without co-product poultry	Meat from laying hens	Pork	Poultry	Beef...	Fish, shellfish	Cocoa, coffee, tee
Home Composting			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
composting 1kg of foodwaste by professional technology; ONLY impacts from compost plant and fossil emissions | Alloc Rec, U PhD	1kg	BF	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
composting 1kg of foodwaste by home composting/CH, without benefits from compost application U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	0.5
composting 1kg of bread by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of diary by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	0.5	-	0.5	-	-	-	-	-	-	-	-
composting 1kg of fruits and vegetables by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	EI	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of meat and fish by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	0.5	-	0.5	-	0.5	0.5	0.5	0.5	0.5	-
composting 1kg of oils and fats by home composting; without impacts from compost plant and benefits from compost application, U PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	BF	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
fertiliser spare, benefit from compost (0.4kg) per kg of foodwaste/CH U PhD	1kg	BF	0.67	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in households/CH U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
improved soil by use of compost from 1 kg of foodwaste, 21% peat substitution in households/CH U PhD	1kg	BF	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, maximum/CH U PhD	1kg	BF	0.30	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
improved soil by use of compost from 1 kg of foodwaste, 100% peat substitution in growth media, minimum/CH U PhD	1kg	BF	0.30	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
improved soil by use of compost from 1 kg of foodwaste, straw substitution/CH U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biowaste collection transport, by 21 ton MSW collection service, per kg of waste; from "treatment of biowaste, composting CH"; PhD	1kg	EI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	EI	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
composting 1kg of foodwaste by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	0.5
composting 1kg of bread by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of diary by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	0.5	-	0.5	-	-	-	-	-	-	-	-
composting 1kg of fruits and vegetables by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
composting 1kg of meat and fish by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	-	0.5	-	0.5	-	0.5	0.5	0.5	0.5	0.5	-
composting 1kg of oils and fats by professional technology; without impacts from compost plant and benefits from compost application, U PhD	1kg	BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-

Assumptions:
> Based on data from Kohler, 2015, and Schleiss, 2015, 6-7% of household foodwaste is collected with biowaste and used for composting, 4-5% is composted in the householders' gardens. Here we assume half home composting and half professional composting.
> Emissions for home composting are very variable depending on good and bad practices; this is a broad estimation based on Zschokke (2015).
> The improved soil effect for home composting is based on the assumption of 21% peat substitution (Boldrin et al., 2009).

LCA processes	Functional Unit	Database	Table apples	Apple juice	Other fresh table fruits	Other fresh fruit juices	Berries	Exotic and citrus table fruits	Exotic and citrus fruit juices	Canned fruits	Potatoes	Fresh vegetables	Legumes	Other storable vegetables	Processed vegetables	Bread and pastries	Pasta	Rice	Maize	Sugar	Vegetal oils and fats	Nuts, seeds, oleiferous fruits	Milk...	Meat co-product from milk	Cheese, whey	Meat co-product from cheese	Butter, buttermilk, skimmed milk	Meat co-product from butter	Eggs without co-product poultry	Meat from laying hens	Pork	Poultry	Beef...	Fish, shellfish	Cocoa, coffee, tee
Anaerobic Digestion			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
biogas from biowaste, without transport, per m3 of biogas /CH U PhD	1m³	BF	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.156	0.070	0.070	0.070	0.070	0.661	0.122	0.122	0.122	0.661	1.210	1.210	0.111	0.140	0.111	0.140	0.111	0.140	0.111	0.140	0.140	0.140	0.140	0.140	1.220
Biowaste collection transport, by 21 ton MSW collection service and transport lorry, per kg of waste; from "biogas from biowaste"; PhD	1kg	EI	1.000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Anaerobic digestion, digestate application, per kg of foodwaste/CH U PhD *(without heavy metal emissions)*	1kg	EI	1.000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	BF	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Electricity, low voltage {CH}| market for | Alloc Rec, U PhD	1MJ	EI	-0.23	-0.23	-0.23	-0.23	-0.23	-0.23	-0.23	-0.23	-0.71	-0.32	-0.32	-0.32	-0.32	-2.77	-0.56	-0.56	-0.56	-3.00	-5.49	-5.49	-0.50	-0.64	-0.50	-0.64	-0.50	-0.64	-0.50	-0.64	-0.64	-0.64	-0.64	-0.64	-0.56
Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Alloc Rec, U PhD	1MJ	EI	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-0.49	-1.52	-0.68	-0.68	-0.68	-0.68	-5.94	-1.19	-1.19	-1.19	-6.43	-11.76	-11.76	-1.08	-1.36	-1.08	-1.36	-1.08	-1.36	-1.08	-1.36	-1.36	-1.36	-1.36	-1.36	-1.19
Feeding			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
Barley grain, feed, Swiss integrated production {CH}| production | Alloc Rec, U PhD	1kg	EI	-0.66	-0.57	-0.65	-0.62	-0.47	-0.41	-0.43	-2.15	-0.65	-0.24	-0.55	-0.24	-0.90	-1.04	-0.99	-1.33	-0.92	-1.51	-	-	-0.19	-0.08	-0.25	-0.08	-0.19	-0.08	-0.36	-0.06	-0.13	-0.07	-0.08	-0.05	-1.41
Wheat grain, feed, Swiss integrated production {CH}| production | Alloc Rec, U PhD	1kg	EI	0.54	0.48	0.54	0.51	0.39	0.34	0.36	1.78	0.528	0.20	0.45	0.20	0.74	0.36	0.34	0.46	0.32	0.52	-	-	0.09	0.20	0.08	0.20	0.09	0.20	0.16	0.15	0.34	0.19	0.20	0.13	0.49
Protein feed, 100% crude {GLO}| soybean meal to generic market for protein feed | Alloc Rec, U PhD	1kg	EI	-0.08	-0.07	-0.08	-0.08	-0.06	-0.05	-0.05	-0.27	-0.08	-0.03	-0.07	-0.03	-0.11	-0.10	-0.10	-0.13	-0.09	-0.15	-	-	-0.10	-0.58	-0.02	-0.58	-0.10	-0.58	-0.19	-0.44	-0.99	-0.57	-0.58	-0.40	-0.14
Transport per kg of Barley, CH production used as feed in CH	1kg	EI	-0.66	-0.57	-0.65	-0.62	-0.47	-0.41	-0.43	-2.15	-0.65	-0.24	-0.55	-0.24	-0.90	-1.04	-0.99	-1.33	-0.92	-1.51	-	-	-0.19	-0.08	-0.25	-0.08	-0.19	-0.08	-0.36	-0.06	-0.13	-0.07	-0.08	-0.05	-1.41
Transport per kg of Wheat, CH production used as feed in CH	1kg	EI	0.54	0.48	0.54	0.51	0.39	0.34	0.36	1.78	0.528	0.20	0.45	0.20	0.74	0.36	0.34	0.46	0.32	0.52	-	-	0.09	0.20	0.08	0.20	0.09	0.20	0.16	0.15	0.34	0.19	0.20	0.13	0.49
Transport per kg of Soybean meal, production 43% in BR, 57% in US, used as feed in CH	1kg	EI	-0.08	-0.07	-0.08	-0.08	-0.06	-0.05	-0.05	-0.27	-0.08	-0.03	-0.07	-0.03	-0.11	-0.10	-0.10	-0.13	-0.09	-0.15	-	-	-0.10	-0.58	-0.02	-0.58	-0.10	-0.58	-0.19	-0.44	-0.99	-0.57	-0.58	-0.40	-0.14
heavy metal emissions into soil by application of 0.4kg compost from 1kg vegetable foodwaste/CH U PhD	1kg	BF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sewage			1.1	1.2	2.1	2.2	3.1	3.2	3.3	4	5	6	7.1	7.2	8	9	10	11	12	13	14.1	14.2	15.1	15.2	16.1	16.2	17.1	17.2	18.1	18.2	19	20	21	22	23
treatment, wastewater from dairy plant, to wastewater treatment, class 3/per liter of milk/CH U PhD	1l	ZH	-	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-
#N/A			-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Coffee processing is included in agricultural production

transport based on average estimates by SV Group, 2015

B.22 LCI RELIABILITY ASSESSMENT

Table B.34: LCI reliability assessment (I)

Pedigree scores and uncertainty estimation for LCA assessment	**Food category**													
	Fruits													
	1 Apples							**2 Fresh fruits**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			⬆		1.08	1	1			⬆		1.17	1	2
Reference 1	Apple CH EI	1	2	2	1			Grape Glo EI	3	2	3	2		
Reference 2								Pear Glo EI	1	2	2	1		
Reference 3								Apricot FR WF	2	2	1	3		
Reference 4								Peach CH importmix WF	1	2	4	1		
Reference 5														
Reference 6														
Reference 7														
Reference 8														
Reference 9														
Reference 10														
Reference 11														
Reference 12														
Reference 13														
Reference 14														
Reference 15														
Reference 16														
Reference 17														

Pedigree scores and uncertainty estimation for LCA assessment	**3 Berries, exotic, citrus fruits**							**4 Canned fruits**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			⬇		3.02	1	2			⬆		1.17	2	3
Reference 1	Kiwi GLO EI	1	2	3	1			Pear CH EI	1	2	2	1		
Reference 2	Strawberry GLO EI	3	2	2	4			Grape GLO EI	3	2	3	2		
Reference 3	Avocado GLO EI	4	2	3	5			Pineapple GLO EI	1	2	3	1		
Reference 4	Banana GLO EI	1	2	3	1			Apricot FR WF	2	2	1	3		
Reference 5	Citrus GLO EI	4	2	3	5			Peach CH importmix WF	1	2	4	1		
Reference 6	Papaya GLO EI	1	2	3	1									
Reference 7	Pineapple GLO EI	1	2	3	1									
Reference 8	Mandarin GLO WF	1	2	3	1									
Reference 9	Orange ES WF	1	5	2	1									
Reference 10	Orange CH importmix WF	4	3	2	3									
Reference 11														
Reference 12														
Reference 13														
Reference 14														
Reference 15														
Reference 16														
Reference 17														

Pedigree scores and uncertainty estimation for LCA assessment	**Vegetables**													
	5 Patatoes							**6 Fresh vegetables**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↗		1.24	1	1			↗		1.32	1	1
Reference 1	Potato organic CH EI	1	3	4	1			Aubergine CH EI	1	2	2	1		
Reference 2	Potato CH EI	1	3	4	1			Broccoli CH EI	1	2	2	1		
Reference 3								Culiflower CH EI	1	2	2	1		
Reference 4								Celery CH EI	1	2	2	1		
Reference 5								Cucumber CH EI	1	2	2	1		
Reference 6								Fennel CH EI	1	2	2	1		
Reference 7								Green asparagus GLO EI	5	2	2	5		
Reference 8								Green bell Pepper GLO EI	5	2	2	3		
Reference 9								Iceberg lettuce CH EI	1	2	2	1		
Reference 10								Lettuce Greenhouse CH EI	1	2	2	1		
Reference 11								Lettuce field CH EI	1	2	2	1		
Reference 12								Melon GLO EI	3	2	3	2		
Reference 13								Radish CH EI	1	2	2	1		
Reference 14								Spinach CH EI	1	2	2	1		
Reference 15								Tomato CH EI	3	2	2	3		
Reference 16								White asparagus GLO EI	5	2	2	5		
Reference 17								Zucchini CH EI	3	2	2	4		

Pedigree scores and uncertainty estimation for LCA assessment	**7 Storable vegetables**							**8 Processed vegetables**
	Reference	a)	b)	c)	d)	e)	f)	Reference
Agricultural production			↗		1.31	3	3	
Reference 1	Fava bean organic CH EI	1	4	4	1			Spinach GLO EI
Reference 2	Fava bean CH EI	1	4	4	1			Fava bean organic CH EI
Reference 3	Cabbage red GLO EI	1	2	2	1			Fava bean CH EI
Reference 4	Cabbage white GLO EI	1	2	2	1			Carrot GLO EI
Reference 5	Carrot GLO EI	1	2	2	1			
Reference 6	Onion GLO EI	1	2	2	1			
Reference 7	Vanilla MG WF	1	5	5	1			
Reference 8								
Reference 9								
Reference 10								
Reference 11								
Reference 12								
Reference 13								
Reference 14								
Reference 15								
Reference 16								
Reference 17								

Legend:

Uncertainty Estimation:	*a) Geographical correlation*
⬆ → **1.0 - 1.2**	*b) Temporal Correlation*
↗ → **1.2 - 1.4**	*c) Reliability*
↘ → **1.4 - 1.6**	*d) Further technological correlation*
⬇ → **> 1.6**	*e) Completeness*
	f) Sample Size

Comments:

CH refers to Swiss integrated production (IP), except if defined as organic

FR	= France	PH	= Philippines
ES	= Spain	IT	= Italy
BR	= Brasil	NL	= Netherlands
GLO	= global production (main producing or exporting countries)		
RoW	= Rest of the World		

LCA Databases:

EI	Ecoinvent
WF	World Food LCA Database
AF	Agrifootprint
ZH	data from ZHAW (Zürcher Hochschule für Angewandte Wissenschaften)
AB	Agri-Balyse
BF	BFE. Biogas and compost from biowaste (2011). http://www.esu-services.ch/data/public-lci-reports/lcidownload/#c875

Table B.35: LCI reliability assessment (II)

Pedigree scores and uncertainty estimation for LCA assessment	**Food category**																				
	Diary																				
	15 Milk **and other diary prod.**							**16 Cheese**							**17 Butter**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			⬆		1.15	1	1			⬆		1.15	1	1			⬆		1.15	1	1
Reference 1	Milk CH ZH	1	3	3	1			Milk CH ZH	1	3	3	1			Milk CH ZH	1	3	3	1		
Reference 2	Milk organic CH ZH	1	3	3	1			Milk organic CH ZH	1	3	3	1			Milk organic CH ZH	1	3	3	1		
Reference 3	Beef CH ZH	1	3	3	1			Beef CH ZH	1	3	3	1			Beef CH ZH	1	3	3	1		
Reference 4	Veal CH ZH	1	3	3	1			Veal CH ZH	1	3	3	1			Veal CH ZH	1	3	3	1		
Reference 5	Veal organic CH ZH	1	3	3	1			Veal organic CH ZH	1	3	3	1			Veal organic CH ZH	1	3	3	1		

Pedigree scores and uncertainty estimation for LCA assessment	**Eggs**							**Meat**													
	18 Eggs							**19 Porc**							**20 Poultry**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↗		1.20	1	1			⬆		1.16	1	1			⬆		1.19	1	1
Reference 1	Eggs NL AF	2	1	3	2			Pigs NL AF	2	2	3	2			Broilers NL AF	2	1	3	2		
Reference 2	Egg average FR AB	2	3	2	3			Pork GLO WF	2	3	3	1			Chicken BR WF	5	3	3	2		
Reference 3																					
Reference 4																					
Reference 5																					

Pedigree scores and uncertainty estimation for LCA assessment								**Fish**						
	21 Beef							**22 Fish**						
	Reference	a)	b)	c)	d)	e)	f)	Reference	a)	b)	c)	d)	e)	f)
Agricultural production			↘		1.41	1	1			⬆		1.19	2	3
Reference 1	Beef GLO WF	5	2	3	2			Large trout FR AB	4	3	3	2		
Reference 2	Beef CH ZH	1	3	3	1			Sea bass FR AB	1	3	3	1		
Reference 3	Beef organic CH ZH	1	3	3	1			Small trout FR AB	4	3	3	2		
Reference 4	Horse CH ZH	2	3	3	5									
Reference 5	Veal CH ZH	1	3	3	1									

Legend:

⬆ → **1.0 - 1.2**	*b) Temporal Correlation*
↗ → **1.2 - 1.4**	*c) Reliability*
↘ → **1.4 - 1.6**	*d) Further technological correlation*
⬇ → **> 1.6**	*e) Completeness*
	f) Sample Size

All Food Categories

↗ 1.36

(Average of all
food categories)

(continuation of Table B.34)

a)	b)	c)	d)	e)	f)
	↗		1.23	3	3
1	2	2	1		
1	4	4	1		
1	4	4	1		
1	2	2	1		

Cereals						
9 Bread Wheat (Breads and pastries)						
Reference	a)	b)	c)	d)	e)	f)
		↗		1.28	1	1
Oat GLO WF	1	2	2	1		
Barley Grain CH extensive EI	2	4	4	1		
Barley Grain CH intensive EI	2	4	4	1		
Rye Grain CH extensive EI	1	4	4	1		
Rye Grain CH intensive EI	1	4	4	1		
Wheat grain organic CH EI	1	4	4	1		
Wheat grain extensive CH EI	1	4	4	1		
Wheat grain intensive CH EI	1	4	4	1		

10 Durum Wheat (Pasta)						
Reference	a)	b)	c)	d)	e)	f)
		↗		1.24	1	1
Durum wheat semolina GLO WF	3	4	2	2		

11 Rice						
Reference	a)	b)	c)	d)	e)	f)
		⬇		2.16	5	5
Rice RoW EI	4	3	4	5		

12 Corn						
Reference	a)	b)	c)	d)	e)	f)
		↗		1.34	1	1
Maize grain organic CH EI	5	4	4	2		
Maize grain CH EI	5	4	4	2		

Sugar						
13 Sugar						
Reference	a)	b)	c)	d)	e)	f)
No Data		⬆		1.11	1	1
Sugar from cane RoW EI	1	3	1	1		
Sugar from beet CH EI	2	3	1	1		

Oils, fats, nuts, seeds						
14 Oils, fats, nuts, seeds						
Reference	a)	b)	c)	d)	e)	f)
		↘		1.60	1	1
Palm oil crude RoW EI	1	3	4	1		
Rape oil CH EI	1	3	2	1		
Margarine ES WF	4	4	2	3		
Olive oil GLO WF	1	4	2	1		
Sunflower oil GLO WF	4	4	2	5		
Coconut PH EI	3	5	5	5		
Tofu RoW EI	4	1	1	4		
Almonds GLO WF	1	2	2	1		
Peanut GLO WF	3	2	2	5		
Olives org IT ZH	1	4	2	1		

Stimulants						
23 Coffee, tea, chocolate						
Reference	a)	b)	c)	d)	e)	f)
		↘		1.46	1	1
Coffe CH cons mix GLO WF	1	4	2	1		
Dark chocolate GLO WF	1	3	3	1		
Milk chocolate GLO WF	1	3	3	1		
Tea Chimportmix WF	3	2	3	5		

B.23 GRAPHICAL OVERVIEW OF THE MAIN RESULTS

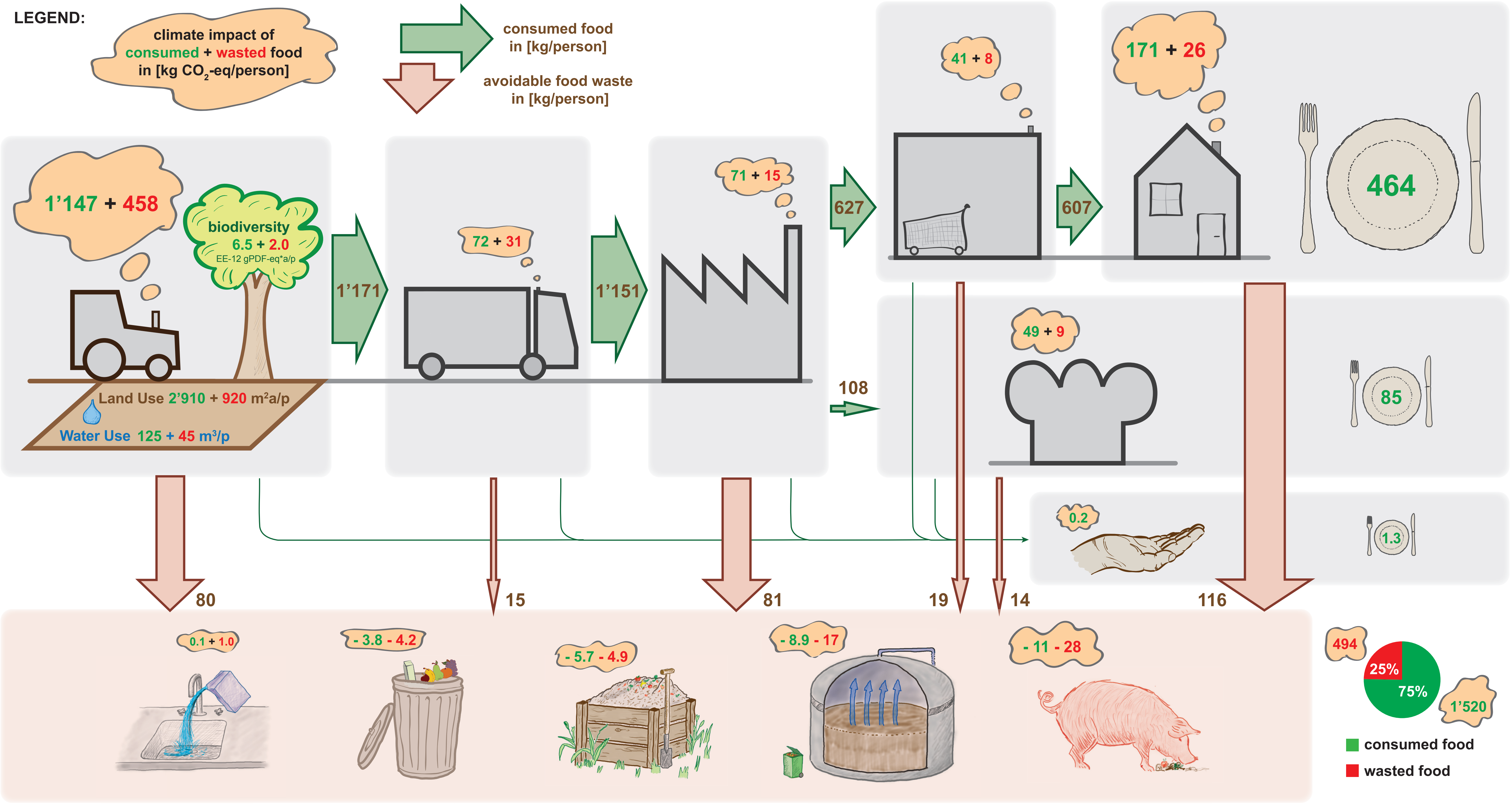


Figure B.45: Mass flows and climate impacts of the Swiss FVC, including credits for substituted products from the treatment of food losses (sewage, incineration, composting, anaerobic digestion, animal feeding), and land use, water use, and biodiversity impacts of agricultural food production. Note: avoidable food waste does not include inedible parts.

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APPENDIX C

SUPPORTING INFORMATION

POTENTIAL ENVIRONMENTAL BENEFITS FROM FOOD WASTE PREVENTION IN THE FOOD SERVICE SECTOR

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DEFINITIONS AND ABBREVIATIONS

Definitions:	
FOOD SYSTEM	
Food value chain (FVC), Food supply chain	Connected series of activities to produce, process, distribute, and consume food, including the stages *agricultural production and fishery, trade, processing, retail, food services, and households.* Also referred to as *"food supply chain".*
Avoidable food losses and waste (FW)	*Food losses and waste* that **can be avoided by best practice methods** of efficient *supply chains* (even if an optimal food distribution system may imply less consumers' freedom of choice for some fresh products than at present), **by a reduction of cosmetic standards** for products such as fruits and vegetables (e.g. using all forms and sizes of potatoes for human consumption), and **by applying appropriate methods of preparation** to use all potentially edible parts of the products (e.g. stem of broccoli and skin of apples). This definition is consistent with Norwegian *FW* studies (Hamilton et al., 2015). However, in some cases the exact boundary between what is considered edible or not differs between cultures, regions, and habits (e.g. potato skin, leaves of radish, inwards, etc.) (Beretta et al., 2017).
Unavoidable food losses and waste (unavoidable FW)	*Food losses and waste* that **cannot be avoided with realistic efforts and current technologies** (e.g. losses from cleaning production lines using best practice methods) and **inedible parts** of food (bones, shells, peels, residues) (Beretta et al., 2017).
Food loss, food waste, food wastage	In this study *food losses and waste* (abbreviated *FW*) refer to food which is **originally produced for human consumption** but then directed to a **non-food use or waste disposal** (e.g. feed for animals, biomass input to a digestion plant, disposal in a municipal solid waste incinerator). We include food originally intended for human consumption but then **diverted to animal feed** in the definition of *FW*, since it represents an environmental loss of resources (Beretta et al., 2017), even though this differs from the FUSIONS definitional framework by Östergren et al. (2014). In the environmental assessment, only the additional environmental impacts of producing the wasted food instead of the substituted feed are attributed to *FW*. The potential food that would be available if the methods of production were optimized (e.g. avoiding crop failures by pesticide application) as well as products with nutritional value that have not originally been produced as food (e.g. wild fungi, berries, game, pets, etc.) are not defined as *FW* even though they represent a potential to increase food availability with given resources. In literature often *food* ***losses*** refer to food not used for human consumption in the early phases of the *food value chain* (agricultural production to trade and processing), whereas *food* ***waste*** and *food* ***wastage*** refer to food not used for human consumption in the consumption phase (retail, *food service* and households) (Gustavsson and Cederberg, 2011). However, since the distinction is not always clear, in this thesis the terms are used as **synonyms**. In contrast to Smil (2004) **over-nutrition**, the gap between the energy value of consumed food per capita and the energy value of food needed per capita, is **not included**. Since the environmental credits of *FW* prevention only refer to the prevention of *avoidable FW* (main focus of this thesis), we often use the term *FW* for avoidable *FW*. *FW* only refers to *unavoidable* or *total FW* if explicitly mentioned (Beretta et al., 2017).
Food service (FS) institution	With *food service institutions* we refer to **companies** offering **out-of-home food consumption**, including the **subsectors 'restaurants', 'school and university canteens', 'business caterings', 'care institutions and hospitals'**, and **'hotels'**. 'Restaurants' mostly include quick-service restaurants (e.g. cafes, take-aways, fast-food), but exclude pubs (Baier and Reinhard, 2007, Oakdene, 2013, UAW, 2016).
Food service (FS) (location)	*Food services* and *food service locations* refer to **individual units or places** of a *FS institution* (e.g. hotels of a hotel chain, restaurants and canteens of a catering company).
Environmental impacts of food waste (FW)	The environmental impacts of *FW* are based on a comparison of the present situation with *FW* and the alternative situation, in which the corresponding **food** is not wasted, assuming that it **replaces food of the same type with the same amount of calories**. In the alternative situation, **useful co-products from *FW* treatment** have to be **produced in an alternative way** ("system expansion"). This includes the additional production and supply of **feed** (same nutritional value as the FW which is presently fed to the animals), **electricity** (present electricity mix), **heat** (natural gas), **inorganic fertilizer**, and **organic matter** (peat). Inorganic fertilizer is substituted based on the content and the utilization rates of N, P, and K for compost, liquid, and solid digestate. The improved soil effect is quantified with peat substitution in growth media based on typical compost densities. Peat and fertilizer substitution in private gardens is based on surveys reporting utilization and replacement rates (21% for peat, 18% for fertilizer) (Beretta et al., 2017). Final **food intake** is assumed to be **constant** and possible **rebound effects** are **ignored**.

METHODOLOGY	
Dataset of FW measurement	A *dataset* of *FW measurement* refers to the **result of weighing *FW* in a *FS* location over a defined period of time**. If measurements are carried out in **more than one *FS* locations without differentiating the amounts and numbers of meals** consumed in each *location*, the result of the measurement is regarded as one *dataset*.
Case study	A *case study* consists of **two *datasets* of *FW* measurements**, one taking place **before and** one **after a measure for *FW* reduction is implemented**, usually in the same *FS location*; a *case study* can also compare *FW* measurements in two different *locations* of the same *FS institution*, if the *locations* have similar customers, but different serving systems.
SCENARIOS	
Status quo	*Status quo* refers to ***FW* amounts, composition, and environmental impacts before *FSs* actively engaged in the problem of *FW* and introduced measures to reduce it**. At the time of this publication some *FS*s have already reduced their *FW*, for example the *FS*s used in our *case studies*. However, since they are a minority in the whole *FS* sector, their reduction is neglected in the estimation of *status quo*.
Base scenario of FW reduction	The *base scenario* of *FW* reduction is based on the assumption that **all *FSs* reduce their in-house *FW* by the same rate as the *case studies* of their corresponding *subsector*** (in total we analysed 13 *case studies* in this thesis; Table C.1).
Extended scenario of FW reduction	The *extended scenario* of *FW* reduction includes the *base scenario*, but **additionally** assumes that **all *FSs* buy 50% of their vegetables from presently non-marketable origin**. It is called “extended”, since it exemplarily **includes a measure for *FW* reduction in the *food value chain*** and therefore demonstrates, that *FW* reduction is not limited to in-house *FW*.
Extended scenario II	The *extended scenario II* includes the *extended scenario*, but **additionally** assumes that **all *FSs* cook 70% of their meat at lower temperatures** than with conventional cooking (e.g. with *sous-vide cooking*) and reduce cooking losses by 15%. Therewith, they need 15% less meat to cook the same meat dishes (Frei, 2018). Since the resulting meat dishes have lower calorific content, we assume the corresponding amount of calories to be consumed as additional average Swiss food (sections C.1.6 and C.5).

Terms:	
Agribalyse	LCA database, mainly containing agricultural products and services from France (Colomb et al., 2015)
Agri-footprint	LCA database, mainly containing agricultural products and services from the Netherlands (Agri-Footprint, 2014)
Ecoinvent	LCA database, initiated by various research institutions (ETH Zurich, EPFL, Agroscope, PSI, EMPA…) (ecoinvent, 2016)
Ecological scarcity 2013	Swiss impact assessment method of LCA, results expressed as ecopoints („Umweltbelastungspunkte“, UBP) (Frischknecht et al., 2013)
Foodsharing	Organisation of volunteers for the distribution of food donated by food services and retailers (Foodsharing, 2018)
Mein Küchenchef	Restaurant in Berne dedicated to avoid in-house FW and to reduce FW in the previous food value chain as much as possible (Mein_Küchenchef, 2018). <https://mein-kuechenchef.ch/>
SimaPro	LCA Software (Pre, 2017)
Sous-vide cooking	Method of cooking in which food is filled in a plastic bag or glass jar, vacuumised, and cooked in a water bath or in steam for longer than normal cooking times at an accurately regulated temperature, which is usually lower than conventional cooking techniques.
World Food LCA Database (WFLDB)	LCA database, mainly containing agricultural products and services from the main producing and exporting countries (Bengoa et al., 2015)

Abbreviations:	
FOEN / BAFU	**F**ederal **O**ffice for the **En**vironment / **B**undes**a**mt **f**ür **U**mwelt
FS	**F**ood **S**ervice
FW	avoidable **f**ood losses and **w**aste, including possibly avoidable (Quested et al., 2013)
gPDF-eq	**g**lobal **P**otentially **D**isappeared **F**raction of Species **eq**uivalents (Chaudhary et al., 2016)
IPCC	**I**ntergovernmental **P**anel on **C**limate **C**hange
LCA	**L**ife **C**ycle **A**ssessment
LCI	**L**ife **C**ycle **I**nventory
LCIA	**L**ife **C**ycle **I**mpact **A**ssessment
SFOE / BFE	**S**wiss **F**ederal **O**ffice of **E**nergy / **B**undesamt **f**ür **E**nergie
UBP	ecopoints (“**U**mwelt**b**elastungs**p**unkte”, unit of the impact assessment method „ecological scarcity“)
WFLDB	**W**orld **F**ood **L**CA **D**ata**b**ase (Bengoa et al., 2015)
ZHAW	**Z**ürcher **H**ochschule für **A**ngewandte **W**issenschaften

C.1 METHODOLOGY

C.1.1 Analysed food service institutions

We collected 20 **datasets from food service (FS) institutions**. In some institutions measurements have been carried out in more than one **location** (e.g. in different hotels of the same hotel chain) without differentiating the results by location and thus only providing one **dataset**. In total, 20 datasets based on measurements in 29 locations are available. For the assessment of status quo food waste (FW) amounts per meal we use 16 datasets based on measurements in 25 locations. Two FSs are not used because they are not representative for status quo (no. 4 in Table C.1 is specialized on FW prevention and no. 18 has implemented plate service system with the main purpose of reducing FW) and two datasets are not used because they do not report the number of meals consumed (only total FW amounts per day are measured: no. 11 and 12 in Table C.1). The composition of status quo FW is based on 13 datasets in 22 locations, since 3 datasets do not differentiate detailed food categories (no. 5, 19, and 20).

We used 14 datasets based on 23 locations for the reduction scenario, since more than one measurement were carried out and measures for FW prevention have been implemented before the second measurement, allowing to analyse their effect on FW reduction. Two datasets, however, were not used for the assessment, since only the total FW amounts are known, but not the number of meals consumed (no. 11 and 12 in Table C.1), which is needed to calculate FW per meal. The remaining 12 FS institutions are used as **case studies** to deduce a realistic FW reduction potential (base scenario of FW reduction). Additionally, we compare two workplace canteens of the same company with different service systems (no. 6 and 7 in Table C.1) in order to deduce the potential FW reduction switching from buffet to plate service. We used these two datasets as an additional case study. The quantitative FW reduction potential is thus based on 13 case studies which include measurements in 22 locations. The composition of FW before and after implementation of measures is based on 11 case studies which include measurements in 20 locations, since two FSs do not distinguish individual food categories (no. 19 and 20 in Table C.1).

Table C.1: Overview of the 20 FS institutions analysed in this thesis, ordered by subsector. The third and fourth columns from the left indicate if the FW measurements are used for the estimation of status quo and for the estimation of the FW reduction scenario (C means that the composition of FW is analysed, T that only total FW has been assessed). The fifth and sixth columns indicate the related case study (A. – F. in chapter 4.3.1.2, A. – M. in chapter C.2.1) and the duration between the first measurement and the measurement used for the reduction scenario (implementation period). The following columns to the right show the number of food categories measured, differentiating different types of FW (Trim = unavoidable trim waste; Edible prep = potentially edible trim waste from preparation; Over-prod = over-production in the kitchen or at the buffet, respectively; Plate = plate waste; Donation = food donated for human consumption). In the right-hand column the measures implemented for FW prevention and the differences between different serving systems are explained (see also text). References: I = own measurements; II = Waskow and Blumenthal (2017); III = Gut (2018); IV = United Against Waste (2018); V = KITRO (2018); VI = SV Group AG (2017).

Food service	Sub-sector	Used for status quo	Used for reduction scenario	Case study	Period of implementation	Number of food categories analysed Kitchen waste Trim	 Edible prep	 Over-prod	 Buffet Over-prod	 Plate	 Donation	Implemented measures or system comparisons	Reference
1) Vegetarian restaurant (buffet)	Restaurant	C	C	**A.**	1 month	1	1		>6	>6	>6	• donating to *Foodsharing* (Foodsharing, 2018)	I
2) Beer hall		C	C	**B.**	2 weeks	1	1	1		12		• serving smaller portions	I
3) Luxury restaurant		C				1	1	5		7			I
4) 0-FW restaurant "Mein Küchenchef"						1	1	1		5		• best case restaurant	I
5) University canteen	Education	T				2	1	8	3	1			I
6) Primary school canteen		C	C	**C.**	14 months			>400		1		• improving communication between school and canteen on the number of available students, reducing production quantities	II
7) Secondary school canteen 1		C	C	G.	3 months			>400		1		• reducing portions, introducing standardised calculation of production quantities, reducing variety of menus offered towards the end of lunch time (only 1 menu with safety margin to be available until to the end)	II
8) Secondary school canteen 2		C	C	H.	3 months			>400		1		• reducing portions	II
9) Secondary school canteen 3,4		C	C	I.	16 months			>400		1		• comparison: service at the counter (canteen 3) *versus* free-flow system (self-service buffet) with option of refilling (canteen 4)	II
10) Cantonal hospital (3 hospitals)	Care	3 x C	3 x C	**D.**	1 year	1		6		4		• doing a coaching program and staff training	III
11) Business hotel A	Hotel	*number of guests*			*1 year*			*20*		*1*		• *doing a coaching program and staff training*	*IV*
12) Business hotel B		*unknown*			*1 year*			*16*		*1*		• *doing a coaching program and staff training*	*IV*
13) Touristic hotel 1 (5 hotels)		5 x C	5 x C	**J.**	4 weeks	1		16		1		• optimizing planning system, employee training, reducing portions and plate size with option for refill, improving communication between service and kitchen, guest information	IV
14) Touristic hotel 2 (4 hotels)		4 x C	4 x C	K.	4 weeks	1		16		1			IV
15) City hotel 3		C	C	E.	9 weeks	1			145			• managing buffet and introducing service instead of refilling the buffet towards the end, optimising forecasts and staff sensibilisation	V
16) City hotel 4 (breakfast buffet)		C				1	3		4	10			I
17) Workplace canteen 1 (buffet)	Business	C				1	1		>6	>6		• comparison: overproduction and plate waste in a location with buffet service	I
18) Workplace canteen 2 (plated)			C	**F.**	since start	1	1			19		*versus* a location with plate service, introduced for food waste prevention	I
19) Workplace canteen 3 (mixed)		T	T	L.	3.5 years		1		3	1		• optimizing planning system, asking guests at counter about portion size	VI
20) Workplace canteen 4 (mixed)		T	T	M.	2 years		1		3	1		• measuring to make losses visible -> sensibilisation of employees	VI
TOTAL individual datasets	**20**	**16**	**13**							18	1		
TOTAL locations	**29**	**25**	**22**							27	1		

The following abstract contains information about measurements in individual FSs (numbering refers to Table C.1). In brackets we indicate for which scenarios the measurements are used (status quo, base scenario of FW reduction, progressive restaurant).

1) Vegetarian restaurant with buffet service and price by weight (status quo, reduction case study A.)

FW from the kitchen, the buffet, and the guests was measured the 20th of November 2017 for the whole day (breakfast, lunch, dinner), and differentiated between individual dishes, edible and inedible waste from preparation, as well as estimated the main components of compound dishes. Also on the 23rd of November 2017 all surplus food from guests and buffet and all edible and inedible FW from preparation were weighed, but without differentiating food categories. Additionally, all dishes and juices donated to Foodsharing (Foodsharing, 2018) were weighed for five days including the days with FW measurements. The food and juices, which are donated to voluntary members of Foodsharing, mainly consist of surpluses from the buffet and are transported in reusable containers organized by the person to which the food is donated.

In order to obtain more reliable FW quantification than a sample of two days we adjusted the FW amounts from kitchen and guests measured the 20th and 23rd of November proportionally to the volume of sales to an average day in 2018 (excluding holidays). FW from the buffet, however, was assumed to be independent from the volume of sales since it mainly arises once at the end of the day and since the size of the buffet is constant every day (Frei, 2018).

Status quo FW before introducing the collaboration with Foodsharing in the beginning of autumn 2017 was assumed to be equal to the sum of FW and food donations measured in November 2017. The composition of FW was based on the detailed measurement on the 23rd of November and the composition of food donations was based on all five measurements. The dishes or their main ingredients were grouped into six food categories.

The number of guests per day was deduced from the total weight of food served to the guests, assuming an average meal weight of 450g (Frei, 2018). The average number of guests per day in November was 548.

2) Beer hall restaurant with plate service "à la carte" (status quo, reduction case study B.)

FW measurements in a beer hall restaurant were carried out on the 2nd and 7th of February 2018 during the entire day (11am to 11pm). On both days, FW from the kitchen was measured and classified into edible and inedible FW from preparation and surplus production. Additionally, plate waste from the guests was weighed during the day. During the dinner service plate waste was differentiated into 12 food categories, assuming the composition of plate waste to be representative for the entire day since the menus offered are constant during the day. The number of meals served was available for each type of meal. On the 2nd of February at least two samples of the main 19 meal types were weighed, finding an average portion of 504g/person. The meal types served one week later were the same or only a few ingredients were substituted. However, the amount served was reduced by 11% to an average portion of 448g/person. According to the service staff only a few guests asked for refill (Schöb, 2018). A total of 396 and 371 main meals were served on the two days, respectively.

3) Luxury restaurant (status quo)

FW was measured on the 16th of February 2011 during lunch (25 guests) and dinner (24 guests) in a luxury restaurant (1 michelin star) in North-Western Switzerland. FW was separated into edible and inedible trim waste, overproduction from the kitchen (5 food categories, mainly bread), and plate waste from the guests (7 food categories). Additionally, the amount of food served was quantified by weighing samples of each dish and multiplying by the amount of dishes served. The main lunch menu consisted of 6 courses, the main dinner menu of 10 courses.

4) Progressive restaurant "Mein Küchenchef"

The company "Mein Küchenchef" was founded in 2014 with the goal of providing fresh, healthy, and delicious meals in its restaurant, its small shop, and for home consumption while avoiding FW as much as possible throughout the whole food value chain. The main pillars of its concept are using local and seasonal products, often not matching the markets' comsmetical norms, directly from the producers, avoiding transports and stages of the food value chain in which there are increased risks of food being wasted, and cooking with sous-vide technique. The latter has several advantages for FW prevention. First, preparation losses are reduced to a minimum (e.g. Mein_Küchenchef (2018) estimates ~15% lower meat losses by weight). Second, the cooked meals are conserveable for up to 4 weeks without additional preserving agents. Third, individual portions are cooked separately or in portions of 5 meals and can therefore be used flexibly during the following days. This allows producing a safety margin without wasting the additional food produced and, in the case of food sold for home consumption, allows consumers using the meal flexibly, which can help reduce FW especially in case of irregular and spontaneous daily life. The use of plastic bags for sous-vide cooking is discussed in section C.1.7.

"Mein Küchenchef" measured all edible and inedible FW from the preparation of 2'184 meals in the period from 29.1.–9.2.2018. In the same period plate waste from 488 meals served in its own restaurant and from 443 meals served in the nearby library restaurant "Lesbar". Plate waste was sorted into 5 food categories. Overproduction was entirely reused during the following days.

Additionally, "Mein Küchenchef" quantified the amount of unmarketable fruits and vegetables used (70% of all fruits and vegetables consumed) and the amount of products removed from its own retail shop close to their shelf life. These products are assumed to avoid FW which would have otherwise occurred in agriculture, trade, and retail.

5) University canteen (status quo)

In the context of a master thesis, which was later published (Beretta et al., 2013), FW was measured by research personnel during lunch on the 19th of April 2012. A total of 1'504 meals were served, mainly to students and university employees. FW was separated into edible and inedible trim waste, over-production from the kitchen and buffet, and plate waste from the guests. The caterer introduced regular staff trainings that also addressed the issue of FW. However, since no specific measures for FW reduction have been taken before April 2012, we consider this measurement as status quo.

6) to 9) School canteens (status quo, reduction case studies C., G.-I.)

Waskow and Blumenthal (2017) analysed FW during lunch in 4 school canteens over a period of about 2 weeks and repeated the measurements after the implementation of several months of FW reduction measures. The measurements were carried out by the kitchen staff after instructions by the research team. Since the publication by Waskow and Blumenthal (2017) only presents aggregated data, they provided detailed datasets for this project. They analysed over-production from the kitchen and weighed each dish individually (more than 400 types). We classified the dishes according to their main ingredients (Table C.6 and Table C.16 in the electronic appendix). Additionally, they measured plate waste from the guests, however without differentiating food categories. Since they did not consider trim waste and storage losses, we estimated them to be equal to the average in 269 business caterings analysed by Borstel et al. (2017) (Figure C.1).

In the secondary school canteen 2 (no. 19) we only used data from one week for the second measurement since the number of meals consumed in the second week was unknown. Secondary schools 3 and 4 (no. 20) are a special case. In the first measurement period in 2016 FW was much lower compared to other school due to careful planning and relatively small portions served. During the following months the kitchen was rebuilt and a new service system introduced. The focus of this innovation was on providing more variety and flexibility to the pupils in selecting the dishes and portions. However, FW increased considerably compared to the previous system. Therefore we use the new kitchen with buffet service and without focus on FW for the status quo estimation and the previous system with service at the counter for the FW reduction scenario.

Further details are provided in Table C.2 and a list of the main measures for FW reduction in Table C.1.

Table C.2: Overview of the school canteens: number of pupils, kitchen and service system (modified from Waskow and Blumenthal (2017)).

	6) primary school	7) Secondary school	8) Secondary school	9) Secondary school
Management	Single-handedly	Run by a medium caterer	Single-handedly	Run by a major caterer
Kitchen system	Cook & serve	Cook & serve and cook & chill	Cook & serve	Cook & serve and cook & chill
Service system	Pupils take from a bowl on each table	Buffet	Service at the counter	2016: Service at the counter 2017: Buffet
Number of pupils	150	980	1’300	1’100
Number of pupils eating in the canteen	150 (eating in the canteen is compulsory)	400	400	290
Name of the school in Waskow and Blumenthal	Grundschule A	Gesamtschule C	Gesamtschule D	Gymnasium E
First measurement	January 2016 (10 days)	June 2016 (10 days)	June 2016 (10 days)	April 2016 (10 days)
Second measurement	March 2017 (10 days)	September 2016 (9 days)	September 2016 (5 days)	September 2017 (10 days)

7) Cantonal hospital (status quo, reduction case study D.)

Three Cantonal hospitals in Central Switzerland carried out FW measurements over 4 weeks in 2017 (6.3.-2.4.2017), supported by the association “United Against Waste” (www.united-against-waste.ch) who coach FSs in FW reduction techniques. The measurements were carried out by the hospital staff with support from civilian service trainees. Overproduction was subdivided into 6 food categories, plate waste from the patients into 4 food categories. Untouched trays were measured separately. Trim waste was not sorted into edible and inedible parts, but the edible fraction of trim waste was roughly estimated at one third.

Based on the assessment a list of 31 measures to reduce FW was elaborated and most measures were implemented in the course of the following year. The measures included making all side dishes optional (e.g. soup in the evening), reducing the size of standard portions (e.g. 90 g of Joghurt instead of 150 g, 28 g of cheese instead of 40 g) and offering half and ¾ size portions, reusing leftovers from the kitchen (e.g. cooking a soup with surplus vegetables twice a week, making bread crumbs and bread soup from surplus bread), eliminating the production of reserve meals, training of staff, reducing the variety of meals offered, and considering food donations. After one year of implementation a second measurement was carried out with the same method over a period of 4 weeks (5.3.-1.4.2018). The numbers of meals (breakfast, lunch, dinner) served during both 4 week periods were about 40’000, 14’000, and 6’000 in the three hospitals, respectively.

8) Business hotel A

In business hotel A a first measurement was carried out by the kitchen staff with a FW tracking tool for 29 days in April 2015. After coaching by the association United Against Waste (www.united-against-waste.ch) and internal staff trainings a second measurement was carried out for 28 days in April 2017. FW was classified into 20 food categories and 9 origins (trim waste, post consumer, overproduction, expired, spoiled, overcooked, misorder, quality, handling).

In this analysis the number of main meals served is unknown (orders do not differentiate meals, snacks, and drinks and the number of hotel guests is not representative since not all of them eat in the hotel). Therefore the FW amounts cannot be normed to gram per meal. Nevertheless we included the case study into the additional results because the detailed composition of FW allows an interesting comparison of the relative contribution of individual food categories to quantitative FW reduction and environmental benefits (Figure C.15).

9) Business hotel B

Differences to business hotel A: In business hotel B a first measurement was carried out between 18.1.-14.2.2016 and a second measurement between 12.6.-9.7.2017. FW was classified into 16 food categories.

10) Touristic hotel 1 with 5 locations (status quo, reduction case study J.)

A hotel chain in Switzerland did FW measurements with a FW tracking tool in 5 touristic hotels in the Swiss Alps and Ticino. The hotel staff measured FW for 4 weeks (29.8.-25.9.2016) and was trained by United Against Waste (www.united-against-waste.ch) how to implement measures to reduce FW (the amounts of FW per week are shown in Figure 3). Over-production was differentiated into 16 food categories; additionally, trim waste and post consumer waste (plate waste from the guests) were measured. Trim waste was not sorted into edible and inedible parts, but the edible fraction of trim waste was roughly estimated at one third. Over all 5 hotels and 4 weeks a total of 34’569 meals were served. The first week was considered the status quo, the 4th week the reduction scenario.

11) Touristic hotel 2 with 4 locations (status quo, reduction case study K.)

Differences to hotel 1: The measurements were carried out in 4 touristic hotels, all situated in the Swiss Alps, during the period 4.7.-31.7.2016. Over all 4 hotels and 4 weeks a total of 30’688 meals were served.

12) City hotel 3 with breakfast buffet, dinner “à la carte”, caterings (status quo, reduction case study E.)

Hotel 3 is located in a major city in Switzerland. The hotel staff carried out FW measurements in a pilot phase with the FW tracking tool of the company KITRO, which support FSs to reduce their FW through quantifying and providing actionable insights into the reasons for FW. The company provided primary data about the measurements and the measures implemented to reduce FW (KITRO, 2018). The measurements were carried out during 5 weeks over a period of 9 weeks, in which the measures for FW reduction were implemented (introducing a person from staff fully responsible for buffet management and checking the time and number of expected people before filling the buffet, using smaller containers and spoons on the buffet, optimised forecasting, cooking lower amounts and recooking on the spot if necessary, training the staff not to throw away unnecessary food). During the 5 weeks a total of 3’200 meals were served as breakfast (buffet), lunch, and dinner (à la carte), and 470 meals at events and banquets. The first week was considered the status quo, the 5th week the reduction scenario. The time series of FW per week is shown in Figure 3.

13) City hotel 4 with breakfast buffet (status quo)

Hotel 4 is also located in a major Swiss city. Personnel from our research group carried out a detailed measurement of FW from the breakfast buffet on the 16th of March 2018, separating plate waste into 10, over-production from the buffet into 4, and preparation waste from the kitchen into inedible and 3 edible food categories. During service time 69 guests were present. The kitchen staff is generally well informed on the issue of FW and tries to reduce the amount of perishable food on the buffet towards the end of the service. However, since no specific measures to reduce FW have been taken in the last years, we consider this hotel as status quo.

14) Workplace canteen 1 with buffet “all you can eat” (status quo)

In a business canteen with breakfast, lunch, and dinner buffet “all you can eat” (dinner every day except Friday) and free food for the employees, FW is measured constantly by the staff with a waste tracking tool. Additionally, personnel of our research team carried out detailed measurements on the 13th and 14th of November 2017 and on the 9th of February and 13th of April 2018 during breakfast and lunch. We weighed edible and inedible trim waste from the kitchen separately, over-production at the free-flow counter and surplus food from the buffet (individual dishes), and the guests’ plate waste (6 food categories). Kitchen and buffet waste during the service of 3’852 guests, plate waste was collected from 2’590 guests (during rush hours some random plates could not be measured due to time constraints).

Since the results showed that the staff’s regular measurements were incomplete, only the detailed measurements were considered in this analysis.

15) Workplace canteen 2 with plate service and refill “all you can eat” (reduction case study B.)

The company which runs workplace canteen 1 recognised that the buffet system with free food for employees leads to considerable amounts of FW and introduced plate service in another canteen on the same campus with the goal to reduce FW. The concept includes offering relatively small, plated portions of basic dishes and assorted salads considering special wishes of the guests, thus preventing guests from over-estimating their hunger and taking large portions at once. In addition to reducing plate waste, the goal of the plate service is to reduce overproduction since plates can be prepared during the service and there is no need to refill a large buffet until the end of the service.

In this canteen, FW was measured by personnel of our research team during lunch on the 14th of November 2017 (150 guests) by separating plate waste into 19 food categories and differentiating edible and inedible waste from preparation as well as over-production (only soup). Since the canteen's concept has been designed with the goal of reducing FW based on previous experiences in other canteens, we assign this canteen to the base scenario of FW reduction.

16) Workplace canteen 3 with mixed service systems (status quo, reduction case study L.)

Workplace canteen 3 is part of a care center. The canteen is run by a large Swiss catering chain, which introduced regular FW measurements in most FS locations during one month of the year. The measurements are carried out by the kitchen staff and accompanied with staff trainings with the goal of continuous improvement.

We consider the first measurement in March 2014 (2'117 main meals) for the status quo estimation and the measurement in October 2017 (927 main meals) for the base scenario of FW reduction. FW was only separated by origin (over-production from kitchen, the salad buffet, the menu counter, the free-choice counter, and plate waste from the guests), but not by food categories. Possibly edible trim waste was not measured. However, since most products are pre-prepared, the amount of edible trim waste is estimated to be low.

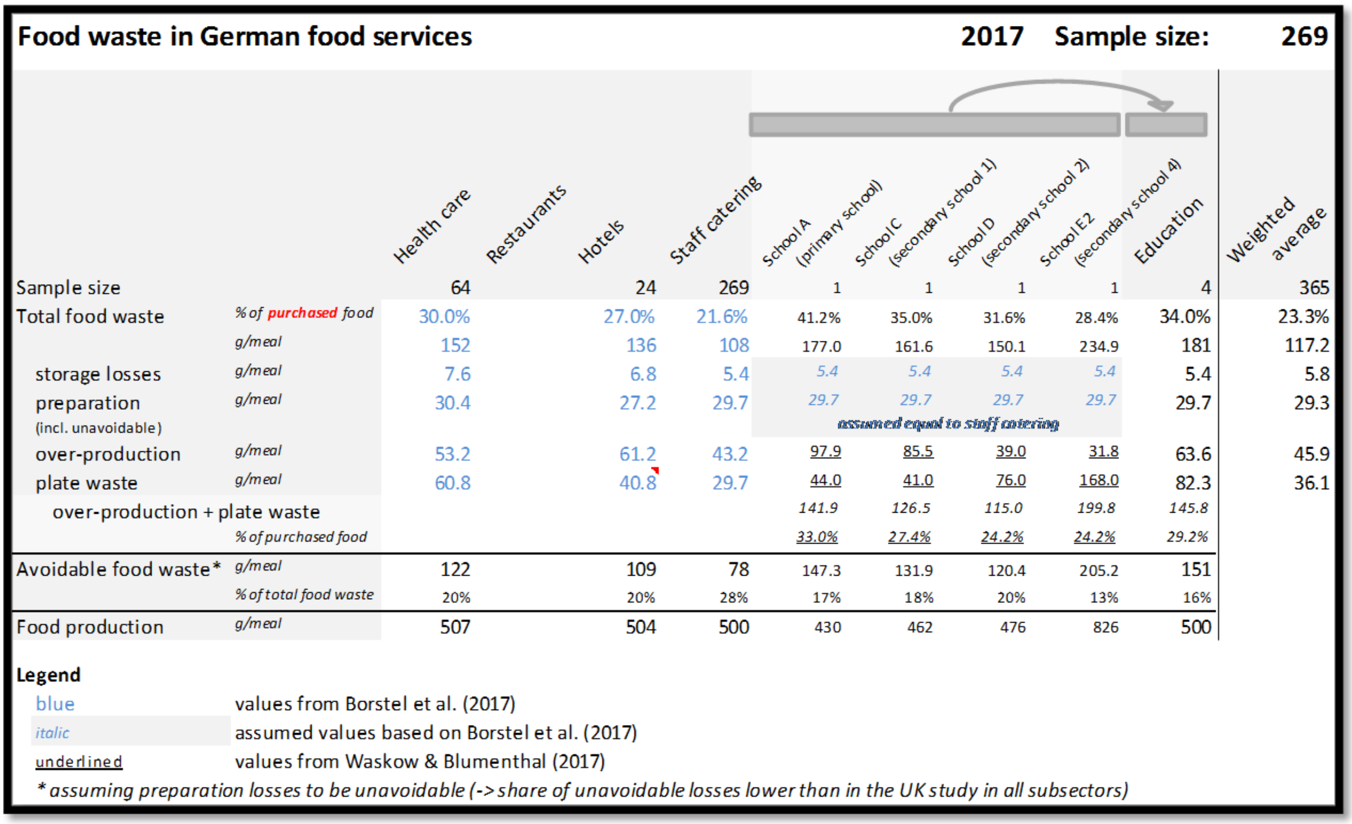
17) Workplace canteen 4 with mixed service systems (status quo, reduction case study M.)

Workplace canteen 4 is run by the same catering chain as workplace canteen 3. We consider the first measurement in March 2015 (4'000 main meals) for the status quo estimation and the measurement in March 2017 (3'436 main meals) for the base scenario of FW reduction.

C.1.2 Status quo food waste in subsectors: estimations from literature in Germany, Austria, Finnland, and the UK

Since FW is not reported in the same units in all studies, the values in some cases have to be converted into "gram avoidable FW per meal".

Borstel et al. (2017) report FW both in "g/meal" and in "% of purchases". However, they do not separate avoidable and unavoidable trim waste. The reported share of preparation losses is lower than the share of unavoidable losses in Oakdene (2013)'s study in all subsectors. Therefore, we assume all preparation losses to be unavoidable. For the subsector "education" Borstel et al. (2017) based their findings on Waskow and Blumenthal (2017), who did not measure losses from storage and preparation. Therefore, we assumed these losses to be equal to staff caterings (Figure C.1).



Food waste in German food services **2017** **Sample size:** **269**

		Health care	Restaurants	Hotels	Staff catering	School A (primary school)	School C (secondary school 1)	School D (secondary school 2)	School E2 (secondary school 4)	Education	Weighted average
Sample size		64		24	269	1	1	1	1	4	365
Total food waste	*% of purchased food*	30.0%		27.0%	21.6%	41.2%	35.0%	31.6%	28.4%	34.0%	23.3%
	g/meal	152		136	108	177.0	161.6	150.1	234.9	181	117.2
storage losses	*g/meal*	7.6		6.8	5.4	*5.4*	*5.4*	*5.4*	*5.4*	5.4	5.8
preparation	*g/meal*	30.4		27.2	29.7	*29.7*	*29.7*	*29.7*	*29.7*	29.7	29.3
(incl. unavoidable)						*assumed equal to staff catering*					
over-production	*g/meal*	53.2		61.2	43.2	97.9	85.5	39.0	31.8	63.6	45.9
plate waste	*g/meal*	60.8		40.8	29.7	44.0	41.0	76.0	168.0	82.3	36.1
over-production + plate waste						*141.9*	*126.5*	*115.0*	*199.8*	*145.8*	
	% of purchased food					*33.0%*	*27.4%*	*24.2%*	*24.2%*	*29.2%*	
Avoidable food waste*	*g/meal*	122		109	78	147.3	131.9	120.4	205.2	151	
	% of total food waste	20%		20%	28%	17%	18%	20%	13%	16%	
Food production	*g/meal*	507		504	500	430	462	476	826	500	

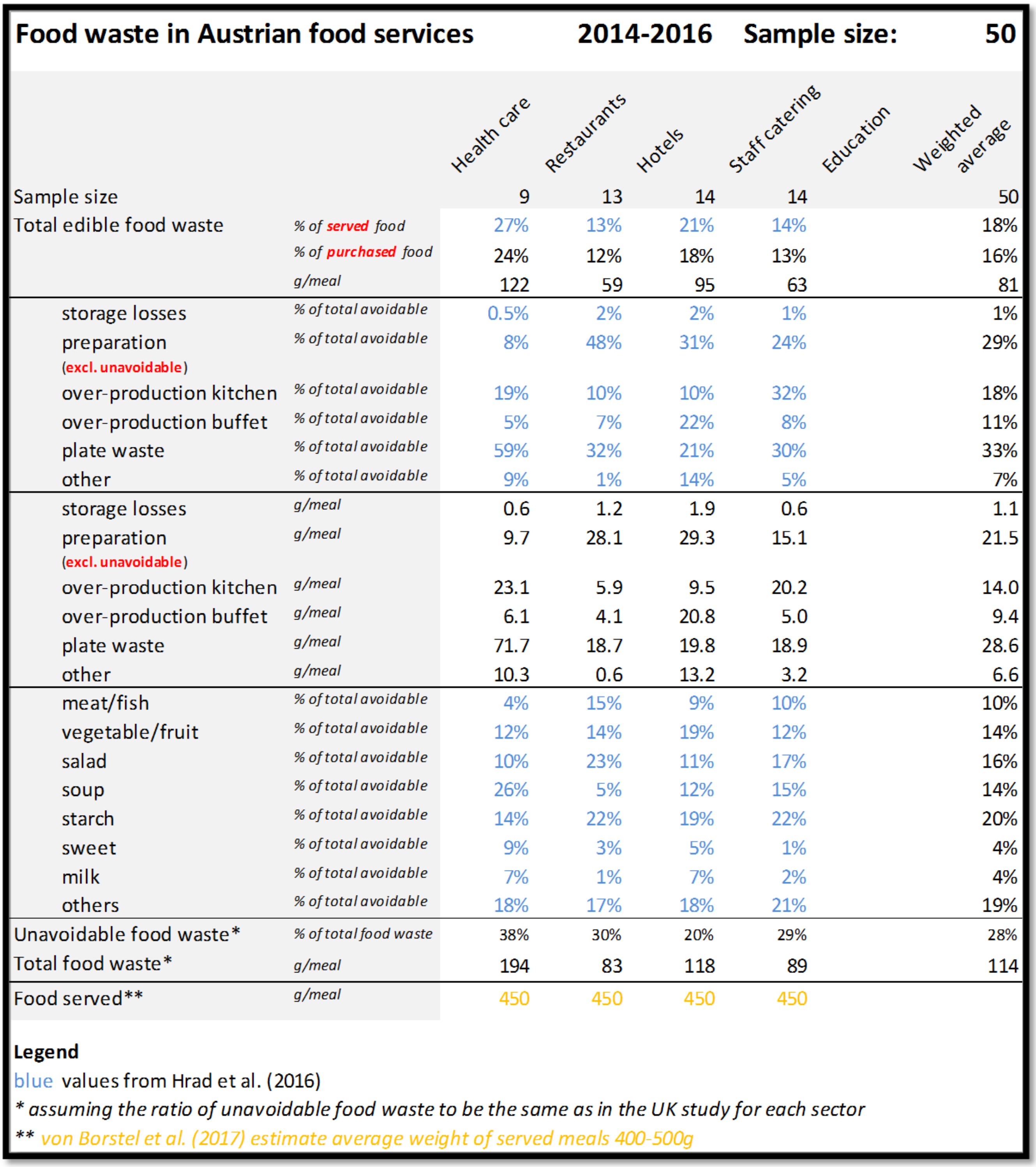
Legend

blue	values from Borstel et al. (2017)
italic	assumed values based on Borstel et al. (2017)
underlined	values from Waskow & Blumenthal (2017)

** assuming preparation losses to be unavoidable (-> share of unavoidable losses lower than in the UK study in all subsectors)*

Figure C.1: Food production and total and avoidable FW in 269 German FSs according to Borstel et al. (2017) and Waskow and Blumenthal (2017) and calculation of weighted average based on sample size in each sector. Storage and preparation losses were not measured in the shool canteens and are therefore assumed to be equal to staff catering.

Hrad et al. (2016) report only avoidable FW and express it in "% of served food" (Figure C.2). We calculated g/meal assuming an average served portion of 450g/meal (Borstel et al., 2017). Oakdene (2013) directly report "g/meal avoidable and unavoidable FW" (Figure C.3). Silvennoinen et al. (2015) report FW in "% of prepared food". Unavoidable FW (called "bio waste" in their study) is not included in the prepared portions. Since they measured the average prepared portions in each subsector, the values can be multiplied obtaining "g avoidable FW/meal" (Figure C.4).



Food waste in Austrian food services 2014-2016 Sample size: 50

		Health care	Restaurants	Hotels	Staff catering	Education	Weighted average
Sample size		9	13	14	14		50
Total edible food waste	*% of **served** food*	27%	13%	21%	14%		18%
	*% of **purchased** food*	24%	12%	18%	13%		16%
	g/meal	122	59	95	63		81
storage losses	*% of total avoidable*	0.5%	2%	2%	1%		1%
preparation (**excl. unavoidable**)	*% of total avoidable*	8%	48%	31%	24%		29%
over-production kitchen	*% of total avoidable*	19%	10%	10%	32%		18%
over-production buffet	*% of total avoidable*	5%	7%	22%	8%		11%
plate waste	*% of total avoidable*	59%	32%	21%	30%		33%
other	*% of total avoidable*	9%	1%	14%	5%		7%
storage losses	*g/meal*	0.6	1.2	1.9	0.6		1.1
preparation (**excl. unavoidable**)	*g/meal*	9.7	28.1	29.3	15.1		21.5
over-production kitchen	*g/meal*	23.1	5.9	9.5	20.2		14.0
over-production buffet	*g/meal*	6.1	4.1	20.8	5.0		9.4
plate waste	*g/meal*	71.7	18.7	19.8	18.9		28.6
other	*g/meal*	10.3	0.6	13.2	3.2		6.6
meat/fish	*% of total avoidable*	4%	15%	9%	10%		10%
vegetable/fruit	*% of total avoidable*	12%	14%	19%	12%		14%
salad	*% of total avoidable*	10%	23%	11%	17%		16%
soup	*% of total avoidable*	26%	5%	12%	15%		14%
starch	*% of total avoidable*	14%	22%	19%	22%		20%
sweet	*% of total avoidable*	9%	3%	5%	1%		4%
milk	*% of total avoidable*	7%	1%	7%	2%		4%
others	*% of total avoidable*	18%	17%	18%	21%		19%
Unavoidable food waste*	*% of total food waste*	38%	30%	20%	29%		28%
Total food waste*	*g/meal*	194	83	118	89		114
Food served**	*g/meal*	450	450	450	450		

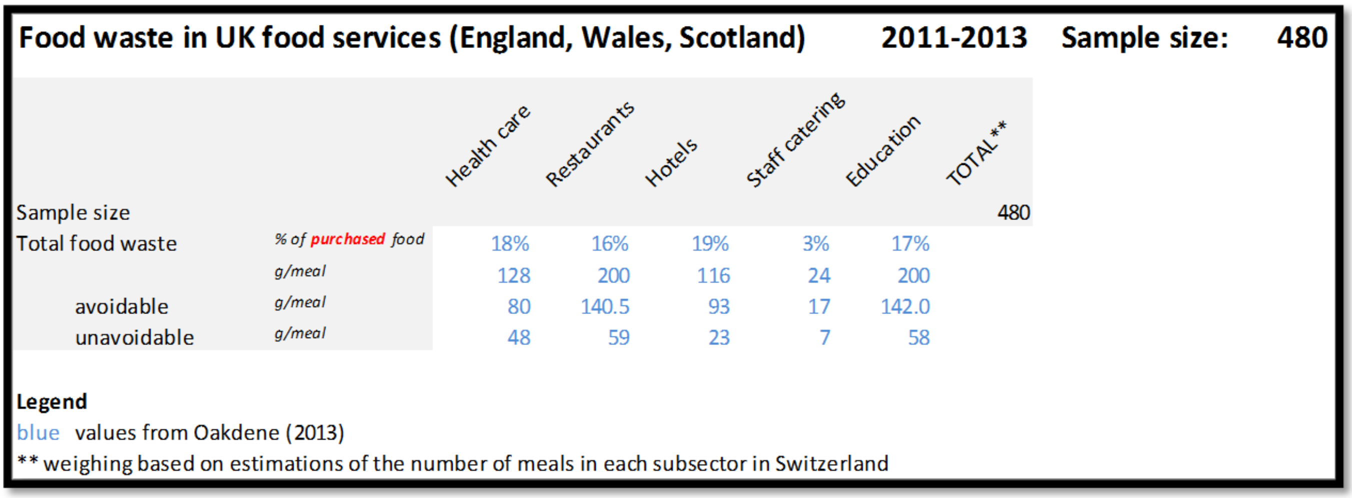
Legend

blue values from Hrad et al. (2016)

** assuming the ratio of unavoidable food waste to be the same as in the UK study for each sector*

*** von Borstel et al. (2017) estimate average weight of served meals 400-500g*

Figure C.2: Total and avoidable FW in 50 Austrian FSs according to Hrad et al. (2016) and calculation of a weighted average based on sample size in each subsector. The values reported as percentages of production are converted to g/meal assuming average served portions of 450 g/meal.

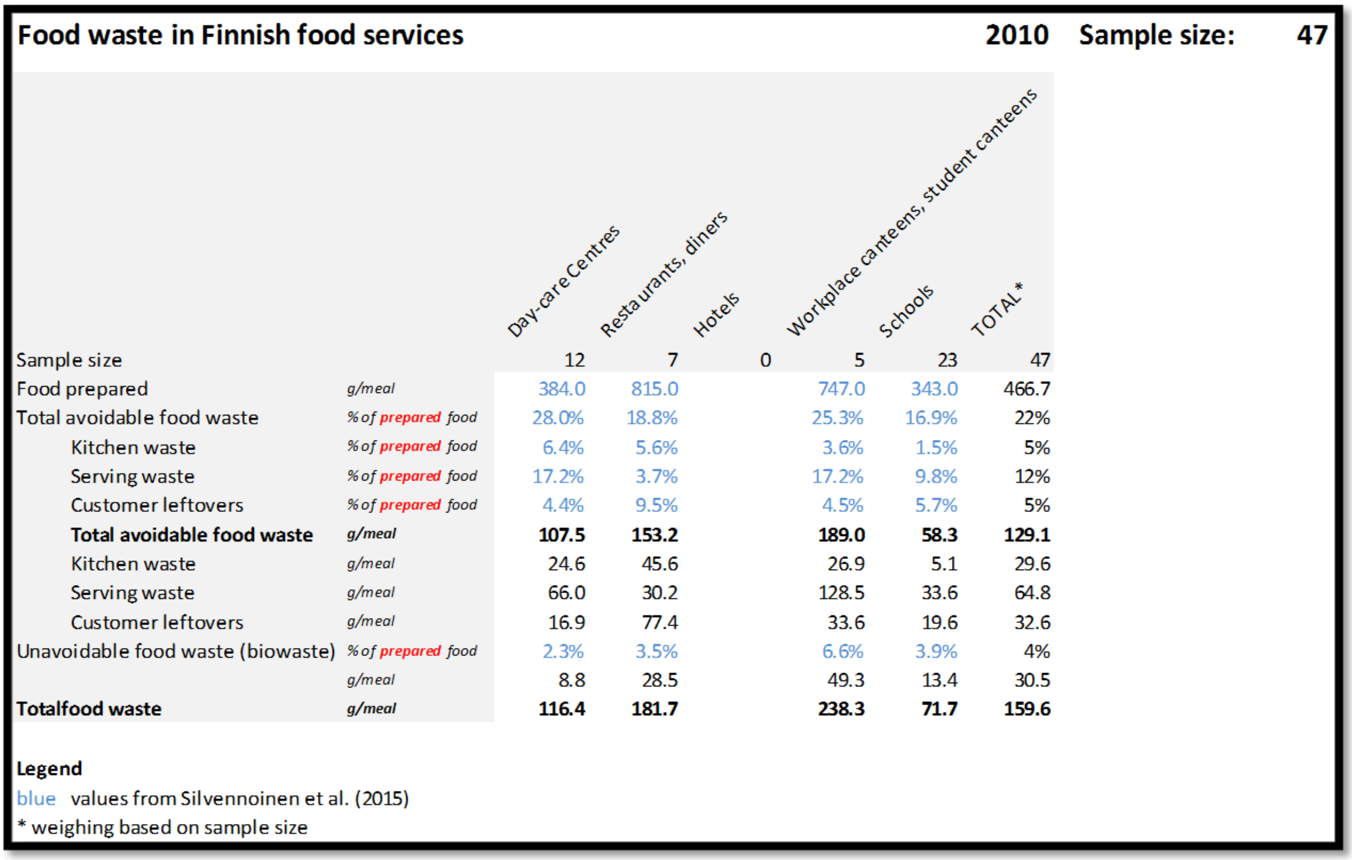


Food waste in UK food services (England, Wales, Scotland) **2011-2013** **Sample size:** **480**

		Health care	Restaurants	Hotels	Staff catering	Education	TOTAL**
Sample size							480
Total food waste	*% of purchased food*	18%	16%	19%	3%	17%	
	g/meal	128	200	116	24	200	
avoidable	*g/meal*	80	140.5	93	17	142.0	
unavoidable	*g/meal*	48	59	23	7	58	

Legend
blue values from Oakdene (2013)
** weighing based on estimations of the number of meals in each subsector in Switzerland

Figure C.3: Total and avoidable FW in 480 FSs in the UK according to Oakdene (2013).



Food waste in Finnish food services **2010** **Sample size:** **47**

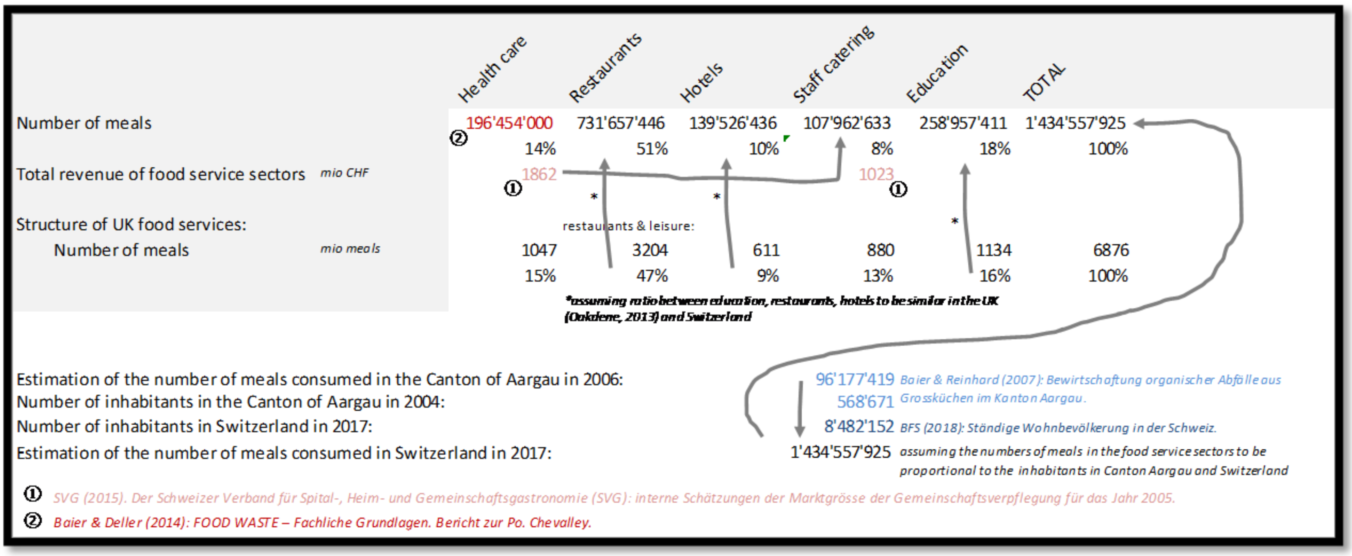
		Day-care Centres	Restaurants, diners	Hotels	Workplace canteens, student canteens	Schools	TOTAL*
Sample size		12	7	0	5	23	47
Food prepared	*g/meal*	384.0	815.0		747.0	343.0	466.7
Total avoidable food waste	*% of prepared food*	28.0%	18.8%		25.3%	16.9%	22%
Kitchen waste	*% of prepared food*	6.4%	5.6%		3.6%	1.5%	5%
Serving waste	*% of prepared food*	17.2%	3.7%		17.2%	9.8%	12%
Customer leftovers	*% of prepared food*	4.4%	9.5%		4.5%	5.7%	5%
Total avoidable food waste	***g/meal***	**107.5**	**153.2**		**189.0**	**58.3**	**129.1**
Kitchen waste	*g/meal*	24.6	45.6		26.9	5.1	29.6
Serving waste	*g/meal*	66.0	30.2		128.5	33.6	64.8
Customer leftovers	*g/meal*	16.9	77.4		33.6	19.6	32.6
Unavoidable food waste (biowaste)	*% of prepared food*	2.3%	3.5%		6.6%	3.9%	4%
	g/meal	8.8	28.5		49.3	13.4	30.5
Totalfood waste	***g/meal***	**116.4**	**181.7**		**238.3**	**71.7**	**159.6**

Legend
blue values from Silvennoinen et al. (2015)
* weighing based on sample size

Figure C.4: Total and avoidable FW in 47 FSs in the Finnland according to Silvennoinen et al. (2015).

C.1.3 Estimation of the number of meals in the Swiss food service sector

The number of meals consumed in Swiss FSs is based on an estimation by Baier and Reinhard (2007) for the Canton of Aargau, assuming it is proportional to the number of inhabitants in Switzerland and Aargau. The number of meals consumed in the health care subsector is based on Baier and Deller (2014). Assuming the revenue per meal in health care kitchens and staff caterings to be similar, SVG (2015)'s quantification of the revenue was used to estimate the number of meals consumed in Swiss staff caterings. The share of meals consumed in the remaining subsectors "restaurants", "hotels", and "education" was assumed to be equal to Oakdene (2013)'s estimation for the UK.



		Health care	Restaurants	Hotels	Staff catering	Education	TOTAL
Number of meals		② 196'454'000	731'657'446	139'526'436	107'962'633	258'957'411	1'434'557'925
		14%	51%	10%	8%	18%	100%
Total revenue of food service sectors	*mio CHF*	① 1862	*	*	1023 ①	*	
Structure of UK food services:			restaurants & leisure:				
Number of meals	*mio meals*	1047	3204	611	880	1134	6876
		15%	47%	9%	13%	16%	100%

***assuming ratio between education, restaurants, hotels to be similar in the UK (Oakdene, 2013) and Switzerland**

Estimation of the number of meals consumed in the Canton of Aargau in 2006:	96'177'419	*Baier & Reinhard (2007): Bewirtschaftung organischer Abfälle aus Grossküchen im Kanton Aargau.*
Number of inhabitants in the Canton of Aargau in 2004:	568'671	
Number of inhabitants in Switzerland in 2017:	8'482'152	*BFS (2018): Ständige Wohnbevölkerung in der Schweiz.*
Estimation of the number of meals consumed in Switzerland in 2017:	1'434'557'925	*assuming the numbers of meals in the food service sectors to be proportional to the inhabitants in Canton Aargau and Switzerland*

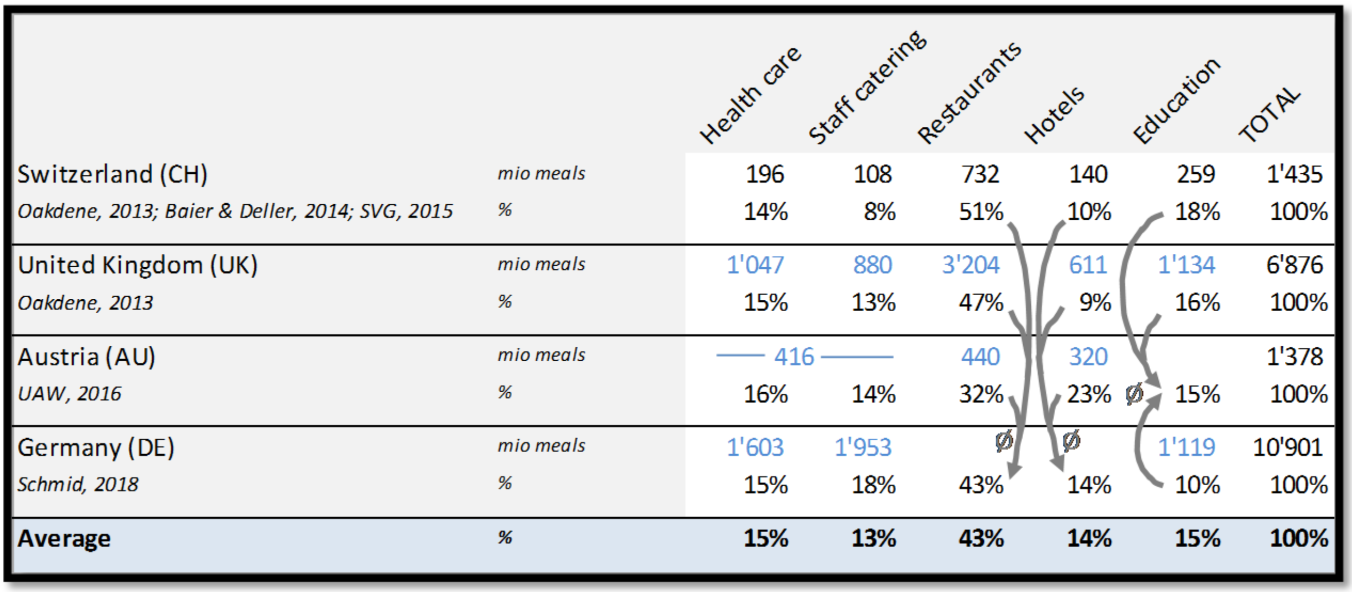
① *SVG (2015). Der Schweizer Verband für Spital-, Heim- und Gemeinschaftsgastronomie (SVG): interne Schätzungen der Marktgrösse der Gemeinschaftsverpflegung für das Jahr 2005.*

② *Baier & Deller (2014): FOOD WASTE – Fachliche Grundlagen. Bericht zur Po. Chevalley.*

Figure C.5: Calculation of the number of meals consumed in FSs in Switzerland. The number of all subsectors (including take-aways, but excluding pubs) is based on Baier's estimation for the Canton of Aargau (Baier and Reinhard, 2007) and assumed to be proportional to population. The number of meals in health care institutions and staff caterings is estimated based on Swiss estimations (Baier and Deller, 2014, SVG, 2015), the share of the remaining subsectors is assumed to be proportional to the UK FS sector (Oakdene, 2013).

C.1.4 Share of food service subsectors based on the number of meals in different Euopean countries

The share of meals consumed in each subsector in Europe is based on estimations of the number of meals consumed in individual subsectors in Switzerland (calculated in the previous section), the UK (Oakdene, 2013), Austria (Hrad et al., 2016), and Germany (Schmid, 2018). For Germany the share of restaurants and hotels and for Austria the share of education were calculated as average of the shares of the corresponding other 3 countries. Since for Austrian health care kitchens and staff caterings only the total number of meals consumed was available, we assumed the proportions to be equal to the average of the same subsectors in the other 3 countries (Figure C.6).



		Health care	Staff catering	Restaurants	Hotels	Education	TOTAL
Switzerland (CH)	*mio meals*	196	108	732	140	259	1'435
Oakdene, 2013; Baier & Deller, 2014; SVG, 2015	*%*	14%	8%	51%	10%	18%	100%
United Kingdom (UK)	*mio meals*	1'047	880	3'204	611	1'134	6'876
Oakdene, 2013	*%*	15%	13%	47%	9%	16%	100%
Austria (AU)	*mio meals*	416		440	320		1'378
UAW, 2016	*%*	16%	14%	32%	23%	Ø 15%	100%
Germany (DE)	*mio meals*	1'603	1'953	Ø	Ø	1'119	10'901
Schmid, 2018	*%*	15%	18%	43%	14%	10%	100%
Average	*%*	**15%**	**13%**	**43%**	**14%**	**15%**	**100%**

Figure C.6: Calculation of the share of meals consumed in FSs in different sub-sectors in average of four European countries (Switzerland, United Kingdom, Austria, and Germany). Numbers in blue originate from the references indicated for each country (Oakdene, 2013, UAW, 2016, Schmid, 2018); the numbers for Switzerland are calculated in Figure C.5. Missing values are calculated based on the average shares of the other countries (indicated with arrows). 'Restaurants' mostly include quick-service restaurants (e.g. cafes, take-aways, fast-food), but exclude pubs (Oakdene, 2013, UAW, 2016).

C.1.5 Synthesis of food waste estimations per sector from literature and case studies

From the 24 case studies used for the status quo estimation (Table C.1), 21 FW measurements were carried out in Switzerland ("CH case studies" in Table C.3) and 4 FW measurements were carried out by Waskow and Blumenthal (2017) and Borstel et al. (2017) in German school canteens, sharing primary data with this project. In order to estimate the amount of FW in Europe more accurately, literature research was done. Based on sample size, data quality, differentiation by subsectors, and compatibility of FW tracking methods with our case studies, we selected one study from Germany (Borstel et al., 2017), one from Austria (Hrad et al., 2016), one from the UK (Oakdene, 2013), and one from Finland (Silvennoinen et al., 2015) in order to quantify FW amounts in each subsector. Two Swiss studies were used even though they did not differentiate subsectors (Andrini and Bauen, 2005, Baier and Reinhard, 2007). Thus, the average of FW in FSs is based on 1'042 FW measurements (Table C.3). The average FW amounts per subsector are weighted based on the number of FW measurements in each study. The subsectors are weighted based on the share of meals consumed in each subsector. For total FW in Switzerland FW per meal was multiplied in each subsector by the number of meals consumed.

Table C.3: Total and avoidable FW and plate waste per meal in each subsector and average of all subsectors based on the number of meals consumed in each subsector (from Figure C.5). The averages from several sources are weighted based on sample size (number of FSs analysed). The bottom rows show the total amounts of FW in Switzerland.

		Health care	Restaurants	Hotels	Staff catering	Education	Weighted average **	Health care	Restaurants	Hotels	Staff catering	Education	TOTAL
Share of meals consumed in food service sub-sectors													
	%	15%	43%	14%	15%	13%	100%						
Total food waste per meal								**Sample size**					
Germany (Borstel et al., 2017)	*g/meal*	152.0		136.0	108.0	180.9	143.2	64	0	24	269	4	361
Austria (Hrad et al., 2016)	*g/meal*	194.4	83.1	117.9	88.9		108.8	9	13	14	14	0	50
United Kingdom (Oakdene, 2013)	*g/meal*	128.0	199.5	116.0	24.0	200.0	151.2	96	96	96	96	96	480
Finland (Silvennoinen et al., 2015)	*g/meal*	116.4	181.7		238.3	71.7	163.4	12	7	0	5	23	47
measurements in Switzerland	*g/meal*	311.8	122.9	93.2	144.8	33.5	138.5	3	3	11	3	1	21
Weighted average*	*g/meal*	141.8	183.8	117.8	88.4	174.2	152.9	184	119	145	387	124	959
Andrini & Bauen (2005)	*g/meal*						116.9	—— *not specified* ——					20
Baier & Reinhard (2007)	*g/meal*						124.0	28	— 17 —		— 18 —		63
Weighted average*	***g/meal***	**131**	**169**	**108**	**81**	**160**	**150**	212	136	145	396	133	1042
Avoidable food waste per meal								**Sample size**					
Germany (Borstel et al., 2017)	*g/meal*	121.6		108.8	78.3	151.2	113.9	64	0	24	269	4	361
Austria (Hrad et al., 2016)	*g/meal*	121.5	58.5	94.5	63.0		75.9	9	13	14	14	0	50
United Kingdom (Oakdene, 2013)	*g/meal*	80.0	140.5	93.0	17.0	142.0	106.7	96	96	96	96	96	480
Finland (Silvennoinen et al., 2015)	*g/meal*	107.5	153.2		189.0	58.3	137.0	12	7	0	5	23	47
measurements in Switzerland	*g/meal*	302.4	104.9	67.3	119.9	31.4	121.7	3	3	11	3	1	21
Andrini & Bauen (2005)	*g/meal*						105.2	—— *not specified* ——					20
Baier & Reinhard (2007)	*g/meal*						63.9	28	— 17 —		— 18 —		63
Weighted average*	***g/meal***	**99**	**128**	**91**	**63**	**123**	**108**	212	136	145	396	133	1042
Plate waste per meal								**Sample size**					
Germany (Borstel et al., 2017)	*g/meal*	60.8		40.8	29.7	82.3	52.7	64	0	24	269	4	361
Austria (Hrad et al., 2016)	*g/meal*	71.7	18.7	19.8	18.9		28.6	9	13	14	14	0	50
Finland (Silvennoinen et al., 2015)	*g/meal*	16.9	77.4		33.6	19.6	17.7	12	7	0	5	23	47
measurements in Switzerland	*g/meal*	199.7	26.3	24.7	14.2	82.3	57.5	3	3	11	3	1	21
Weighted average*	*g/meal*	60.7	37.6	31.2	29.1	30.7	38.0	88	23	49	291	28	479
Number of meals consumed in food services in CH (2006)													
	1000 meals	196'454	731'657	139'526	107'963	258'957	1'434'558						
Total food waste in food services in CH													
Weighted average*	*t*	27'864	134'482	16'431	9'548	45'121	233'447						
Avoidable food waste in food services in CH													
Weighted average*	*t*	19'488	93'567	12'739	6'756	31'727	164'277						

**weighted based on sample size*

***weighted based on the number of meals consumed in Swiss food services in each subsector*

C.1.6 Extended scenario II: using 50% non-marketable vegetables and cooking meat with sous-vide technique

In the extended scenario II, FSs do not only use 50% non-marketable vegetables and save them from being wasted (extended scenario in section 4.3.3), but they also **cook 70% of the meat with sous-vide technique** (30% of the meat is not considered suitable for this technique, e.g. fried sausages). With this technique, Mein_Küchenchef (2018) estimates **15% less meat input needed for the same meals** due to lower cooking losses. Sous-vide meat has a lower calorific content due to better conservation of its texture and lower water losses thanks to lower cooking temperatures than with conventional high-heat cooking, such as oven roasting or grilling (Frei, 2018); the **difference in calories is assumed to be replaced with average Swiss food**.

C.1.7 Environmental relevance of plastic bags used for sous-vide cooking

Sous-vide cooking implies the use of plastic bags or glass jars. Since in large kitchens plastic bags are more common and easier to handle at present (Mein_Küchenchef, 2018), in this section we estimate the environmental relevance of using additional plastic bags compared to the efficiency benefits of sous-vide cooking.

Menus can be cooked in bags of 1 meal with a weight of 11 g or in bags of 5 meals with a weight of 20 g (Mein_Küchenchef, 2018). The bags are primarily made of polyethylene (PE) (Frei, 2018). Some products might be reinforced with polyamide (PA) in an exterior layer of the bag. According to the Ecoinvent database 3.4 the production of 1kg of polyethylene causes between 1.9 and 2.3 kg CO_2-eq and the treatment of polyethylene waste in an average European incineration plant about 3 kg CO_2- eq (Table C.4). Thus, by using single-meal bags 58 g CO_2-eq per meal are released, which corresponds to about 64% of the impacts of average wasted food from overproduction and buffet surplus. This means that cooking with sous-vide technique in order to reduce the climate impacts of FW only makes sense if more than 64% of average overproduction (34 g/meal) can be avoided. If the plastic bags are recycled instead of sent to incineration, the impacts can roughly be halved. If bags of 5 meals instead of single-meal bags are used, the impacts can be reduced by roughly $^2/_3$. In combination, the impacts of the plastic bags can be reduced to 10 g CO_2-eq per meal. In this case, cooking with sous-vide technique in order to reduce FW already makes sense, if more than 11% of average overproduction (6 g/meal) can be avoided. The impacts of plastic bags might further be reduced with reusable plastic bags compatible with a vacuum machine; however, further technical improvements are needed since implementation of reusable bags is difficult to apply in large kitchens due to safety reasons and low efficiency in handling (Frei, 2018).

For the extended scenario II, in which meat is cooked more efficiently with sous-vide technique in order to reduce its input, plastic bags of 20 g can be used to cook 20 portions of 130 g of meat (Mein_Küchenchef, 2018). This is consistent with Frei (2018)'s estimation of cooking 12 portions of meat of 160-220 g in bags of 13-15 g (40x30 cm). With this measure, the climate impacts of the plastic bags can be reduced to 2.6 g CO_2-eq per meal, which is 2.5% of the savings of reduced meat consumption (without considering potential additional savings since sous-vide products are storable and over-production can thus be used later).

We conclude that **impacts of plastic bags for sous-vide cooking** are higly variable and **need to be reduced to a minimum before sous-vide cooking is recommended as a way to reduce FW**, e.g. by **using larger bags of more than one meal,** by **using reusable bags** or **recycling waste bags**, or by using environmentally friendlier **alternatives**. According to Frei (2018) **biodegradable bags** primarily made of cellulose exist and comply with the requirements of heat and frost resistance and flexibility, but their production was stopped due to low demand. However, no information on the environmental impacts and the degree of biodegradability is available. Therefore, more research is needed to **assess the environmental and health impacts of possible alternatives** to conventional one-use plastic bags and to **make promising technologies marketable**.

The environmental impacts of plastic bags used in the progressive restaurant "Mein Küchenchef" are estimated in Table C.5 (bags of 20 g for 5 menus sent to municipal incineration). This is a maximum estimation, which does not consider that "Mein Küchenchef" saves plastic due to direct food supply from the farmers in reusable containers (Mein_Küchenchef, 2018).

Table C.4: Climate impact and aggregated ReCiPe impact of plastic bags for sous-vide cooking, per kg of polyethylene (PE). Scenarios of maximum and minimum impacts using different plastic bags (11-20g of plastic per bag) (Mein_Küchenchef, 2018), different types of polyethylene and different treatment methods (municipal incineration, recycling; without credits for substituted products). The impacts of plastic bags per meal are also shown as a share of the impacts of status quo FW in FSs per meal and the benefits from cooking a meat dish with sous-vide technique instead of conventional cooking (extended scenario II, section C.1.6).

Maximum scenario	*g CO2 eq*	*mPt*	*Dataset from the Ecoinvent 3.4 database*
Production PE (per kg)	2'269	333	***Polyethylene, low density**, granulate {**GLO**}| market for | Cut-off, S*
Treatment (per kg)	3'026	151	*Waste **polyethylene** {Europe without Switzerland}| treatment of waste polyethylene, **municipal incineration** | Cut-off, S*
Total (per kg)	5'296	484	
Bag weight: 11g per single-menu bag			
per meal:	58.3	5.3	
Compare:	240.0	25.4	impacts of status quo total avoidable FW, per meal
	24.3%	*21.0%*	*of status quo total avoidable FW*
	90.7	9.8	impacts of status quo overproduction and buffet surplus, per meal
	64.2%	*54.4%*	*of status quo overproduction and buffet surplus*
	105.4	10.8	savings by cooking meat with sous-vide technique (extended scenario II), per meal with 130g meat
	55.3%	*49.5%*	*of savings by cooking meat with sous-vide technique*

Minimum scenario	*g CO2 eq*	*mPt*	*Dataset from the Ecoinvent 3.4 database*
Production PE (per kg)	1'927	310	***Polyethylene, linear low density**, granulate {RER}| production | Cut-off, S*
Treatment (per kg)	655	71	*Polyethylene, high density, granulate, **recycled** {Europe without Switzerland}| market for polyethylene, high density, granulate, recycled | Cut-off, S*
Total (per kg)	2'582	381	
Bag weight: 20g per 5-menu bag			
per meal:	10.3	1.5	
Compare:	240.0	25.4	impacts of status quo total avoidable FW, per meal
	4.3%	*6.0%*	*of status quo total avoidable FW*
	90.7	9.8	impacts of status quo overproduction and buffet surplus, per meal
	11.4%	*15.5%*	*of status quo overproduction and buffet surplus*
Bag weight: 20g per bag with 20 meat portions			
per meal:	2.6	0.4	
Compare:	105.4	10.8	savings by cooking meat with sous-vide technique (extended scenario II), per meal with 130g meat
	2.5%	*3.5%*	*of savings by cooking meat with sous-vide technique*

Table C.5: Climate impact and aggregated ReCiPe impacts of plastic bags for sous-vide cooking used in the progressive restaurant Mein Küchenchef, per kg of polyethylene (PE) and per meal.

C.1.8 Comparison with Beretta et al. (2017)

Compared to Beretta et al. (2017)'s estimation of FW in the FS sector this thesis includes additional case studies and recent literature (Table C.3). The resulting total FW amounts in Switzerland are higher (1 kt, Table C.3) than in our previous publication (114 kt). Accordingly, also the relative contribution of the FS sector to total FW is higher (6% of mass instead of 4%, 8% of metabolizable energy instead of 6%, 10% of climate impacts instead of 8%; Figure C.7).

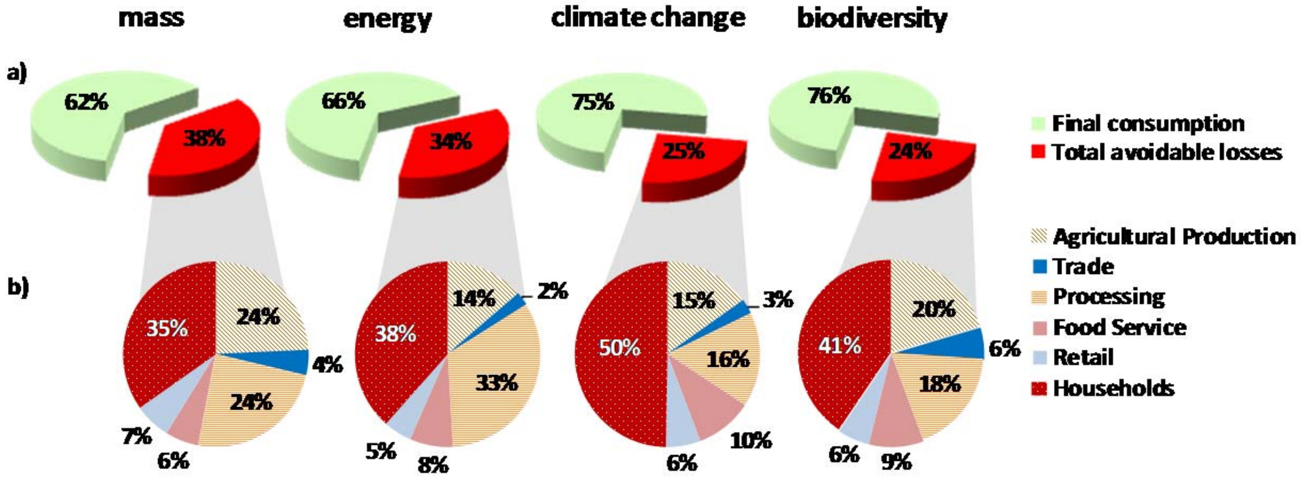


Figure C.7: (a) Share of FW and final consumption and (b) share of FW arising at the various stages of the food value chain in terms of mass, metabolizable energy, and impacts on climate change and global biodiversity, updated version based on Beretta et al. (2017).

C.1.9 Food category classification and unit environmental impacts

Table C.6 shows the environmental impacts per functional unit (1 kg) of (A) 112 food products and types of food classified into the 30 food categories used by Beretta et al. (2017), (B) 6 mixed food categories, and (C) 21 compound dishes. All wasted dishes which were quantified separately are listed in Table C.16 in the electronic appendix. For food category classifications they are classified according to their main ingredient 1 into one of the 30 food categories by Beretta et al. (2017) (number 1-30 in the first column of Table C.6 A) or to an aggregated (P, D, M, FS, ST, -; Table C.6 B) or combined food category (Table C.6 C). The combined food categories are classified according to the letters and numbers indicated in the first column in the table, which refer to one of the 30 food categories from Table C.6 A or to an aggregated food category from Table C.6 B.

Table C.6 (P.275ff): (A) Environmental impacts of 112 products (grey background) attributed to the 30 food categories modelled by Beretta et al. (2017) (red background) with country codes referring to the place of origin (IP = integrated production, a Swiss agricultural standard) and indication of the database (DB) used for the LCI (EI = Ecoinvent, WF = World Food LCA Database, AF = Agrifootprint, AB = Agribalyse, ZH = database from ZHAW). The preparation factors define the weight of the final relative to the initial product (>100% means water uptake and <100% water evaporation or removal of inedible parts) and are only indicated if they deviate from the factors modelled by Beretta et al. (2017). The right-hand columns show the unit environmental impacts per kg of food at the stage of agricultural production (AP) and at the stage of FSs. (B) Environmental impacts of aggregated food categories, referring to the average Swiss consumption mix. (C) Environmental impacts of combined food categories and compound dishes based on simplified recipes with ingredients from (A). The assumed composition by mass is indicated in percentages. For air imports the impacts differ substantially from their average food category. Therefore, the most important products imported by air (asparagus, beans, and papaya) are modelled with additional impacts from transport. Numbers in the first column define the food categories in Table (A) and letters the aggregated food categories in Table (B) (P = plant based products, D = dairy products and eggs, M = meat and fish, FV = fruits and vegetables, ST = starch), to which the combined food categories are attributed.

A Food category classification for LCI

Category	Products and food categories	DB	Preparation factor	Climate impacts		Environmental Scarcity 2013		RECIPE single score		Biodiversity impacts from land use	
				AP	FS	AP	FS	AP	FS	AP	FS
				kg CO2-eq/kg		1000 UBP/kg		mPt/kg		gPDF-eq/kg	
1	Table apples			0.27	**0.66**	0.91	**2.49**	30	**88**	5.7E-16	**6.2E-16**
1	Apple IP CH	EI		0.09	**0.47**	0.39	**1.93**	12	**69**	1.1E-15	**1.2E-15**
2	Apple juice			0.27	**1.03**	0.91	**2.89**	30	**118**	5.7E-16	**7.7E-16**
2	Apple IP CH	EI		0.09	**0.79**	0.39	**2.20**	12	**93**	1.1E-15	**1.5E-15**
3	Average fresh table fruits (except apples, exotic, citrus fruits)			0.21	**0.68**	1.04	**3.20**	25	**99**	1.2E-14	**1.7E-14**
3	Grape GLO	EI		0.20	**0.67**	0.57	**2.55**	24	**99**	6.1E-15	**8.3E-15**
3	Pear GLO	EI		0.33	**0.84**	0.87	**2.97**	34	**112**	2.1E-15	**2.8E-15**
3	Apricot FR	WF		0.13	**0.57**	1.74	**4.14**	18	**91**	4.6E-15	**6.3E-15**
3	Peach CH-mix	WF		0.16	**0.61**	1.47	**3.78**	21	**94**	3.4E-15	**4.6E-15**
4	Average fresh fruit juices (except apples, exotic, citrus fruits)			0.27	**1.01**	0.72	**2.73**	29	**119**	1.2E-14	**1.7E-14**
4	Pear GLO	EI		0.33	**1.10**	0.87	**2.94**	34	**126**	2.1E-15	**3.0E-15**
4	Grape GLO	EI		0.20	**0.92**	0.57	**2.51**	24	**112**	6.1E-15	**8.7E-15**
5	Berries			0.23	**0.59**	0.93	**2.49**	25	**82**	4.7E-15	**5.3E-15**
5	Kiwi GLO	EI		0.42	**0.80**	1.05	**2.63**	48	**108**	7.4E-15	**8.2E-15**
5	Strawberry GLO	EI		1.57	**2.09**	2.34	**4.07**	186	**262**	1.3E-14	**1.4E-14**
6	Exotic and citrus table fruits			0.19	**1.11**	1.25	**3.48**	22	**139**	1.7E-15	**1.9E-15**
6	Avocado GLO	EI		0.65	**1.61**	2.96	**5.40**	76	**200**	4.5E-14	**5.1E-14**
6	Banana GLO	EI		0.07	**0.97**	0.55	**2.70**	12	**128**	9.2E-14	**1.0E-13**
6	Citrus GLO	EI		0.18	**1.10**	0.76	**2.93**	20	**137**	1.2E-13	**1.3E-13**
6	Papaya GLO	EI		0.13	**1.04**	0.45	**2.58**	14	**130**	2.6E-14	**2.9E-14**
6	Pineapple GLO	EI		0.09	**0.99**	0.50	**2.64**	10	**125**	4.5E-14	**5.0E-14**
6	Mandarin GLO	WF		0.27	**1.19**	2.10	**4.44**	33	**151**	9.6E-15	**1.1E-14**
6	Orange fresh grade ES	WF		0.16	**1.06**	1.05	**3.25**	18	**134**	9.6E-15	**1.1E-14**
7	Exotic and citrus fruit juices			0.10	**1.48**	1.00	**5.30**	13	**192**	1.7E-15	**3.8E-15**
7	Citrus GLO	EI		0.18	**1.67**	0.76	**4.76**	20	**210**	1.2E-13	**2.6E-13**
7	Orange processing grade CH-mix	WF		0.10	**1.47**	0.77	**4.79**	12	**191**	9.6E-15	**2.2E-14**
8	Canned fruits			0.14	**0.40**	0.78	**5.68**	16	**120**	1.2E-14	**6.2E-14**
8	Pear GLO	EI		0.33	**1.35**	0.87	**6.14**	34	**209**	2.1E-15	**1.1E-14**
8	Pineapple GLO	EI		0.09	**0.12**	0.50	**4.27**	10	**87**	4.5E-14	**2.2E-13**
8	Apricot FR	WF		0.13	**0.37**	1.74	**10.49**	18	**131**	4.6E-15	**2.3E-14**
8	Peach CH-mix	WF		0.16	**0.49**	1.47	**9.17**	21	**143**	3.4E-15	**1.7E-14**
9	Potatoes			0.09	**0.54**	0.85	**2.64**	11	**75**	3.6E-16	**4.4E-16**
9	Potato organic CH	EI		0.13	**0.58**	1.85	**3.86**	16	**81**	6.3E-16	**7.7E-16**
9	Potato IP CH	EI		0.09	**0.53**	0.67	**2.43**	10	**74**	6.3E-16	**7.7E-16**
10	Fresh vegetables			1.28	**2.15**	1.54	**3.67**	115	**223**	2.4E-15	**2.7E-15**
10	Aubergine greenhouse IP CH	EI		4.11	**5.41**	4.32	**6.89**	369	**516**	4.0E-14	**4.6E-14**
10	Broccoli open field IP CH	EI		0.34	**1.06**	1.10	**3.16**	35	**129**	2.6E-15	**3.0E-15**
10	Cauliflower open field IP CH	EI		0.30	**1.01**	0.97	**3.01**	30	**124**	2.6E-15	**3.0E-15**
10	Celery open field IP CH	EI		0.40	**1.13**	1.76	**3.92**	44	**140**	1.5E-15	**1.8E-15**
10	Cucumber greenhouse IP CH	EI		3.00	**4.13**	2.78	**5.10**	264	**395**	3.7E-15	**4.3E-15**
10	Fennel open field IP CH	EI		0.32	**1.03**	0.88	**2.90**	33	**127**	1.5E-15	**1.8E-15**
10	Green asparagus open field IP CH	EI		0.83	**1.62**	5.10	**7.79**	82	**184**	4.8E-14	**5.6E-14**
10	Green bell pepper greenhouse IP CH	EI		2.24	**3.25**	2.23	**4.47**	207	**328**	1.4E-15	**1.6E-15**
10	Iceberg lettuce open field IP CH	EI		0.14	**0.83**	0.54	**2.51**	15	**106**	1.4E-15	**1.6E-15**
10	Lettuce greenhouse IP CH	EI		6.22	**7.86**	5.69	**8.46**	548	**723**	1.4E-15	**1.6E-15**
10	Lettuce open field IP CH	EI		0.16	**0.85**	0.42	**2.37**	17	**109**	1.4E-15	**1.6E-15**
10	Melon open field GLO	EI		0.12	**0.80**	0.46	**2.42**	13	**104**	7.6E-15	**8.8E-15**
10	Radish open field IP GLO	EI		7.13	**8.91**	6.48	**9.37**	625	**812**	1.7E-14	**2.0E-14**
10	Spinach open field IP CH	EI		0.09	**0.77**	0.32	**2.25**	9	**100**	5.1E-15	**5.9E-15**
10	Tomato greenhouse IP CH	EI		1.40	**2.29**	1.50	**3.62**	127	**236**	1.4E-15	**1.6E-15**
10	White asparagus open filed IP CH	EI		1.94	**2.91**	3.06	**5.42**	155	**268**	4.8E-14	**5.6E-14**
10	Zucchini open fied IP CH	EI		0.18	**0.87**	0.48	**2.44**	20	**112**	3.7E-15	**4.3E-15**
11	Legumes			0.53	**1.10**	3.33	**5.55**	50	**127**	2.4E-15	**2.7E-15**
11	Fava bean organic CH	EI		0.66	**1.25**	3.61	**5.88**	66	**146**	8.1E-14	**9.3E-14**
11	Fava bean IP CH	EI		0.51	**1.07**	3.28	**5.49**	47	**124**	8.1E-14	**9.3E-14**
12	Other storable vegetables			0.35	**0.84**	0.79	**2.52**	38	**107**	2.4E-15	**2.7E-15**
12	Cabbage red open field IP CH	EI		0.26	**0.74**	1.07	**2.85**	29	**97**	1.5E-15	**1.8E-15**
12	Cabbage white open field IP CH	EI		0.26	**0.73**	1.05	**2.83**	28	**96**	1.5E-15	**1.8E-15**
12	Carrot open field IP CH	EI		0.08	**0.53**	0.80	**2.54**	24	**91**	6.0E-16	**7.0E-16**
12	Onion open field IP CH	EI		0.19	**0.65**	0.80	**2.54**	22	**89**	9.6E-16	**1.1E-15**
12	Vanilla MG	WF		1.42	**2.07**	19.86	**24.58**	65	**138**	6.0E-11	**6.9E-11**

13	Processed vegetables			0.27	0.94	1.43	4.68	26	119	2.4E-15	5.1E-15
13	Fava bean organic CH	EI		0.66	1.78	3.61	9.36	66	205	8.1E-14	1.7E-13
13	Fava bean IP CH	EI		0.51	1.45	3.28	8.65	47	164	8.1E-14	1.7E-13
13	Carrot open field IP CH	WF		0.09	0.55	0.62	2.94	11	87	6.0E-16	1.3E-15
13	Spinach open field IP CH	EI		0.09	0.56	0.32	2.29	9	83	5.1E-15	1.1E-14
14	Bread and pastries			0.49	1.13	3.17	5.46	54	128	3.6E-15	4.1E-15
14	Barley organic CH	EI		0.36	0.99	3.86	6.24	49	122	5.4E-15	6.2E-15
14	Barley IP extensive CH	EI		0.44	1.08	2.63	4.83	47	120	5.4E-15	6.2E-15
14	Barley IP intensive CH	EI		0.38	1.01	2.59	4.79	41	113	5.4E-15	6.2E-15
14	Rye organic CH	EI		0.33	0.95	3.78	6.15	43	115	3.9E-15	4.5E-15
14	Rye IP extensive CH	EI		0.36	0.99	2.25	4.40	38	110	3.9E-15	4.5E-15
14	Rye IP intensive CH	EI		0.31	0.92	2.27	4.43	33	104	3.9E-15	4.5E-15
14	Wheat organic CH	EI		0.43	1.06	4.65	7.15	58	133	4.8E-15	5.5E-15
14	Wheat IP extensive CH	EI		0.49	1.13	2.73	4.95	51	124	4.8E-15	5.5E-15
14	Wheat IP intensive CH	EI		0.45	1.09	2.82	5.05	46	119	4.8E-15	5.5E-15
14	Oat GLO	WF		0.43	1.07	3.31	5.61	58	132	5.0E-15	5.8E-15
15	Pasta		210%	0.91	0.74	5.49	3.75	114	94	3.6E-15	2.0E-15
15	Durum wheat semolina GLO cooked	WF	210%	0.95	0.76	5.68	3.854	119	97	4.8E-15	2.6E-15
16	Rice		304%	2.01	1.06	4.34	2.31	146	89	1.1E-14	4.6E-15
16	Rice US/IN/... cooked	EI	304%	2.05	1.07	4.66	2.44	157	94	5.3E-14	2.2E-14
17	Maize			0.26	0.77	1.40	3.16	25	83	1.9E-15	3.7E-15
17	Maize organic CH	EI		0.49	0.84	2.69	3.64	55	99	4.2E-15	8.3E-15
17	Maize IP CH	EI		0.50	0.85	2.56	3.49	49	92	4.2E-15	8.3E-15
18	Sugar			0.04	0.94	0.19	2.54	4	102	5.4E-16	3.2E-15
18	Sugar from beet CH	EI		0.04	0.93	0.19	2.516	4	99	3.7E-16	2.2E-15
18	Sugarcane BR	EI		0.03	0.88	0.20	2.617	5	104	2.3E-14	1.4E-13
19	Vegetal oils and fats			1.23	2.98	5.21	12.40	115	281	9.5E-15	2.0E-14
19	Palm oil crude per kg refined GLO	EI		2.53	3.23	4.18	6.244	168	230	7.4E-14	8.2E-14
19	Rape oil crude CH	EI		1.67	2.29	10.89	13.682	185	248	7.0E-15	7.8E-15
19	Soybean oil crude CH	EI		1.83	2.46	10.14	12.850	178	240	2.5E-14	2.7E-14
19	Margarine 60% fat ES	WF		2.42	3.11	8.43	10.954	223	290	7.0E-15	7.8E-15
19	Olive for oil per kg oil GLO	WF		1.10	1.65	10.20	12.918	156	216	5.8E-14	6.4E-14
19	Sunflower for oil per kg oil GLO	WF		1.75	2.37	17.28	20.756	178	241	2.3E-13	2.6E-13
20	Nuts, seeds, oleiferous fruits			0.62	1.09	3.13	7.16	78	145	2.6E-14	5.3E-14
20	Coconut husked PH	EI	73% (nut shell)	0.78	0.78	4.55	4.550	89	89	2.5E-13	2.5E-13
20	Tofu organic GLO wo CA QC	EI	180%	0.78	0.24	3.46	1.068	76	23	2.5E-14	1.4E-14
20	Almonds GLO	WF	51% (nut shell)	2.20	4.07	11.34	22.614	264	496	4.2E-14	8.3E-14
20	Peanut GLO	WF	80% (nut shell)	1.70	1.26	10.28	8.369	168	126	1.5E-13	1.8E-13
20	Olives conv IT	EI	80% (stone)	0.71	0.49	2.30	2.134	93	68	5.8E-14	7.3E-14
20	Olives organic IT	EI	80% (stone)	0.79	0.55	6.60	5.495	257	196	5.8E-14	7.3E-14
21	Milk, other dairy			1.23	1.88	2.11	3.76	113	189	2.0E-15	2.0E-15
21	Milk IP CH	ZH		1.23	1.88	2.12	3.76	116	191	2.0E-15	2.0E-15
21	Milk organic CH	ZH		1.16	1.81	2.07	3.72	96	171	2.0E-15	2.0E-15
22	Cheese, whey			1.22	3.34	2.11	6.53	113	327	2.0E-15	5.0E-15
22	Cheese GLO	EI		7.38	7.69	13.82	15.118	591	637	2.0E-15	8.9E-15
22	Milk IP CH	ZH		1.23	1.56	2.12	3.44	116	163	2.0E-15	2.0E-15
22	Milk organic CH	ZH		1.16	1.49	2.07	3.40	96	143	2.0E-15	2.0E-15
23	Butter, buttermilk, skimmed milk			1.22	2.19	2.11	4.50	113	219	2.0E-15	2.1E-15
23	Butter GLO	EI		10.12	11.01	19.38	21.653	781	880	1.1E-14	1.2E-13
23	Buttermilk GLO	EI		4.46	5.35	8.54	10.812	344	443	1.1E-14	6.0E-15
23	Milk IP CH	ZH		1.23	1.88	2.12	3.764	116	191	1.1E-14	1.1E-14
23	Milk organic CH	ZH		1.16	1.81	2.07	3.716	96	171	1.1E-14	1.1E-14
24	Eggs without co-product poultry			4.50	6.34	10.62	15.20	450	647	4.6E-15	5.8E-15
24	Egg from laying hen NL	AF		5.27	7.31	11.52	16.32	467	669	3.2E-14	4.0E-14
24	Egg FR	AB		1.77	2.91	7.45	11.23	388	570	3.2E-14	4.0E-14
25	Meat from laying hens			3.22	8.40	7.07	19.07	285	768	5.0E-15	1.2E-14
25	Meat from laying hen	AF		5.31	8.45	11.60	19.10	471	772	4.3E-14	1.0E-13
26	Pork			4.16	6.93	10.69	18.27	399	682	5.2E-15	8.2E-15
26	Pork from pig fattening NL	AF		4.01	4.86	8.11	10.51	322	413	1.3E-14	2.1E-14
26	Pork incl offal GLO	WF		7.88	9.16	22.35	26.33	819	966	1.3E-14	2.1E-14
27	Poultry			4.13	9.90	8.50	20.97	735	1727	5.0E-15	1.1E-14
27	Poultry from broiler NL	AF		6.27	9.23	11.32	17.40	509	776	4.3E-14	9.6E-14
27	Poultry incl offal BR	WF		6.86	10.04	14.28	21.45	1297	1852	4.3E-14	9.6E-14
27	Poultry incl offal US	WF		3.54	5.50	12.83	19.47	369	585	4.3E-14	9.6E-14
28	Beef, horse, veal			8.40	21.39	15.96	41.41	698	1799	4.3E-14	1.1E-13
28	Beef incl offal GLO	WF		22.73	24.83	47.84	52.95	1925	2124	3.7E-13	9.2E-13
28	Beef incl offal intensive fattening IP CH	ZH		15.12	16.64	29.78	33.52	1251	1399	3.7E-13	9.2E-13
28	Beef incl offal Weidebeef CH	ZH		25.31	27.60	42.14	46.82	2051	2259	3.7E-13	9.2E-13
28	Horse meat IP CH	ZH		14.80	16.29	49.62	54.86	2017	2223	3.7E-13	9.2E-13
28	Veal incl offal combined fattening IP CH	ZH		30.83	33.54	49.67	54.91	2541	2786	3.7E-13	9.2E-13
28	Veal incl offal whole milk fattening IP CH	ZH		21.69	23.71	36.04	40.25	1808	1997	3.7E-13	9.2E-13
28	Veal inl offal whole milk fattening organic C	ZH		19.30	21.13	43.05	47.79	1798	1988	3.7E-13	9.2E-13
29	Fish, shellfish			2.76	3.60	7.02	9.50	370	480	4.8E-15	5.4E-15
29	Large trout conv FR	AB		2.40	3.19	6.85	9.30	366	475	2.4E-13	2.7E-13
29	Sea bass or bream conv in cage FR	AB		4.49	5.55	9.29	12.05	570	706	2.4E-13	2.7E-13
29	Small trout conv FR	AB		1.98	2.72	5.72	8.02	243	337	2.4E-13	2.7E-13
30	Cocoa, coffee, tea			8.54	9.68	48.36	52.25	826	949	2.6E-13	2.7E-13
30	Coffee CH-mix	EI		9.32	10.49	49.58	53.52	1049	1181	1.7E-12	1.8E-12
30	Cocoa bean for dark chocolate GLO	WF		9.12	10.29	92.90	98.71	663	779	3.1E-12	3.3E-12
30	Cocoa bean for milk chocolate GLO	WF		7.85	8.96	79.96	85.21	570	682	3.1E-12	3.3E-12
30	Tea dried CH-mix	WF		7.10	8.18	16.17	18.68	573	685	1.2E-12	1.2E-12
30	Dark chocolate ingredients CH	WF		0.83	1.64	20.95	23.66	90	181	3.1E-12	3.3E-12
30	Milk chocolate ingredients CH	WF		4.60	5.57	21.75	24.50	400	505	3.1E-12	3.3E-12

B Aggregated food categories (weighted by Swiss food consumption)

		kg CO2-eq/kg		1000 UBP/kg		mPt/kg		gPDF-eq/kg	
		AP	AS	AP	AS	AP	AS	AP	AS
P	All plant based products (1-14, 23)	0.57	1.48	2.24	5.05	56	163	6.7E-15	7.7E-15
D	All dairy products and eggs (15-18)	1.45	3.03	2.58	6.06	135	298	2.7E-15	5.2E-15
M	All meat (19-22)	5.38	11.59	11.60	24.80	549	1184	1.7E-14	4.1E-14
-	All food categories (1-23)	1.20	2.55	3.06	6.82	117	267	6.3E-15	1.0E-14
FV	Fruits, Vegetables (1-3, 6-8)	0.63	1.35	1.72	3.84	61	152	2.9E-15	3.5E-15
ST	Starch (10-12)	1.11	0.82	4.79	3.34	113	92	5.2E-15	2.8E-15

C Combined food categories and recipes

	Composition/weighing	kg CO2-eq/kg		1000 UBP/kg		mPt/kg		gPDF-eq/kg	
		AP	AS	AP	AS	AP	AS	AP	AS
- Sandwich meat	100%	2.23	**4.69**	5.77	**11.57**	227	**487**	7.9E-15	**1.5E-14**
Bread and pastries	50%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
All meat (19-22)	33%	5.38	**11.38**	11.60	**24.48**	549	**1169**	1.7E-14	**3.9E-14**
Butter, buttermilk, skimmed milk	17%	1.22	**2.19**	2.11	**4.51**	113	**219**	2.0E-15	**2.1E-15**
- Sandwich vegi	100%	0.88	**1.65**	2.45	**4.71**	84	**175**	2.9E-15	**3.3E-15**
Bread and pastries	50%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Fresh vegetables	33%	1.28	**2.15**	1.54	**3.67**	115	**223**	2.4E-15	**2.7E-15**
Butter, buttermilk, skimmed milk	17%	1.22	**2.19**	2.11	**4.51**	113	**219**	2.0E-15	**2.1E-15**
15 Cheese	447%	5.48	**8.39**	9.44	**16.81**	507	**845**	8.9E-15	**9.1E-15**
Milk, other dairy	447%	1.23	**1.88**	2.11	**3.76**	113	**189**	2.0E-15	**2.0E-15**
- Pizza	100%	2.60	**4.09**	5.37	**9.03**	236	**402**	4.7E-15	**9.2E-15**
Bread and pastries	30%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Tomato greenhouse IP CH	25%	1.40	**2.29**	1.50	**3.62**	127	**236**	1.4E-15	**1.6E-15**
Cheese GLO	15%	7.38	**7.69**	13.82	**15.12**	591	**637**	2.0E-15	**8.9E-15**
Fresh vegetables	15%	1.28	**2.15**	1.54	**3.67**	115	**223**	2.4E-15	**2.7E-15**
All meat (19-22)	15%	5.38	**11.38**	11.60	**24.48**	549	**1169**	1.7E-14	**3.9E-14**
6 Vegetables, Salad	100%	1.00	**1.76**	1.43	**3.54**	91	**189**	2.4E-15	**2.9E-15**
Fresh vegetables	69%	1.28	**2.15**	1.54	**3.67**	115	**223**	2.4E-15	**2.7E-15**
Legumes	3%	0.53	**1.10**	3.33	**5.55**	50	**127**	2.4E-15	**2.7E-15**
Other storable vegetables	21%	0.35	**0.83**	0.79	**2.52**	38	**106**	2.4E-15	**2.7E-15**
Processed vegetables	6%	0.27	**0.94**	1.43	**4.68**	26	**119**	2.4E-15	**5.1E-15**
2 Fruits	100%	0.20	**1.01**	1.08	**3.48**	23	**130**	3.0E-15	**4.4E-15**
Table apples	17%	0.27	**0.66**	0.91	**2.49**	30	**88**	5.7E-16	**6.2E-16**
Apple juice	8%	0.27	**1.03**	0.91	**2.89**	30	**118**	5.7E-16	**7.7E-16**
Average fresh table fruits (except apples, exotic, citrus fruits)	10%	0.21	**0.68**	1.04	**3.20**	25	**99**	1.2E-14	**1.7E-14**
Average fresh fruit juices (except apples, exotic, citrus fruits)	2%	0.27	**1.01**	0.72	**2.73**	29	**119**	1.2E-14	**1.7E-14**
Berries	5%	0.23	**0.59**	0.93	**2.49**	25	**82**	4.7E-15	**5.3E-15**
Exotic and citrus table fruits	42%	0.19	**1.11**	1.25	**3.49**	22	**139**	1.7E-15	**1.9E-15**
Exotic and citrus fruit juices	16%	0.10	**1.48**	1.00	**5.29**	13	**192**	1.7E-15	**3.8E-15**
Canned fruits	1%	0.14	**0.40**	0.78	**5.68**	16	**120**	1.2E-14	**6.2E-14**
- Cake	100%	1.34	**2.01**	5.34	**7.48**	123	**202**	2.9E-14	**3.6E-14**
Milk, other dairy	10%	1.23	**1.88**	2.11	**3.76**	113	**189**	2.0E-15	**2.0E-15**
Bread and pastries	40%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Sugar	15%	0.04	**0.93**	0.19	**2.53**	4	**100**	5.4E-16	**3.2E-15**
Coconut husked PH	5%	0.78	**0.78**	4.55	**4.55**	89	**89**	2.5E-13	**2.5E-13**
Butter GLO	5%	10.12	**11.02**	19.38	**21.66**	781	**881**	1.1E-14	**1.2E-13**
Cocoa, coffee, tea	5%	8.54	**9.69**	48.36	**52.26**	826	**949**	2.6E-13	**2.7E-13**
Average fresh table fruits (except apples, exotic, citrus fruits)	10%	0.21	**0.68**	1.04	**3.20**	25	**99**	1.2E-14	**1.7E-14**
Berries	5%	0.23	**0.59**	0.93	**2.49**	25	**82**	4.7E-15	**5.3E-15**
Exotic and citrus table fruits	5%	0.19	**1.11**	1.25	**3.49**	22	**139**	1.7E-15	**1.9E-15**
5 Mashed potatoes	18%	0.02	**0.10**	0.15	**0.47**	2	**14**	6.5E-17	**8.0E-17**
Potatoes	18%	0.09	**0.54**	0.85	**2.64**	11	**75**	3.6E-16	**4.4E-16**
21 Cooked Beef	143%	12.00	**30.56**	22.80	**59.16**	997	**2570**	6.1E-14	**1.5E-13**
Beef, horse, veal	143%	8.40	**21.39**	15.96	**41.41**	698	**1799**	4.3E-14	**1.1E-13**
19 Cooked Pork	147%	6.11	**10.18**	15.72	**26.87**	587	**1002**	7.7E-15	**1.2E-14**
Pork	147%	4.16	**6.92**	10.69	**18.27**	399	**681**	5.2E-15	**8.2E-15**
6 Asparagus by air	100%	0.83	**0.83**	5.10	**5.10**	82	**82**	4.8E-14	**5.6E-14**
Green asparagus open field IP CH	100%	0.83		5.10		82.02		4.8E-14	
air intercontinental	9671 tkm	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-01**	0.0E+00	**0.0E+00**
Lorry 16-32t	100 tkm	0.0E+00	**1.7E-04**	0.0E+00	**2.3E-04**	0.0E+00	**2.1E-02**	0.0E+00	**0.0E+00**
7.1 Beans by air	100%	0.66	**0.66**	3.61	**3.61**	66	**66**	8.1E-14	**9.3E-14**
Fava bean organic CH	100%	0.66		3.61		66.38		8.1E-14	
air intercontinental	9671 tkm	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-01**	0.0E+00	**0.0E+00**
Lorry 16-32t	100 tkm	0.0E+00	**1.7E-04**	0.0E+00	**2.3E-04**	0.0E+00	**2.1E-02**	0.0E+00	**0.0E+00**
3.2 Papaya by air	100%	0.13	**-**	0.45	**0.45**	14	**14**	2.6E-14	**2.9E-14**
Papaya GLO	100%	0.13		0.45		14.17		2.6E-14	
air intercontinental	9671 tkm	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-03**	0.0E+00	**1.1E-01**	0.0E+00	**0.0E+00**
Lorry 16-32t	100 tkm	0.0E+00	**1.7E-04**	0.0E+00	**2.3E-04**	0.0E+00	**2.1E-02**	0.0E+00	**0.0E+00**
- Dessert	100%	1.42	**2.08**	5.23	**7.40**	130	**209**	3.0E-14	**3.8E-14**
Milk, other dairy	20%	1.23	**1.88**	2.11	**3.76**	113	**189**	2.0E-15	**2.0E-15**
Bread and pastries	25%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Sugar	15%	0.04	**0.93**	0.19	**2.53**	4	**100**	5.4E-16	**3.2E-15**
Coconut husked PH	5%	0.78	**0.78**	4.55	**4.55**	89	**89**	2.5E-13	**2.5E-13**
Butter GLO	5%	10.12	**11.02**	19.38	**21.66**	781	**881**	1.1E-14	**1.2E-13**
Cocoa, coffee, tea	5%	8.54	**9.69**	48.36	**52.26**	826	**949**	2.6E-13	**2.7E-13**
Average fresh table fruits (except apples, exotic, citrus fruits)	10%	0.21	**0.68**	1.04	**3.20**	25	**99**	1.2E-14	**1.7E-14**
Berries	5%	0.23	**0.59**	0.93	**2.49**	25	**82**	4.7E-15	**5.3E-15**
Exotic and citrus table fruits	5%	0.19	**1.11**	1.25	**3.49**	22	**139**	1.7E-15	**1.9E-15**
Nuts, seeds, oleiferous fruits	5%	0.62	**1.09**	3.13	**7.16**	78	**145**	2.6E-14	**5.3E-14**
23 Espresso	30%	2.84	**3.20**	15.09	**16.29**	319	**360**	5.3E-13	**5.5E-13**
Coffee CH-mix	30%	9.32	**10.51**	49.58	**53.53**	1049	**1181**	1.7E-12	**1.8E-12**
9 Empanada vegetarian	100%	1.00	**1.71**	3.39	**5.58**	100	**182**	2.7E-15	**3.2E-15**
Bread and pastries	38%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Butter, buttermilk, skimmed milk	13%	1.22	**2.19**	2.11	**4.51**	113	**219**	2.0E-15	**2.1E-15**
Eggs without co-product poultry	13%	4.50	**6.34**	10.62	**15.20**	450	**647**	4.6E-15	**5.8E-15**
Maize	8%	0.26	**0.76**	1.40	**3.16**	25	**82**	1.9E-15	**3.7E-15**
Legumes	15%	0.53	**1.10**	3.33	**5.55**	50	**127**	2.4E-15	**2.7E-15**
2.2 Wine	140%	0.29	**0.93**	0.79	**3.57**	34	**138**	8.6E-15	**1.2E-14**
Grape GLO	140%	0.20	**0.66**	0.57	**2.55**	24	**99**	6.1E-15	**8.3E-15**
fv Muesli	100%	0.63	**1.23**	2.21	**4.18**	63	**138**	3.6E-15	**4.3E-15**
Milk, other dairy	30%	1.23	**1.88**	2.11	**3.76**	113	**189**	2.0E-15	**2.0E-15**
Average fresh table fruits (except apples, exotic, citrus fruits)	10%	0.21	**0.68**	1.04	**3.20**	25	**99**	1.2E-14	**1.7E-14**
Table apples	10%	0.27	**0.66**	0.91	**2.49**	30	**88**	5.7E-16	**6.2E-16**
Berries	5%	0.23	**0.59**	0.93	**2.49**	25	**82**	4.7E-15	**5.3E-15**
Exotic and citrus table fruits	5%	0.19	**1.11**	1.25	**3.49**	22	**139**	1.7E-15	**1.9E-15**
Bread and pastries	40%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
9 Puff Pastry	100%	1.07	**1.92**	3.65	**6.19**	108	**203**	3.3E-15	**3.8E-15**
Bread and pastries	65%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Butter, buttermilk, skimmed milk	25%	1.22	**2.19**	2.11	**4.51**	113	**219**	2.0E-15	**2.1E-15**
Eggs without co-product poultry	10%	4.50	**6.34**	10.62	**15.20**	450	**647**	4.6E-15	**5.8E-15**
19 Schnitzel	100%	3.51	**5.88**	8.83	**15.54**	335	**583**	6.0E-15	**8.8E-15**
Pork	60%	4.16	**6.92**	10.69	**18.27**	399	**681**	5.2E-15	**8.2E-15**
Bread and pastries	15%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Cheese	15%	5.48	**8.39**	9.44	**16.81**	507	**845**	8.9E-15	**9.1E-15**
Vegetal oils and fats	10%	1.23	**2.98**	5.21	**12.40**	115	**281**	9.5E-15	**2.0E-14**
fv Quiche veg	100%	1.22	**2.11**	3.09	**5.77**	118	**222**	3.3E-15	**4.3E-15**
Bread and pastries	30%	0.49	**1.13**	3.17	**5.46**	54	**128**	3.6E-15	**4.1E-15**
Eggs without co-product poultry	10%	4.50	**6.34**	10.62	**15.20**	450	**647**	4.6E-15	**5.8E-15**
Butter, buttermilk, skimmed milk	5%	1.22	**2.19**	2.11	**4.51**	113	**219**	2.0E-15	**2.1E-15**
Vegetal oils and fats	5%	1.23	**2.98**	5.21	**12.40**	115	**281**	9.5E-15	**2.0E-14**
Vegetables, Salad	50%	1.00	**1.76**	1.43	**3.54**	91	**189**	2.4E-15	**2.9E-15**

C.1.10 Environmental impacts of food services

In analogy to Beretta et al. (2017), water use and electricity consumption in FSs are estimated based on data from SV Group and include cooking, cooling, ventilation, lighting, and cleaning based on measurements in 15 gastronomic businesses (SV_Group_AG, 2017). For the transport distances we modelled half of the food delivered over an average distance of 90 km by a chilled 18 t lorry and the rest by local suppliers over an estimated distance of 45 km by 3.5-8 t lorry, half of it as chilled transport (SV_Group_AG, 2017). The impacts are equally allocated by mass to every type of food considering 500 g as an average portion of main meals (SV_Group_AG, 2017). For more details see Chapter B.

C.2 TABULATIONS OF THE MAIN RESULTS

C.2.1 Status quo food waste

Table C.7: *Status quo* amounts and environmental impacts per meal of individual case studies and weighted average including literature (for weighing and references see Table C.3, for graphical visualization Figure 4.1). Note: In City hotel 3 plate waste is included in over-production. This Table is also provided in Excel in the electronic appendix.

by food category	*Restaurant Buffet*	*Beer Hall Restaurant*	*Luxury Restaurant*	*University Canteen*	*Primary School*	*Secondary School 1*	*Secondary School 2*	*Secondary School 3*	*Secondary School 4*	*Hospital*	*Turistic Hotel 1*	*Turistic Hotel 2*	*City hotel 3*	*Hotel 4 Bf Buffet*	*Business 1 Buffet*	*Business 2 Plated*	*Business 3 mixed*	*Business 4 mixed*	*Weighted average*
Mass [g/meal]																			
mixed	1.7	27.8	8.3	0.0	68.9	60.1	91.3	59.7	184.1	105.6	23.5	48.5	6.3	23.6	0.4	0.0	74.9	95.4	28.6
sugar, cocoa, coffee	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.1	1.7	0.0	0.0	0.0	0.0	0.4
oils, fats	7.0	30.3	0.0	1.5	0.0	3.5	0.0	2.4	2.1	3.0	0.0	0.0	1.0	0.5	2.3	3.7	0.0	0.0	10.3
fruits	22.8	13.1	33.3	2.4	6.4	11.0	0.0	0.0	2.3	19.2	1.6	1.5	4.5	7.2	23.2	3.5	0.0	0.0	12.5
vegetables	52.4	4.9	9.5	13.3	31.0	19.1	8.2	18.9	5.6	73.0	12.0	22.7	13.6	7.4	69.0	33.7	0.0	0.0	26.8
bread, starch	18.9	20.1	81.7	10.7	21.6	18.4	11.7	16.6	6.6	39.8	9.7	11.5	19.8	0.0	61.2	3.2	0.0	0.0	19.4
dairy products, eggs	2.1	0.9	5.9	1.3	2.9	5.0	7.2	0.2	4.5	44.5	3.3	0.4	5.5	7.5	18.4	0.4	0.0	0.0	5.0
meat, fish	0.0	7.2	9.2	2.1	16.5	14.9	2.0	1.8	0.0	12.9	0.4	2.4	13.4	9.5	14.9	10.8	0.0	0.0	5.2
TOTAL edible FW	105.4	104.5	148.0	31.4	147.3	131.9	120.4	99.7	205.2	302.4	50.6	87.0	64.2	57.5	189.4	55.3	74.9	95.4	108.1
by origin																			
trim waste inedible	0.6	35.4	333.6	2.2	19.8	19.8	19.8	19.8	19.8	9.4	25.8	47.7	4.4	30.0	39.4	11.0	0.0	0.0	18.9
preference	36.5	41.7	27.9	0.6	9.9	9.9	9.9	9.9	9.9	4.7	12.9	23.9	2.2	9.8	32.9	6.6	0.0	0.0	25.9
overproduction	2.8	13.9	75.3	9.8	93.4	81.0	34.5	48.8	27.3	98.0	12.3	14.6	62.0	4.6	17.6	26.4	57.6	15.8	21.9
buffet surplus	62.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	116.5	0.0	4.8	28.4	22.2
plate waste	3.6	48.9	44.8	20.9	44.0	41.0	76.0	41.0	168.0	199.7	25.5	48.5		43.1	22.4	22.3	12.5	51.3	38.1
TOTAL FW	106.0	139.8	481.5	33.5	167.1	151.7	140.2	119.5	225.0	311.8	76.4	134.7	68.5	87.4	228.8	66.3	74.9	95.4	127.0
Climate impacts [g CO_2-eq/meal]																			
by food category																			
mixed	4.7	69.6	16.8	0.0	162.8	148.6	228.8	150.0	462.1	264.7	59.0	121.6	15.5	21.5	0.8	0.0	187.7	239.2	71.5
sugar, cocoa, coffee	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.2	0.0	0.0	1.4	3.0	0.0	0.0	0.0	0.0	0.8
oils, fats	3.6	89.1	0.0	4.3	0.0	7.3	0.0	6.7	6.2	7.1	0.0	0.0	0.8	1.6	2.8	15.0	0.0	0.0	25.3
fruits	27.0	7.2	48.1	3.2	5.7	10.9	0.0	0.0	1.5	23.1	1.6	1.5	4.4	7.3	22.9	4.8	0.0	0.0	12.2
vegetables	64.8	8.7	12.8	33.9	47.8	47.6	17.1	38.1	11.5	44.0	11.5	23.4	30.6	10.7	111.7	38.2	0.0	0.0	34.4
bread, starch	21.2	21.1	92.4	8.7	15.8	20.1	12.2	13.8	5.1	37.6	9.4	8.2	18.2	0.0	59.4	3.0	0.0	0.0	19.5
dairy products, eggs	7.8	6.9	53.9	3.3	6.5	38.1	16.0	1.4	11.2	130.8	22.8	2.3	33.8	59.5	59.4	3.3	0.0	0.0	18.8
meat, fish	0.0	82.2	56.7	25.9	56.7	228.6	12.5	6.6	0.0	147.3	5.0	27.1	113.6	62.9	193.5	62.1	0.0	0.0	55.4
TOTAL edible FW	129.2	284.8	280.6	79.3	295.2	501.4	286.6	216.6	497.6	668.8	109.3	184.1	218.2	166.7	450.4	126.3	187.7	239.2	238.0
by origin																			
trim waste inedible																			
preference	45.2	117.7	49.9	0.6	24.8	24.8	24.8	24.8	24.8	6.3	16.1	28.3	5.2	34.2	52.8	8.9	0.0	0.0	51.5
overproduction	3.7	34.8	85.2	21.9	160.1	373.8	71.3	89.1	51.8	231.1	33.2	34.2	213.0	37.4	60.8	56.8	144.3	39.5	59.5
buffet surplus	75.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	222.8	0.0	12.0	71.2	30.7
plate waste	5.2	132.3	145.5	56.8	110.3	102.8	190.5	102.8	421.1	431.5	59.9	121.6		95.0	114.1	60.7	31.4	128.4	96.2
TOTAL FW	129.2	284.8	280.6	79.3	295.2	501.4	286.6	216.6	497.6	668.8	109.3	184.1	218.2	166.7	450.4	126.3	187.7	239.2	238.0
Ecological scarcity [UBP/meal]																			
by food category																			
mixed	14	186	62	0	446	403	613	401	1237	709	158	325	43	58	3	0	502	640	192
sugar, cocoa, coffee	1	0	0	0	0	0	0	0	0	69	0	0	7	20	0	0	0	0	4
oils, fats	15	365	0	16	0	26	0	28	26	32	0	0	4	7	12	48	0	0	104
fruits	82	19	163	10	19	32	0	0	7	69	6	5	15	23	72	14	0	0	37
vegetables	170	17	37	59	102	91	34	86	21	103	56	103	55	23	262	74	0	0	87
bread, starch	81	75	444	34	71	79	45	48	22	167	45	39	69	0	215	15	0	0	75
dairy products, eggs	17	15	106	7	18	75	32	3	27	263	45	4	78	125	126	9	0	0	39
meat, fish	0	177	133	55	137	467	33	18	0	317	11	58	261	166	403	123	0	0	120
TOTAL edible FW	379	856	944	180	792	1173	757	583	1339	1729	321	536	533	422	1092	282	502	640	658
by origin																			
trim waste inedible																			
preference	120	438	165	2	66	66	66	66	66	18	65	111	18	91	131	25	0	0	173
overproduction	9	93	409	52	430	832	180	241	145	556	87	100	515	78	150	110	386	106	148
buffet surplus	236	0	0	0	0	0	0	0	0	0	0	0	0	0	563	0	32	191	90
plate waste	15	325	371	126	295	275	510	275	1127	1155	169	325		253	248	147	84	344	248
TOTAL FW	379	856	944	180	792	1173	757	583	1339	1729	321	536	533	422	1092	282	502	640	658
ReCiPe [µPt/meal]																			
by food category																			
mixed	464	7'328	1'687	0	17'204	15'641	24'085	15'787	48'640	27'866	6'206	12'799	1'597	2'266	84	0	19'752	25'173	7'516
sugar, cocoa, coffee	22	0	0	0	0	0	0	0	0	1'420	0	0	133	274	0	0	0	0	84
oils, fats	355	8'421	0	406	0	733	0	630	582	714	0	0	84	151	269	1'480	0	0	2'397
fruits	3'283	901	6'011	373	692	1'193	0	0	225	2'694	206	190	542	937	2'908	542	0	0	1'491
vegetables	7'613	931	1'448	3'395	5'247	4'846	1'759	3'967	1'194	4'808	1'440	2'868	3'156	1'200	12'123	4'056	0	0	3'895
bread, starch	2'326	2'436	10'434	950	1'950	2'567	1'391	1'455	592	4'236	1'104	1'039	1'964	0	6'320	356	0	0	2'202
dairy products, eggs	786	699	4'380	332	649	3'156	1'575	119	1'155	12'911	1'903	190	3'318	5'878	5'724	322	0	0	1'819
meat, fish	0	8'448	6'513	2'300	8'528	19'836	1'293	884	0	15'133	517	2'791	14'304	6'293	19'961	5'431	0	0	5'841
TOTAL edible FW	14'849	29'162	30'472	7'756	34'270	47'971	30'104	22'840	52'388	69'782	11'376	19'878	25'098	16'998	47'389	12'188	19'752	25'173	25'246
by origin																			
trim waste inedible																			
preference	5'484	11'483	6'518	74	2'612	2'612	2'612	2'612	2'612	708	1'920	3'367	531	3'525	5'922	1'005	0	0	5'434
overproduction	409	3'664	9'619	2'266	20'051	34'544	7'443	9'413	5'458	24'227	3'216	3'712	24'568	3'759	7'831	4'948	15'184	4'161	6'418
buffet surplus	8'387	0	0	0	0	0	0	0	0	0	0	0	0	0	23'132	0	1'264	7'492	3'343
plate waste	569	14'015	14'336	5'417	11'607	10'816	20'049	10'816	44'318	44'847	6'240	12'799		9'714	10'504	6'235	3'303	13'520	10'051
TOTAL FW	14'849	29'162	30'472	7'756	34'270	47'971	30'104	22'840	52'388	69'782	11'376	19'878	25'099	16'998	47'389	12'188	19'752	25'173	25'246
Biodiversity [10^{-16} gPDF-eq*a/meal]																			
by food category																			
mixed	0.5	2.7	3.0	0.0	6.4	5.8	8.8	5.7	17.7	10.1	2.3	4.7	1.1	0.8	0.1	0.0	7.2	9.2	2.9
sugar, cocoa, coffee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.4	5.3	0.0	0.0	0.0	0.0	0.2
oils, fats	0.8	5.8	0.0	0.2	0.0	0.7	0.0	0.4	0.4	0.9	0.0	0.0	0.3	0.1	0.6	0.6	0.0	0.0	1.9
fruits	3.2	8.7	1.2	0.1	0.4	0.2	0.0	0.0	0.4	0.7	0.1	0.1	1.5	1.2	3.5	0.2	0.0	0.0	3.5
vegetables	2.1	0.1	0.3	0.3	0.6	1.1	0.3	0.7	0.1	0.9	0.6	1.1	0.7	0.3	4.1	0.4	0.0	0.0	1.0
bread, starch	0.7	0.4	3.3	0.3	0.4	0.5	0.3	0.5	0.2	1.3	0.3	0.2	0.7	0.0	1.9	0.1	0.0	0.0	0.5
dairy products, eggs	2.1	0.1	3.4	0.0	0.4	0.4	0.2	0.0	3.7	2.1	0.3	0.0	0.3	1.3	1.2	0.2	0.0	0.0	0.9
meat, fish	0.0	2.8	1.5	1.0	4.2	10.6	0.2	0.1	0.0	5.0	0.2	0.9	2.3	0.8	7.2	3.0	0.0	0.0	1.9
TOTAL edible FW	9.4	20.6	12.8	2.1	12.4	19.3	9.6	7.4	22.4	24.4	3.7	6.9	7.3	9.6	18.6	4.4	7.2	9.2	12.8
by origin																			
trim waste inedible																			
preference	1.5	6.8	1.1	0.0	0.9	0.9	0.9	0.9	0.9	0.2	0.7	1.2	0.6	1.4	2.4	0.2	0.0	0.0	2.6
overproduction	0.0	1.3	3.1	0.3	7.2	14.5	1.4	2.6	5.4	7.1	0.8	1.1	6.8	0.4	1.1	2.6	5.5	1.5	2.1
buffet surplus	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.0	0.5	2.7	2.4
plate waste	0.5	12.4	8.6	1.7	4.2	3.9	7.3	3.9	16.1	17.2	2.2	4.7		7.8	5.4	1.6	1.2	4.9	5.8
TOTAL FW	9.4	20.6	12.8	2.1	12.4	19.3	9.6	7.4	22.4	24.4	3.7	6.9	7.3	9.6	18.6	4.4	7.2	9.2	12.8

C.2.2 Reduction scenarios

Table C.8: *(1) Status quo* FW amounts and environmental impacts per meal and *(2) base reduction scenario* in each subsector, based on the average of the case studies analysed in this thesis (Table C.1), and weighted average (Ø, including all studies in Table C.3). Additionally, we included the progressive restaurant "Mein Küchenchef". The reduction in % of status quo is shown at the bottom for each subsector, for the progressive restaurant "Mein Küchenchef" (values below -100% mean that not only FW in the restaurant, but also in the supply chain is avoided), and for the weighted average in Europe (Ø) and Switzerland (CH Ø) (differences due to variable shares of the subsectors, Figure C.5 and Figure C.6). Graphical visualisation in Figure 4.5 and Figure 4.7. Environmental impacts from packaging are not included. This Table is also provided in Excel in the electronic appendix.

	Care 1	Care 2	Business 1	Business 2	Education 1	Education 2	Hotels 1	Hotels 2	Restaurants 1	Restaurants 2	Mein Küchenchef	Ø 1	Ø 2	
Mass [g/meal]														
by food category														
mixed	105.6	100.0	0.3	0.0	101.1	61.9	26.1	20.1	14.7	5.4	-2.3	28.6	17.8	
sugar, cocoa, coffee	4.2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.1	
oils, fats	3.0	2.2	1.5	3.1	1.4	1.3	0.3	0.4	18.7	18.2	0.0	10.3	10.0	
fruits	19.2	11.2	14.7	2.9	4.9	0.4	2.5	1.1	17.9	11.9	0.0	12.5	7.2	
vegetables	73.0	33.8	43.7	28.1	16.0	17.5	16.1	11.4	28.7	24.1	-105.0	26.8	20.3	
bread, starch	39.8	20.4	38.7	2.7	14.6	12.6	13.7	7.4	19.5	5.5	-10.6	19.4	6.7	
dairy products, eggs	44.5	29.8	11.6	0.3	4.9	3.2	3.0	1.2	1.5	0.2	0.0	5.0	2.1	
meat, fish	12.9	3.6	9.4	9.0	8.3	5.4	5.4	1.3	3.6	1.6	0.0	5.2	2.5	
TOTAL edible FW	302.4	203.9	119.9	46.1	151.2	102.3	67.3	42.8	104.9	66.9	-117.9	108.1	66.7	-38%
by origin														
trim waste inedible	9.4	5.7	24.9	9.2	19.8	19.8	26.0	26.3	18.0	12.0	8.3	18.9	14.2	
preference	4.7	2.8	20.8	5.5	9.9	9.9	13.0	13.1	39.1	35.6	-117.9	25.9	22.5	
overproduction	98.0	42.2	11.1	22.0	59.1	49.0	29.6	10.8	8.4	4.0	-2.3	21.9	12.9	
buffet surplus	0.0	0.0	73.8	0.0	0.0	0.0	0.0	0.0	31.2	7.0	0.0	22.2	3.7	
plate waste	199.7	158.9	14.2	18.6	82.3	43.4	24.7	18.9	26.3	20.3	2.3	38.1	27.7	
TOTAL FW	302.4	209.6	144.8	55.3	171.0	122.1	93.2	69.2	122.9	78.9	-109.5	127.0	80.9	
Climate impacts [g CO_2-eq/meal]														
by food category														
mixed	264.7	250.7	0.5	0.0	250.6	153.4	65.3	50.1	37.1	13.3	-5.7	71.5	45.0	
sugar, cocoa, coffee	14.2	9.9	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	0.8	0.5	
oils, fats	7.1	5.0	1.7	12.5	3.4	3.4	0.3	0.3	46.3	49.1	0.0	25.3	27.5	
fruits	23.1	13.3	14.5	4.0	4.5	0.4	2.5	1.1	17.1	9.1	0.0	12.2	6.0	
vegetables	44.0	21.3	70.7	31.8	31.0	34.5	21.8	12.2	36.8	32.0	-103.1	34.4	26.3	
bread, starch	37.6	20.2	37.6	2.5	13.3	11.7	11.9	6.6	21.1	5.9	-2.5	19.5	6.8	
dairy products, eggs	130.8	87.6	37.6	2.7	17.9	12.6	19.6	6.4	7.3	0.4	0.0	18.8	7.3	
meat, fish	147.3	40.4	122.5	51.7	74.5	42.3	48.6	12.8	41.1	17.7	0.0	55.4	22.2	
TOTAL edible FW	668.8	448.3	285.1	105.2	395.2	258.4	170.5	89.4	207.0	127.5	-111.4	238.0	141.5	-41%
by origin														
trim waste inedible														
preference	6.3	3.8	33.4	7.4	24.8	24.8	16.5	19.0	81.4	73.2	-107.6	51.5	45.5	
overproduction	231.1	79.5	38.5	47.3	164.2	124.7	93.5	24.1	19.3	8.2	-5.7	59.5	29.7	
buffet surplus	0.0	0.0	141.0	0.0	0.0	0.0	0.0	0.0	37.5	7.6	0.0	30.7	4.0	
plate waste	431.5	365.0	72.2	50.5	206.1	108.8	60.5	46.8	68.8	38.5	1.9	96.2	62.5	
TOTAL FW	668.8	448.3	285.1	105.2	395.2	258.4	170.5	89.4	207.0	127.5	-111.4	238.0	141.6	
Ecological scarcity [UBP/meal]														
by food category														
mixed	709	671	2	0	675	413	176	135	100	36	-15	192	122	
sugar, cocoa, coffee	69	48	0	0	0	0	2	0	0	0	0	4	2	
oils, fats	32	23	7	40	13	12	1	1	190	201	0	104	112	
fruits	69	40	46	11	15	1	9	4	51	27	0	37	18	
vegetables	103	51	166	61	62	72	72	52	94	79	-143	87	66	
bread, starch	167	92	136	12	54	42	51	30	78	23	-17	75	28	
dairy products, eggs	263	176	80	7	38	27	42	13	16	1	0	39	15	
meat, fish	317	87	255	103	159	93	110	28	88	38	0	120	47	
TOTAL edible FW	1729	1187	692	235	1015	660	463	264	617	404	-175	658	410	-38%
by origin														
trim waste inedible														
preference	18	11	83	21	66	66	65	68	279	261	-166	173	160	
overproduction	556	196	95	92	397	302	234	74	51	21	-15	148	74	
buffet surplus	0	0	356	0	0	0	0	0	118	25	0	90	13	
plate waste	1155	980	157	122	552	291	165	125	170	97	6	248	163	
TOTAL FW	1729	1187	692	235	1015	660	463	264	617	404	-175	658	410	
ReCiPe [µPt/meal]														
by food category														
mixed	27'866	26'384	53	0	26'392	16'156	6'867	5'267	3'896	1'400	-600	7'516	4'738	
sugar, cocoa, coffee	1'420	992	0	0	0	0	44	0	11	0	0	84	49	
oils, fats	714	501	170	1'233	329	324	28	27	4'388	4'647	0	2'397	2'605	
fruits	2'694	1'559	1'841	452	528	47	313	135	2'092	1'142	0	1'491	743	
vegetables	4'808	2'332	7'674	3'378	3'262	3'786	2'488	1'477	4'272	3'719	-9'395	3'895	3'014	
bread, starch	4'236	2'275	4'001	296	1'625	1'251	1'369	784	2'381	653	-208	2'202	759	
dairy products, eggs	12'911	8'641	3'623	269	1'634	1'136	1'804	575	742	40	0	1'819	694	
meat, fish	15'133	4'155	12'635	4'524	7'414	6'272	5'871	1'327	4'224	1'815	0	5'841	2'426	
TOTAL edible FW	69'782	46'839	29'996	10'151	41'183	28'973	18'784	9'592	22'005	13'417	-10'203	25'246	15'029	-40%
by origin														
trim waste inedible														
preference	708	427	3'749	837	2'612	2'612	1'939	2'167	8'484	7'585	-9'809	5'434	4'764	
overproduction	24'227	8'390	4'957	4'121	16'874	14'904	10'499	2'556	2'036	874	-604	6'418	3'254	
buffet surplus	0	0	14'642	0	0	0	0	0	4'193	834	0	3'343	439	
plate waste	44'847	38'022	6'649	5'193	21'697	11'457	6'346	4'927	7'292	4'125	210	10'051	6'583	
TOTAL FW	69'782	46'839	29'996	10'151	41'183	28'973	18'784	9'592	22'005	13'417	-10'203	25'246	15'029	
Biodiversity [10^{-16} gPDF*a-eq/meal]														
by food category														
mixed	10.1	9.6	0.1	0.0	9.7	5.9	2.7	2.1	1.6	0.6	-0.2	2.9	1.8	
sugar, cocoa, coffee	3.2	2.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.1	
oils, fats	0.9	0.7	0.4	0.5	0.3	0.2	0.1	0.1	3.3	3.2	0.0	1.9	1.8	
fruits	0.7	0.4	2.2	0.2	0.3	0.0	0.5	0.1	6.0	6.1	0.0	3.5	3.3	
vegetables	0.9	0.4	2.6	0.3	0.5	0.7	0.8	0.6	1.1	0.8	-2.5	1.0	0.7	
bread, starch	1.3	0.7	1.2	0.1	0.3	0.6	0.4	0.2	0.5	0.2	-0.4	0.5	0.2	
dairy products, eggs	2.1	1.4	0.8	0.2	1.2	0.2	0.2	0.1	1.1	0.4	0.0	0.9	0.3	
meat, fish	5.0	1.4	4.6	2.5	3.7	0.7	1.1	0.4	1.4	0.6	0.0	1.9	0.7	
TOTAL edible FW	24.4	16.9	11.8	3.7	16.0	8.3	6.0	3.5	15.0	11.9	-3.1	12.8	8.9	-30%
by origin														
trim waste inedible														
preference	0.2	0.1	1.5	0.2	0.9	0.9	0.8	1.7	4.1	3.9	-3.0	2.6	2.5	
overproduction	7.1	2.3	0.7	2.2	7.1	3.2	2.9	1.0	0.7	0.3	-0.2	2.1	1.0	
buffet surplus	0.0	0.0	6.2	0.0	0.0	0.0	0.0	0.0	3.7	0.9	0.0	2.4	0.5	
plate waste	17.2	14.5	3.4	1.4	7.9	4.2	2.3	1.8	6.5	6.8	0.1	5.8	5.2	
TOTAL FW	24.4	16.9	11.8	3.7	16.0	8.3	6.0	3.5	15.0	11.9	-3.1	12.8	8.9	

Reduction in % of status quo food waste in food services

	Care	Business	Education	Hotels	Restaurants	Mein K.	Ø	CH Ø
Mass	-33%	-62%	-32%	-36%	-36%	-212%	-38%	-36%
Climate	-33%	-63%	-35%	-47%	-38%	-154%	-41%	-39%
Ecological scarcity	-31%	-66%	-35%	-42%	-34%	-128%	-38%	-36%
ReCiPe	-33%	-66%	-30%	-49%	-39%	-146%	-40%	-38%
Biodiversity	-31%	-69%	-48%	-41%	-20%	-121%	-30%	-29%

Table C.9: Amount of total edible FW and plate waste in (1) the *status quo* and (2) the *base reduction scenario* in each subsector and weighted average (Ø). The numbers in [kg/person/year] and [g/person/day] are based on the number of meals an average Swiss person consumes in the FS sector (Figure C.5). The range of the percentages depends on the assumption of an average served portion, ranging from 450g/meal (Borstel et al., 2017) to 500g/meal (SV Group AG, 2017).

	Care 1	Care 2	Business 1	Business 2	Education 1	Education 2	Hotels 1	Hotels 2	Restaurants 1	Restaurants 2	Mein Küchenchef	Ø 1	Ø 2
Mass of total edible FW													
[g/meal]	302.4	203.9	119.9	46.1	151.2	102.3	67.3	42.8	104.9	66.9	-117.9	108.1	66.7
[kg/person/year]	51.1	34.5	20.3	7.8	25.6	17.3	11.4	7.2	17.7	11.3	-19.9	18.3	11.3
[g/person/day]	140	94	56	21	70	47	31	20	49	31	-55	50	31
% of input (purchases)	50-55%	37-41%	19-21%	9%	26-28%	18-19%	12-13%	8-9%	18-19%	12-13%	30-35%	18-20%	12-13%
Mass of plate waste													
[g/meal]	199.7	158.9	14.2	18.6	82.3	43.4	24.7	18.9	26.3	20.3	2.3	38.1	27.7
[kg/person/year]	33.8	26.9	2.4	3.1	13.9	7.3	4.2	3.2	4.4	3.4	0.4	6.4	4.7
[g/person/day]	93	74	7	9	38	20	11	9	12	9	1.1	18	13
% of served	25-27%	23-24%	2%	3-4%	12-13%	7-8%	4-5%	3-4%	4-5%	4%	0.6-0.7%	6-7%	5%

Table C.10: Amounts, climate, and biodiversity impacts of status quo FW, including and excluding the supply chain, of the FW reduction in the *base scenario* and of the additional FW reduction in the *extended scenarios* by using 50% non-marketable vegetables, which would otherwise be wasted. In the *extended scenario II* cooking losses are additionally reduced by cooking 70% of the meat and fish with sous-vide technique, resulting in 4.3 g/meal lower meat and fish consumption needed for the same dishes. To compensate for the lower calorific content of the meat and fish dishes prepared with sous-vide technique, 6.3 g/meal higher average food consumption is modelled (section C.1.6). In this Table only the net difference in food consumption is shown (+2 g/meal).

Food waste reduction scenarios		g/meal		g CO_2-eq/meal		10^{-16} gPDF-eq*a/meal
Status quo food waste in food services		108		238		12.8
Status quo food waste across the entire supply chain	*100%*	252	*100%*	380	*100%*	20.0
Reduction of the base scenario	*-16%*	-41	*-25%*	-96	*-19%*	-3.9
Reduction using 50% non-marketable vegetables	*-13%*	-34	*-11%*	-41	*-4%*	-0.9
Reduction with sous-vide cooking of 70% of the meat	*1%*	2	*-7%*	-28	*-3%*	-0.7
Total reduction in the extended scenario	*-30%*	-75	*-36%*	-138	*-24%*	-4.7
Total reduction in the extended scenario II	*-29%*	-73	*-44%*	-167	*-27%*	-5.4

C.2.3 Extrapolation to Switzerland: amounts, climate, biodiversity impacts, ReCiPe, ecological scarcity

Table C.11: Tabulation of data shown in Figure C.8 and in Figure 4.8: Amounts and climate, biodiversity, and aggregated environmental impacts (ReCiPe and method of ecological scarcity) of total FW in Swiss FSs in the *status quo* and the *base reduction scenario*. All values are also shown as percentage of the status quo of the whole Swiss FS sector (CH FS sector). The bottom lines display the number of meals consumed in each subsector (Figure C.5).

		Restaurants	Education	Health care	Hotels	Staff catering	CH FS sector
Status quo	*kt*	93.6	31.7	19.5	12.7	6.8	164.3
Reduction Sc.	*kt*	59.6	21.5	13.1	8.1	2.6	105.0
Status quo	*% mass*	57%	19%	12%	8%	4%	100%
Reduction scenario	*% mass*	36%	13%	8%	5%	2%	64%
Reduction	*% mass*	-21%	-6%	-4%	-3%	-3%	**-36%**
Status quo	*kt CO_2-eq*	184.6	82.9	43.1	32.3	16.1	359.0
Reduction Sc.	*kt CO_2-eq*	113.7	54.2	28.9	17.0	5.9	219.8
Status quo	*% CO_2-eq*	51%	23%	12%	9%	4%	100%
Reduction Sc.	*% CO_2-eq*	32%	15%	8%	5%	2%	61%
Reduction of impacts	*% CO_2-eq*	-20%	-8%	-4%	-4%	-3%	**-39%**
Status quo	*gPDF-eq*a*	1.3E-06	3.3E-07	1.6E-07	1.1E-07	6.6E-08	2.0E-06
Reduction Sc.	*gPDF-eq*a*	1.1E-06	1.7E-07	1.1E-07	6.7E-08	2.1E-08	1.4E-06
Status quo	*% biodiversity*	67%	17%	8%	6%	3%	100%
Reduction Sc.	*% biodiversity*	53%	9%	5%	3%	1%	71%
Reduction of impacts	*% biodiversity*	-14%	-8%	-2%	-2%	-2%	**-29%**
Status quo	*kPt*	19.6	8.6	4.5	3.6	1.7	38.0
Reduction Sc.	*kPt*	12.0	6.1	3.0	1.8	0.6	23.5
Status quo	*% ReCiPe*	52%	23%	12%	9%	4%	100%
Reduction Sc.	*% ReCiPe*	31%	16%	8%	5%	2%	62%
Reduction of impacts	*% ReCiPe*	-20%	-7%	-4%	-5%	-3%	**-38%**
Status quo	*mio UBP*	550.36	213.01	111.43	87.76	38.96	1'001.52
Reduction Sc.	*mio UBP*	360.53	138.49	76.51	50.58	13.25	639.36
Status quo	*% UBP*	55%	21%	11%	9%	4%	100%
Reduction Sc.	*% UBP*	36%	14%	8%	5%	1%	64%
Reduction of impacts	*% UBP*	-19%	-7%	-3%	-4%	-3%	**-36%**
No. of meals	*mio meals*	732	259	196	140	108	1'435
	% meals	51%	18%	14%	10%	8%	100%

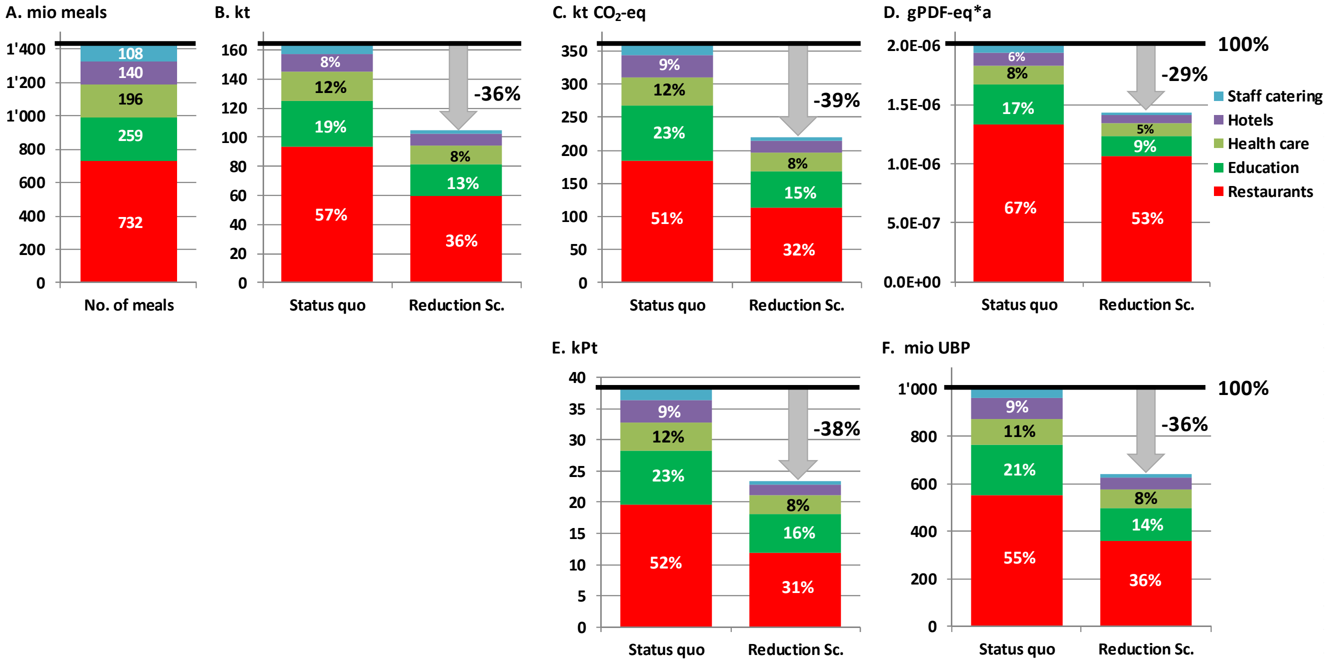


Figure C.8: (A.) Number of meals estimated in each subsector in Switzerland and (B.) comparison of FW amounts, (C.) climate impacts, (D.) biodiversity impacts, (E.) aggregated impacts with the method of ReCiPe, and (F.) with the Swiss method of ecological Scarcity in the *status quo* versus the *base reduction scenario*. *Status quo* FW is based on averages per meal in each subsector (Figure 6), the *reduction scenario* on the relative reduction in each subsector (Figure 5).

C.3 CASE STUDIES FOR THE BASE SCENARIO OF FOOD WASTE REDUCTION

C.3.1 Complete results of case studies A. – K.

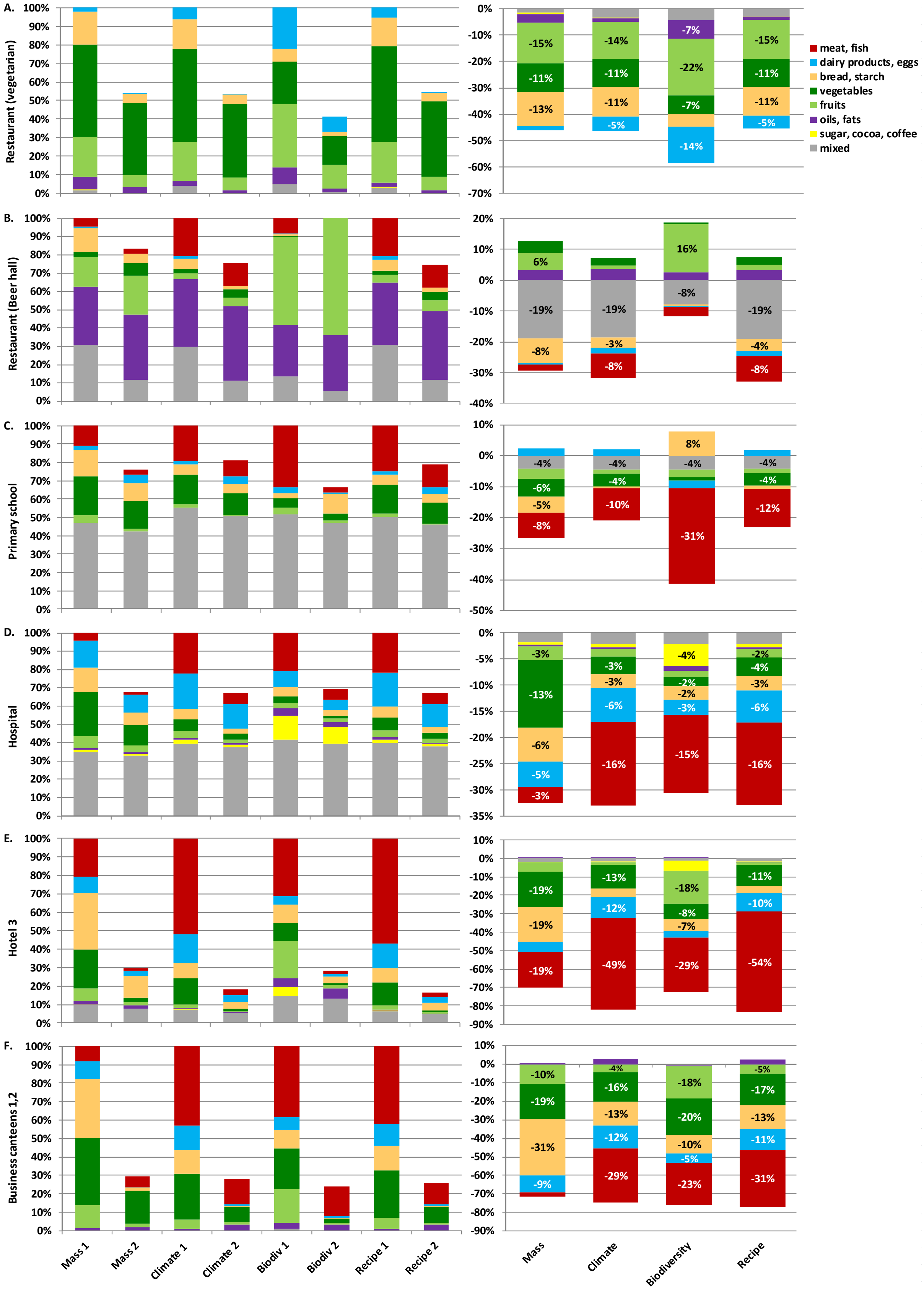


Figure C.9: Amounts and environmental impacts of FW in the case studies A. to F. before and after implementation of measures for reduction (left graphs) and reduction relative to status quo, achieved after implementation of measures (right graphs). For a description of the case studies see chapter 4.3.1.2.

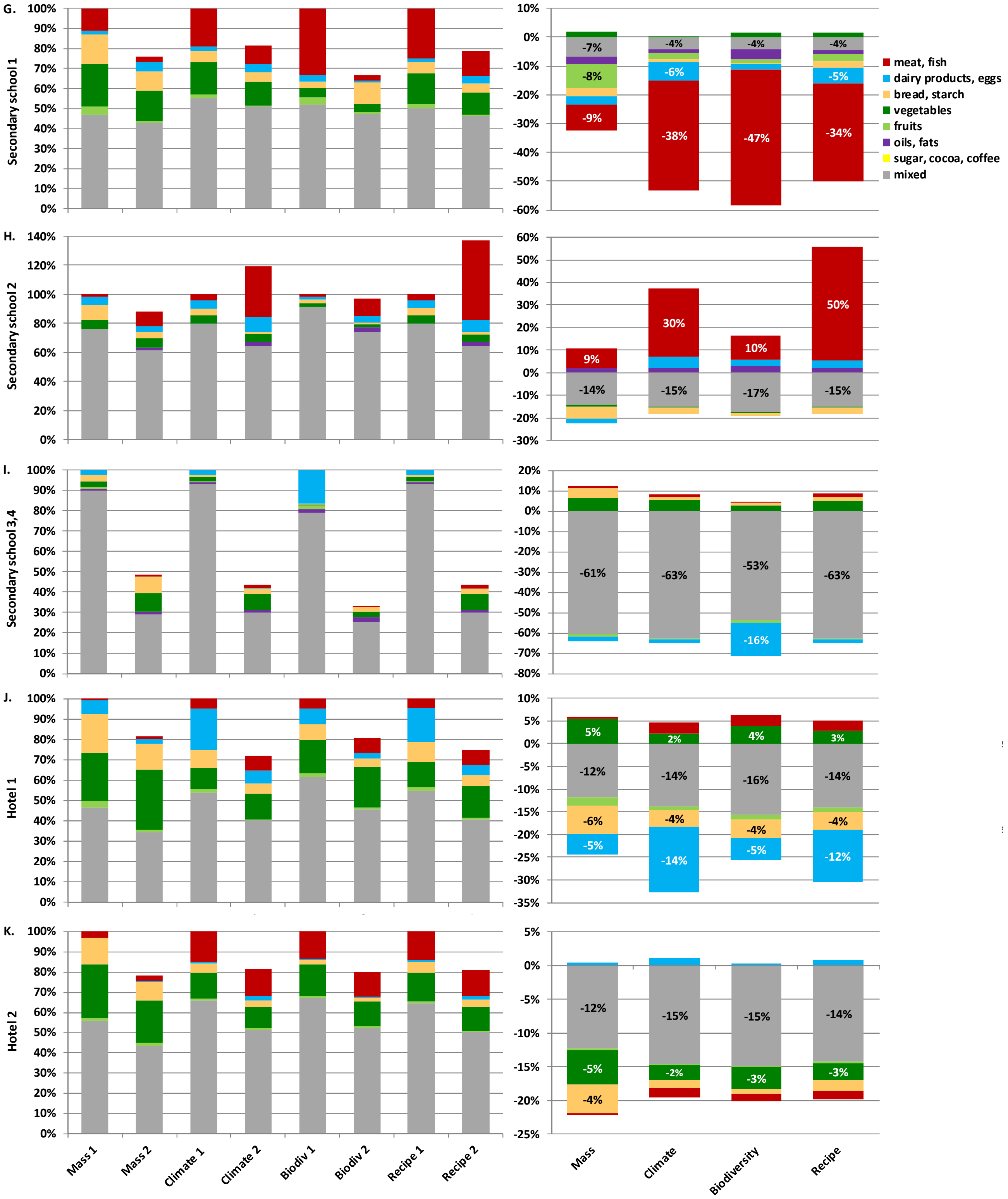


Figure C.10 Amounts and environmental impacts of FW of case studies G. – K. before and after implementation of measures for reduction (left graphs) and reduction relative to status quo, achieved after implementation of measures (right graphs).

C.3.2 Description of case studies G. – K.

G. Secondary school 1

In secondary school 1, a quantitative **reduction of FW by 1/3** of the initial impacts leads to less than half of the climate impacts and a **reduction of biodiversity impacts by nearly 60%**, mainly due to the high share of animal products in the avoided FW (about 1/3, **mainly minced meat**).

H. Secondary school 2

In secondary school 2, overproduction at the counter was the main reason for kitchen FW. Therefore, a new ordering system was introduced, allowing pupils to order their menu online in advance. However, at the time of the second measurement, the new system was rarely used and therefore did not help to reduce overproduction. On the contrary, overproduction at the counter increased by 3.3 g/meal. Since the main dish wasted during the second measurement period was environmentally relevant (poultry), the climate impacts increased by about 40% and the aggregated ReCiPe impacts by 50-60% (Figure C.8 H.).

The case study shows that the massive investment into an **online ordering system** only pays off if it used frequently. This might be achieved by providing **incentives**, e.g. a reduced price for guests ordering in advance. The case study also confirms that **dishes with large environmental impacts, e.g. containing meat or products imported by air, should be planned more carefully**. **New recipes and spices should be tested before producing large amounts**. Similarly, storable and quickly prepared **back-up dishes** should ensure supply until to the end of the service.

I. Secondary schools 3 and 4

In secondary school 4, overproduction was 21.5 g/meal lower in the **buffet system** than in the system with service at the counter (school 3). However, since in the buffet system a large share of the surplus food was vanilla pudding with high biodiversity impacts, overproduction at the counter caused lower impacts on biodiversity. But nevertheless, in total the system with **service at the counter caused 50-60% lower climate impacts and 60-70% lower biodiversity impacts**, mainly due to **127 g/meal less plate waste**.

J. Touristic Hotel 1

In touristic hotel 1, FW of most food categories could be reduced in the course of 4 weeks with an optimized planning system, employee trainings, and reducing the portions and plate size with the option for refill. The quantitative reduction by about 20% leads to climate and aggregated environmental impact reductions by 25-30%. Thereby, a **reduction of cheese waste by only 5% leads to a 14% reduction of climate impacts**. Thus, **good management of cheese is crucial, especially on buffets**, e.g. by not precutting the cheese, refrigerating the buffet, and reusing surplus cheese.

K. Touristic hotel 2

With similar measures FW of most food categories in touristic hotel 2 could be reduced by more than 20%, mainly due to **reduced portions and plate size,** leading to a reduction of **plate waste from 49 to 39 g/meal**. The environmental impacts could be reduced slightly less due to a high share of vegetables and starch with relatively low environmental impacts; however, 50-60% of the measured FW was mixed. More accurate differentiation of food categories would be needed for a reliable environmental assessment.

C.3.3 Food donations to Foodsharing (case study A)

Table C.12 shows the quantitative reduction and environmental benefits of a vegetarian restaurant (case study A) introducing a collaboration with Foodsharing (Foodsharing, 2018). The table differentiates more detailed food categories than visualized in Figure 4.2. The results show that fresh fruits (mainly used for juicing) provide the major quantitative and environmental benefits. The restaurant produces all juices from fresh fruits. Since most of the juices cannot be stored for more than one day, large amounts of juices were wasted and can now be donated to Foodsharing. Quantitatively, bread and pastries and vegetables are also donated in large amounts. They provide the largest climate and ReCiPe benefits of all food categories. In terms of biodiversity impacts, dairy products provide the largest environmental benefits due to dishes with biodiversity relevant ingredients (vanilla).

In total, **46% of the avoidable FW is donated** to Foodsharing, **reducing the climate impacts by 46%**, the **biodiversity** impacts **by 59%**, and the aggregated **ReCiPe** impacts **by 45%**. **If potentially edible trim waste from preparation is excluded**, up to **70%** of the avoidable FW **can be donated** to Foodsharing. So, depending where the boundary is set between edible and inedible trim waste, in this restaurant the sustainable development goal (SDG) of halving FW can be achieved through donations to Foodsharing only. In terms of biodiversity impacts, the goal could be achieved with donations only. In order to halve climate and aggregated ReCiPe impacts, food donations need to be **combined with other measures for FW prevention**.

However, this result might not be generalizable to all restaurants. Probst and Schmid (2018) quantified FW in four restaurants and differentiated FW which is suitable for food donations. They concluded that in the restaurants with buffets more than half of the avoidable FW was suitable for food donations, while in the other restaurants this measure has to be combined with other measures for FW prevention in order to reach SDG 12.3. Furthermore, legislations for food security at a national and company level provide barriers and limits to food donation, which differ between countries and companies. Political activities should support legislations towards a reasonable balance between food security and FW prevention.

Table C.12: Reduction of FW and related impacts on climate, biodiversity, and aggregated ReCiPe impacts relative to total of *status quo* in a vegetarian restaurant (case study A in Figure 4.4), which introduced food donations to Foodsharing. The category "milk" contains vanilla cream, which is mainly responsible for high impacts on biodiversity.

	Mass	*Climate*	*Biodiversity*	*ReCiPe*
Apples	-1.0%	-0.8%	-0.1%	-0.8%
Other Fresh Fruits	-8.3%	-6.8%	-12.7%	-7.2%
Berries and Exotic Fruits	-5.7%	-6.1%	-8.6%	-6.3%
Potatoes	-2.6%	-1.5%	-0.5%	-1.6%
Fresh Vegetables	-4.9%	-7.3%	-5.9%	-6.5%
Storable Vegetables	-5.7%	-3.0%	-1.2%	-3.6%
Bread and Pastries	-7.5%	-7.7%	-3.2%	-7.5%
Pasta	-1.5%	-0.9%	-0.5%	-1.0%
Rice	-1.2%	-1.1%	-0.6%	-0.9%
Maize	-0.1%	0.0%	0.0%	0.0%
Sugar	-0.5%	-0.2%	-0.1%	-0.1%
Vegetal Oils, Fats, Nuts Seeds	-3.3%	-1.2%	-6.8%	-1.1%
Milk	-1.5%	-5.2%	-13.8%	-4.6%
Dairy Products, Eggs	-0.1%	-0.2%	0.0%	-0.1%
Mixed	-1.5%	-3.4%	-4.4%	-2.9%
Fruits, Vegetables	-0.7%	-0.9%	-0.3%	-0.9%
Total (possibly) edible	-45.9%	-46.3%	-58.6%	-45.2%

C.3.4 Food waste comparison between business canteens: serving system *and* management are relevant (case study F.)

Figure C.11 and Figure C.12 show the amount of FW originating from two business canteens of the same company. In canteen 1 avoidable FW amounted to 189 g/meal (average of 2 days), which mainly originated from buffet surplus. An important reason for high amounts is the company's policy to offer the same variety of dishes from the beginning until to 15 min before the end of the service. In canteen 2, however, avoidable FW was only 55 g/meal (1-day measurement). In this canteen, **plate service** was introduced as a measure to avoid FW. Surplus food at the buffet was entirely avoided. Instead, there was slightly more overproduction at the counter (Figure C.12), but in total **avoidable FW was reduced by about 70%** (Figure C.11). The reduction of environmental impacts in canteen 2 compared to canteen 1 was slightly larger than the quantitative reduction. However, the food categories which dominate the results are different. While vegetables and cereals make up half of the quantitative reduction, they are less relevant for the environment. Meat losses, however, are only 2% lower in canteen 2 compared to 1, but are responsible for 23-31% of the difference in environmental impacts (Figure C.11).

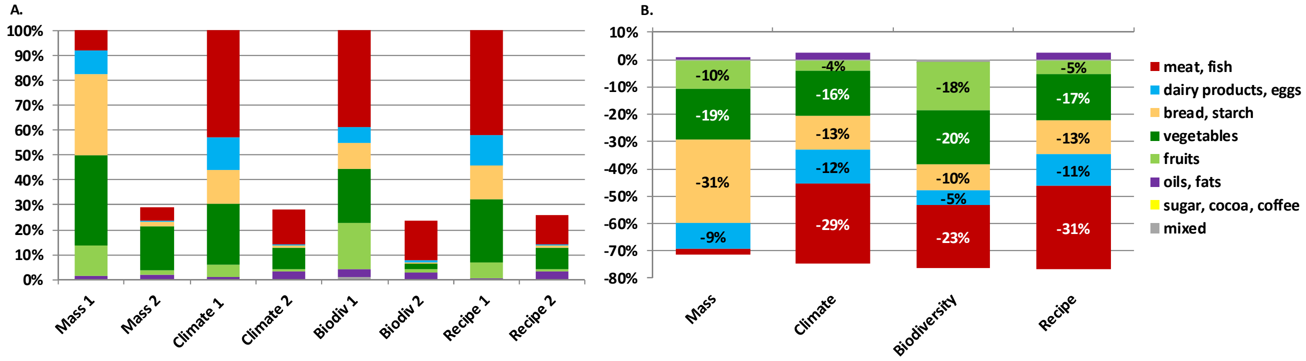


Figure C.11: Measurements in two business canteens (No. 17 and 18 in Table C.1). Chart A. shows the amount (mass) and the environmental impacts (climate, Biodiversity, ReCiPe) of avoidable FW measured in 2 canteens of the same company (1 with buffet and 2 with plate service). Chart B. shows the corresponding reduction. All percentages refer to the totals of canteen 1.

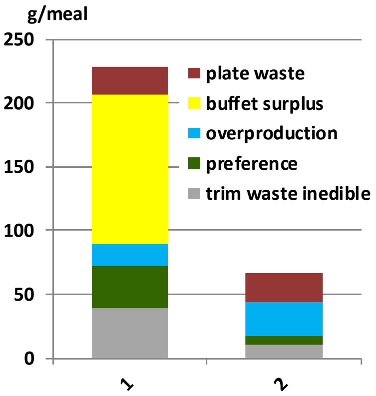


Figure C.12: The same FW amounts as in the previous figure, but expressed in absolute amounts (gram per meal) and differentiating by origin of FW. Again, 2 canteens of the same company are compared (1 with buffet and 2 with plate service). Additionally to the previous figure, the grey columns show inedible trim waste.

Plate waste is similar in canteen 2 and in canteen 1 (both 22 g/meal). However, the measured amount of plate waste in canteen 2 is uncertain since it is based on a one-day measurement and usually fluctuates based on the offered dishes. The composition of plate waste (Figure C.13) indicates that many guests did not like the vegetables, which were served as standard on the plates and which were cooked al dente, and the tomato chutney, which was available as standard portion and contained a lot of fat. On the other hand, plate service has the advantage to prevent guests from taking too large portions. We conclude that **plate service may only lead to lower plate waste with good communication**, e.g. if the staff at the counter asks the guests which dishes they prefer and does not serve less popular or unknown dishes as a standard.

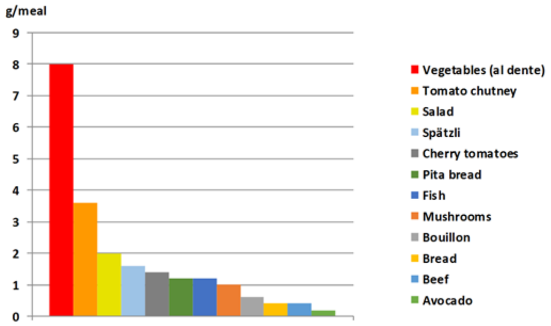


Figure C.13: Composition of plate waste in canteen 2 with plate service (12 main food categories).

The case study showed that **not only plate service, but also kitchen and service management are crucial**. Food needs to be prepared *during* the service in order to adjust production quantities to the consumed dishes. The served portions should be relatively small providing the option for refill, unless the customer explicitely asks for a larger portion in the beginning. Good communication between personnel and guests should ensure that the guests receive what they wish. The portions of individual components should be reduced during service if the plates returned from the earlier guests contain leftovers of the same component. Feedback from the guests should be used to avoid dishes which some guests do not like or to mark the dishes explicitly. This ensures that guests can select the dishes of preference (e.g. hot, spicy, al dente).

C.3.5 Food waste reduction in two business canteens: a long-term challenge (case studies L. and M.)

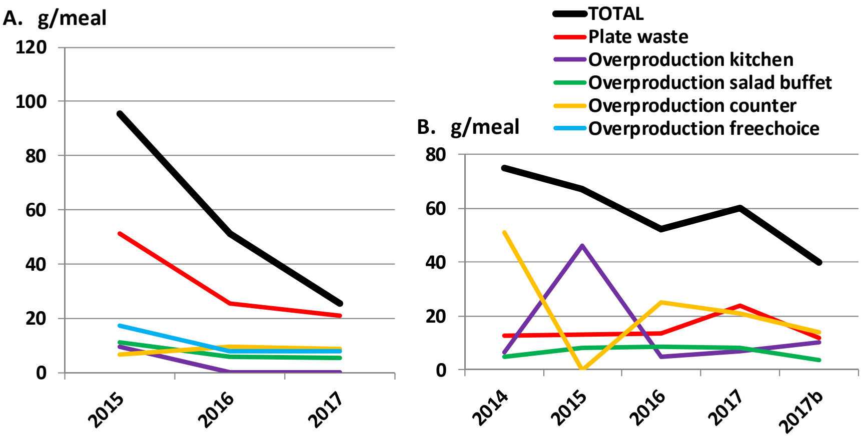


Figure C.14: Development of FW in two business canteens (No. 19 and 20 in Table C.1) measuring their FW in 3 and 5 periods, respectively. Total FW is divided into 5 categories by origin (kitchen, counter, free choice, salad buffet, guests).

Figure C.14 shows the amount of FW originating from the kitchen, the service (buffet, counter, free choice), and the guests in two business canteens. In case study A. (No. 20 in Table C.1) FW could be reduced in both periods in all categories except at the counter. The restaurant did not take any specific measures, but they introduced constant FW tracking, which makes FW visible to the staff and thus provides motivation to waste less and adjust portions more carefully. In case study B (No. 19 in Table C.1) higher fluctuations can be observed than in case study A. A reason for the higher variability might be more frequent staff changes, which hinder consistent FW classification (e.g. *surplus food at the counter* was sometimes classified as *overproduction kitchen*) and interrupt long-term experience and awareness building (e.g. portion sizes 2017 higher than 2016).

We can draw the following conclusions. First, **FW prevention** in these cases is not a systematic change, but rather a consequence of good management practices and remains therefore **a constant long-term challenge**, especially if new staff members are introduced. Secondly, **in order to improve strategies for FW prevention it is** not only **helpful to distinguish** food categories, but also **the origin of FW**. Both options should be considered in each individual case.

C.4 ADDITIONAL CASE STUDIES

C.4.1 Food waste reduction in two hotels with coachings: the composition of food waste matters

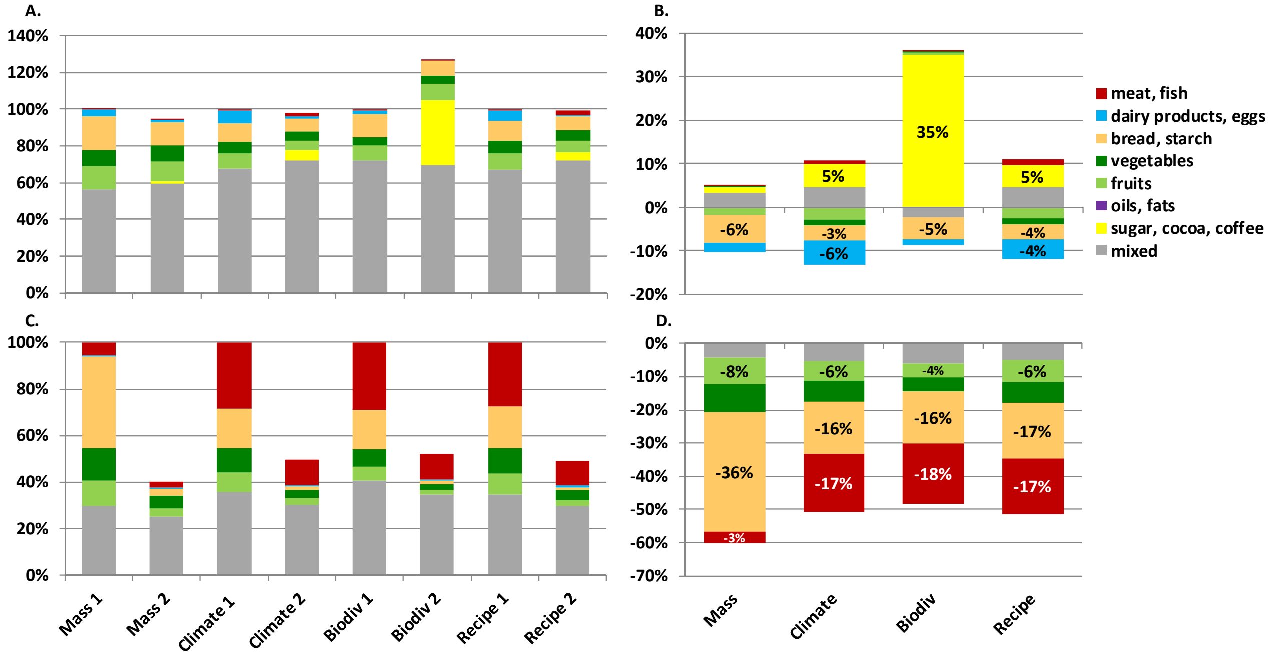


Figure C.15: Measurements in two business hotels (No. 11 and 12 in Table C.1). Charts A. and C. show the amount (mass) and the environmental impacts (climate, biodiversity, ReCiPe) of FW measured in week 1 and 2 (before and after coaching and staff training). Charts B. and D. show the corresponding reduction. All percentages refer to the status quo of week 1.

Figure C.15 shows the amounts and environmental impacts of FW measured in two business hotels (No. 11 and 12 in Table C.1) in week 1 and in week 2, after a coaching program and staff training have taken place. Since the number of guests in both test periods is not available, it is not interesting to compare the absolute numbers, but rather the reduction or increase of the amounts and environmental impacts of different food categories. First, the results show that the **composition of food categories can vary substantially, even between similar types of FSs**. Secondly, a **reduction of the amount of FW can lead to different environmental benefits depending on the composition of FW**. If environmentally more relevant food categories are wasted after the quantitative reduction of FW, the environmental impacts can even increase (e.g. biodiversity impacts of hotel No. 11 due to high amounts of coffee overproduction and surplus from the guests). In hotel No. 12 a small reduction of meat waste by 3% of total FW leads to environmental benefits of 17-18%, whereas a considerable reduction of bread and starch by 36% only leads to 16-17% environmental benefits.

C.4.2 Food waste reduction in a university cafeteria: large potential for sale at a reduced price

A university cafeteria introduced the project “do good”, in which they sell their packaged products in the last 30 minutes before closure at a reduced price. Additionally, they sell surplus menus from the university canteen located nearby (no. 5 in Table C.1). In order to quantify the effect of their project, a few weeks after its introduction they quantified food which was sold at a regular price, sold at a reduced price (“do good”), and wasted, by counting the corresponding food products during 2 weeks between the 23rd of October and the 3rd of November 2017 (Table C.13).

The results show that **39% of the produced sandwiches**, **18% of the joghurts and “Müeslis”**, and **15% of the salads** were **still wasted**. Only 3.9% of the sandwiches were sold as “do good” at a reduced price. For Joghurts, Müesli, and salads 0.2-0.3% of the production could be saved. The two meals saved from the canteen correspond to 0.01% of the produced meals in the same period. In total, the **potential of saving products** with “do good” is **25x larger than** what has been sold during the 2 weeks of the **test period** (0.8% versus 20% wasted products).

In a next step the FS will try to **improve** its **communication and positioning** of the “do good” products. Alternatively, **collaboration with Foodsharing** (Foodsharing, 2018) **for food donations** might be an effective complementary measure.

Table C.13: Sold and wasted food in a university cafeteria, which introduced the project “do good” in order to sell their packaged products before closure and some menus from the nearby canteen after lunch service at a reduced price. The bottom section of the table shows the sum of all products over 2 weeks.

No. of sold or wasted items		Monday	Tuesday	Wednesday	Thursday	Friday	Monday	Tuesday	Wednesday	Thursday	Friday	TOTAL	
in a university cafeteria		23.10.2017	24.10.2017	25.10.2017	26.10.2017	27.10.2017	30.10.2017	31.10.2017	01.11.2017	02.11.2017	03.11.2017	2 weeks	% of production
Sandwiches	regular sale	24	18	18	26	16	24	27	21	25	20	**219**	***57%***
	"do good"	0	0	0	0	0	3	5	3	3	1	**15**	***3.9%***
Joghurts, Müeslis	regular sale	94	91	90	82	67	56	59	103	87	84	**813**	***82.1%***
	"do good"	0	0	0	0	0	1	1	1	0	0	**3**	***0.3%***
Salads	regular sale	87	104	116	114	70	94	79	98	93	64	**919**	***85.3%***
	"do good"	0	0	0	0	0	0	1	1	0	0	**2**	***0.2%***
meals from the canteen	"do good"	0	0	0	0	0	0	1	1	0	0	**2**	***0.01%***
Sandwiches	wasted	0	14	0	0	12	24	27	24	50	0	**151**	***39.2%***
Joghurts, Müeslis	wasted	36	0	18	15	18	17	18	20	17	15	**174**	***17.6%***
Salads	wasted	33	5	12	0	21	10	12	34	25	5	**157**	***14.6%***

Synthesis	2 weeks	% of production		2 weeks	% of production	
Regular sales	1'951	*80%*				
"Do good"	20	***0.8%***	no. of meals from the canteen sold as " do good":	2	***0.01%***	*of the average no. of meals produced in 2 weeks*
Food losses	482	***20%***				
Food production	2'453	*100%*	no. of meals produced in the canteen:	23'097	*100%*	

C.5 EXTENDED SCENARIO II: REDUCING COOKING LOSSES

C.5.1 Results

In the **extended scenario II**, which is shown in Figure C.16, we demonstrate that not only the reduction of quantitative food losses can lead to relevant environmental benefits, but also the reduction of quality and nutrient losses. The scenario is based on the extended scenario presented in section 4.3.3, in which FSs reduce in-house FW and use 50% presently non-marketable vegetables, preventing them from being wasted in agriculture and trade. Additionally, **FSs cook 70% of the meat and fish with sous-vide technique**. Due to lower cooking losses, they need **15% less meat and fish** (~6'200 t if implemented in Swiss FSs) to prepare the same menus. They compensate for the reduced calorific content of sous-vide meat with additional food of the average Swiss consumption mix (Figure C.16 D only shows the net difference per meal). This dietary change **saves 28 g CO_2-eq/meal** (**-12% of the status quo impacts** of FW in FSs). The environmental impacts of additional plastic bags used for sous-vide cooking are not included in the calculations. Depending on the size of the bags, the amount of meat cooked per bag and if the plastic is recycled or sent to incineration, the **climate impact of additional plastic bags** vary **between 2.5% and 55% of the savings** by cooking meat with sous-vide technique (more details in section C.1.7) and should therefore be reduced to a minimum before sous-vide cooking can be recommended as a way to reduce FW.

In total in the extended scenario II, **FW** in FSs and the food value chain is **reduced by 73 g/meal** (**-68%** relative to status quo FW in FSs), **related climate impacts by 167 g CO_2-eq/meal (-70%)** and **biodiversity impacts by 5.4x10^{-16} gPDF-eq*a/meal (-42%)** (Figure C.16).

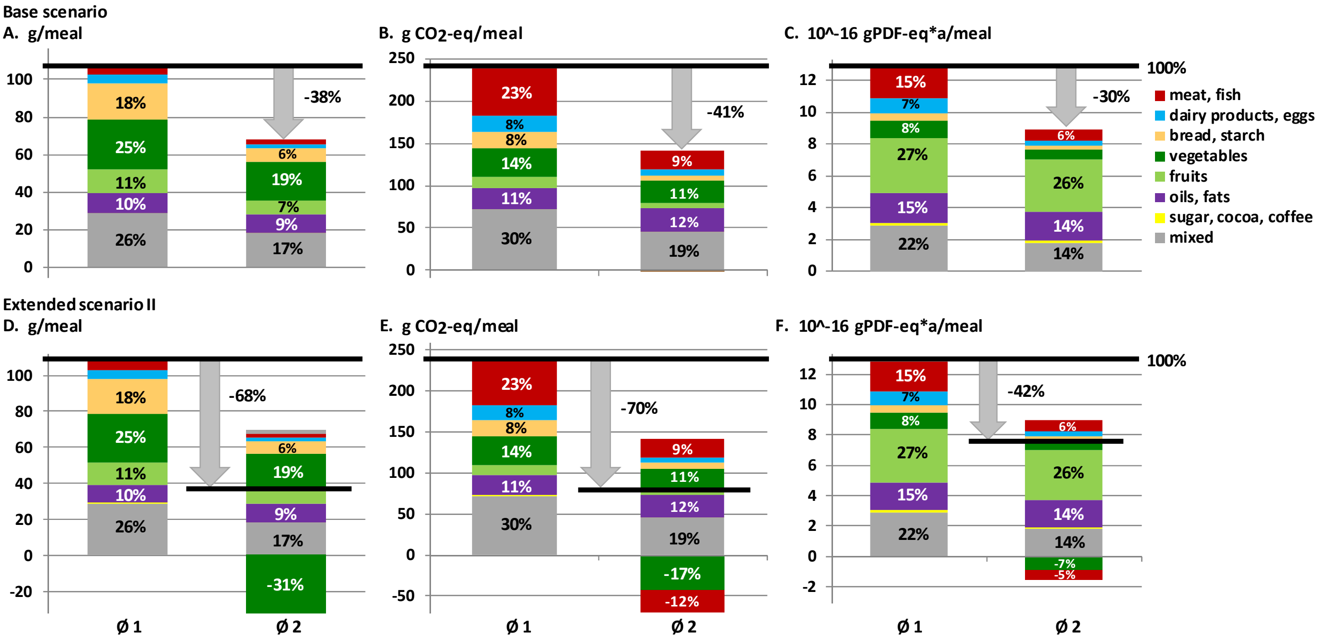


Figure C.16: Status quo FW (Ø 1) in terms of mass (g/meal), climate impacts (g CO2-eq/meal) and biodiversity impacts (gPDF-eq*a/meal) and reduction scenarios (Ø 2). Charts A.-C. show the *base reduction*, charts D.-F. the *extended reduction scenario II*, differentiating 8 food categories. The negative bars in the *extended scenario II* show FW "saved" from the food value chain (see text), the horizontal black lines the net FW amounts and impacts caused in FSs in the *extended scenario II* compared to *status quo*.

C.5.2 Limitations and outlook

The share of 70% of meat and fish dishes appropriate for **sous-vide technique** and the **saved cooking losses of ~15%** (C.3.2.3.) are based on a single estimation by Mein Küchenchef (2018). According to Frei (2018) 15% reduction of cooking losses is **partly due to the sous-vide bag** minimizing water evaporation and partly **due to the constant, lower temperature (<60°C) which avoids the denaturation of actin and myosin**. However, if guests explicitly prefer meat as "bien cuit" (well-done), even with sous-vide cooking temperatures need to be higher than 60°C. In this case, he estimates the reduction of cooking losses only at ~**5%** compared to conventional cooking. As a further limitation, we assume that the consumers' perception of a portion of meat is based on the weight and texture and not on the calorific content. We also assume that after a meal with fewer calories additional average food is consumed during other meals. However, what is a typical functional unit of people's eating behaviour? Is it the weight of food, its volume, the amount of calories or other nutrients, or a sum of factors including taste? Further research is needed to find out how different types of food and preparation methods influence people's eating behaviour.

Furthermore, for sous-vide cooking **additional plastic bags** are needed (section C.1.7). We estimate the **climate impacts** of polyethylene plastic production and disposal **between 2.5 and 55% of the benefits of the dietary change**, depending on the size of the bags (1-20 portions) and if they are incinerated or recycled (Table C.4). Therefore, **sous-vide cooking needs further development** in order to unroll its potential environmental benefits, **e.g. with reusable bags, closed-loop recycling** (only for plastics used in the food industry) **or biodegradable alternatives** (considering the biodegradability of small residues and nanoparticles). Further research is needed to assess the environmental and health impacts of possible alternatives to conventional plastic bags and to make more sustainable technologies marketable.

A further uncertainty refers to **energy consumption of sous-vide versus conventional cooking**. Mein_Küchenchef (2018) suggests sous-vide cooking to use less energy than conventional cooking due to lower cooking temperatures and heat losses.

C.5.3 Conclusion

The example of cooking meat at reduced temperatures in extended scenario II shows that **measures reducing quality loss and nutrient loss can potentially save considerable environmental impacts**. Cooking carefully, e.g. at reduced temperature, can therefore be considered as a measure for FW reduction, since it can reduce quality and nutrient losses of the cooking process and thus the amount of food needed to prepare meals with a given nutritional value or providing a given feeling of satiety. However, the environmental impacts of food consumption can only be reduced with such measures if food consumption is not only measured by weight and calories, but also by nutritional value and taste. **Further research is needed to analyse how different preparation methods influence nutritional quality, taste and people's eating behaviour.**

C.6 CONTEXT OF THE RESULTS AND COMPARISONS

C.6.1 Food waste reduction in Switzerland in a supply chain perspective (base and extended scenario II)

In order to prioritize measures for FW prevention over the whole food supply chain, it is important to know their potential to reduce overall FW. Table C.14 shows the potential FW reduction of (A) the base reduction scenario, in which all FSs reduce their in-house FW, and (B) the extended FW reduction scenario II. In this scenario, they do not only reduce in-house FW, but also FW in their supply chain, by buying 50% of their vegetables from a non-marketable origin. Additionally, they cook 70% of the meat and fish with sous-vide technique to reduce preparation losses (section C.1.6).

The **base scenario** of FW reduction results in a quantitative reduction of avoidable **FW in FSs [164'000 t] by -36%** (-39% of climate impacts) (Table C.14 and Figure 4.8). Compared to **FW** arising **across the entire food value chain** of out-of-home consumption **[362'000t]**, the reduction is **-16%** (-25% of climate impacts) (Table C.14, Figure C.17) and compared to **total avoidable FW including household consumption [2'651'000 t]**, the reduction is **-2.2%** (-3.4% of climate impacts) (Table C.14).

The **extended scenario II** results in a quantitative reduction of avoidable **FW by 105'000 t** or **4% of total FW in Switzerland** and in a **reduction of climate impacts by 239 kt CO_2-eq** or **5.9%** (Table C.14). So, **targeting FSs can potentially fulfil more than 8% of the goal of halving per capita FW in the whole country**; in terms of **climate change, more than 10%** of the goal can be achieved with the extended scenario II. This is similar to the share of FW caused by the FS sector (section C.1.8).

The base reduction scenario is an **ambitional *short-term* goal** which in most case studies was reached in less than 1 or 2 years. The additional measures of the extended scenario II (buying 50% non-marketable vegetables and cooking meat with sous-vide technique) can be implemented in parallel with other measures. The **progressive restaurant** "Mein Küchenchef", which **reduced the climate impacts of its supply chain FW by 86%** compared to the present Swiss average (section 4.3.1), shows that the **long-term potential** by 2030 is even **larger** than the scenarios presented in Table C.14.

			kt	kt CO_2-eq
A	**base scenario of food waste reduction**		**-59**	**-138**
B	**extended scenario II of food waste reduction**		**-105**	**-239**
I	food waste (FW) in food services (FS)		164	359
	-> reduction in %	A	-36%	-39%
		B	-64%	-67%
II	FW across the entire FS supply chain		362	545
	-> reduction in %	A	-16%	-25%
		B	-29%	-44%
III	total food waste (incl. households)		2'651	4'038
	-> reduction in %	A	-2.2%	-3.4%
		B	-4.0%	-5.9%

Table C.14: Reduction of FW and related impacts on climate in (A) the *base* and (B) the *extended FW reduction scenario II* in Switzerland in absolute numbers and relative to (I) FW in FSs, (II) FW in FSs and their supply chain, and (III) total FW including household consumption and its supply.

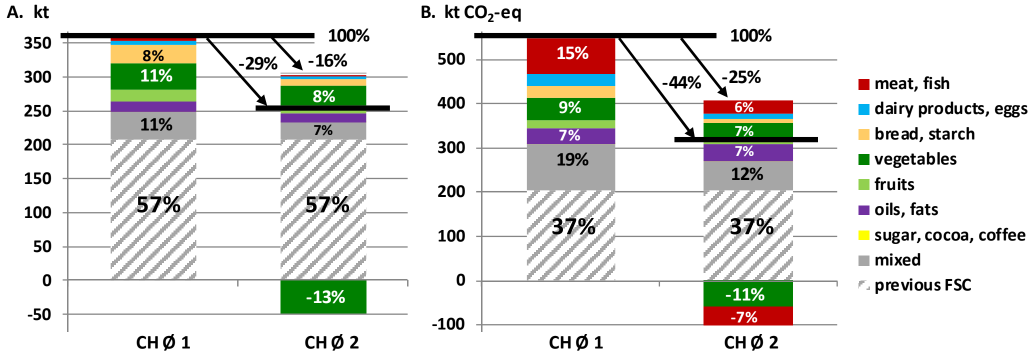


Figure C.17: *Status quo* FW in Switzerland (CH Ø 1) in terms of mass (chart A.) versus climate impacts (chart B) and *base reduction scenario*, if all FSs in Switzerland reduced their FW equally to the case studies presented in section 4.3.1.4. (CH Ø 2), differentiating 8 food categories. The horizontal black lines show the net FW amounts and impacts of the *extended FW reduction scenario II*, in which all FSs use 50% presently non-marketable vegetables and cook 70% of the meat with sous-vide technique (Figure C.16). In combination, FW across the whole food supply chain could be reduced by 105 kt (-29%) and related climate impacts by 239 kt CO_2-eq (-44%) with measures implementable by FSs only.

C.6.2 Food waste reduction in Europe in a supply chain perspective (base and extended scenarios)

Table C.15: Reduction of FW and related impacts on climate in (A) the *base*, (B) the *extended scenario*, and (C) *the extended scenario II* in Europe in absolute numbers and relative to (I) FW in FSs and (II) FW in FSs and their supply chain. The reduction slightly differs from the scenario for Switzerland (Table C.14) due to different shares of the subsectors in Switzerland and Europe (Figure C.5 and Figure C.6). Illustrations in Figure 4.7 and in Figure C.16.

			g/meal	g CO_2-eq/meal
A	**base scenario of food waste reduction**		**-41**	**-96**
B	**extended scenario**		**-75**	**-139**
C	**extended scenario II**		**-73**	**-167**
I	food waste (FW) in food services (FS)		108	238
	-> reduction in %	A	-38%	-41%
		B	-70%	-58%
		C	-68%	-70%
II	FW across the entire FS supply chain		252	380
	-> reduction in %	A	-16%	-25%
		B	-30%	-37%
		C	-29%	-44%

C.6.3 Food waste reduction relative to consumption (base, extended scenarios, progressive restaurant)

One of the main motivations to reduce FW is the reduction of environmental impacts of food consumption (Tukker et al., 2006). Therefore, in this section we compare the amounts and climate impacts of wasted food and its reduction potential to total food consumption. Figure C.18 A shows that about 730 g of food have to be produced for one meal consumed in an average FS institution. This is based on the average amount of 475 g/meal of food consumed in a Swiss FS institution, excluding plate waste (Beretta et al., 2017). In the **status quo FW estimation** 144 g/meal are wasted in the food supply chain (agricultural production, trade, processing) and 108 g/meal in FS institutions. So, more than half of the food is wasted in the supply chain. However, the climate impacts of FW in the supply chain are 142 g CO_2-eq/meal, whereas the impacts of FW in FSs are higher at 238 g CO2-eq/meal due to higher supply chain impacts per kg (the wasted food was transported, stored, prepared, etc.) (Figure C.18 B).

In the **base reduction scenario** FW in FSs can be reduced to 67 g, meaning that 6% less agricultural production is needed to provide the same weight of a meal. The climate impacts of FW in FSs are reduced to 142 g CO_2-eq/meal, which corresponds to a reduction of climate impacts of total food consumption in FSs by 4.9%. This scenario could be reached if all FSs reduced their FW equally to the case studies presented in section 4.3.1.4.

In the **extended reduction scenario**, in addition to the measures reducing inhouse FW, all FSs use 50% non-marketable vegetables which would have otherwise been wasted in the FS chain. In the **extended scenario II**, the FSs further reduce the environmental impact of their meals by cooking 70% of the meat with sous-vide technique and thus need up to 15% less meat input for the same meat dishes (sections C.1.6 and C.5). Since we assume that the guests compensate the lower calorific content of the meat dishes with additional average food, total food consumption rises slightly to 477 g/meal. However, since the share of meat decreases, the environmental impacts of consumed food are reduced from 1’601 g CO_2-eq/meal to 1’573 g CO_2-eq/meal. In total, with these measures 167 g CO_2-eq/meal or 8.3% of the total impacts of FS food consumption can be avoided.

The **progressive restaurant “Mein Küchenchef”** reduced its FW to 6.7 g/meal with climate impacts of 23 g CO_2-eq/meal (including impacts of plastic bags for sous-vide cooking). This was mainly achieved avoiding over-production with sous-vide cooking, which makes the produced food storable, and by serving small portions with the option for refill and good communication between service personnel and guests. By using 77% non-marketable vegetables, wholegrain flour, and by buying retail products close to their expiry date and thus preventing them from being wasted, the FW arising in the supply chain could be reduced to 19 g/meal with climate impacts of 29 g CO_2-eq/ meal (Figure C.18). The amounts and environmental impacts of consumed food are assumed to be equal to average FSs, since in this case study the focus lies on FW prevention. Therewith, **the amount of produced food for one meal in the restaurant “Mein Küchenchef” is 31% lower than in an average FS institution** and causes 328 g CO_2-eq/meal less climate impacts than in an average status quo FS institution. This corresponds to **17% lower climate impacts of food consumption**. These results only include measures targeting FW reduction. However, **if the use of mostly local, seasonal, and plant-based products in the restaurant “Mein Küchenchef” was considered, the impacts of consumed food are expected to be even lower**.

Figure C.18: (A.) Amount and (B.) climate impacts of consumed and wasted food per meal in an average status quo FS institution, in the *base* and the *extended scenarios* of FW reduction, and in the progressive restaurant "Mein Küchenchef", differentiating FW arising in the food supply chain (agricultural production, trade, processing) and in the FSs. The scenarios only consider measures for FW reduction, assuming the amount and composition of consumed food to be constant (except for the implication of sous-vide cooking used for meat products; more details in the text).

C.6.4 Comparison of climate impacts with cars

Estimating the **climate impacts of FW** in the Swiss FS sector at 545 kt CO$_2$-eq including the supply chain, the impacts are equivalent to more than **5% of private mobility by car** (BFS, 2015). The **base scenario** of FW reduction saves an equivalent to the direct carbon emissions of about **60'000 average cars** in Switzerland, the extended scenario II **more than 100'000 cars** (2.3% of the fleet) (Table C.16). In relation to 100 meals, the climate benefits are equivalent to 60-104 pkm of a car ride. In the restaurant "Mein Küchenchef" the consumption of 100 meals even saves climate impacts equivalent to 226 pkm of a car ride compared to status quo (Figure C.19).

Table C.16: Direct carbon emissions of private mobility by car in 2013 (BFS, 2015) and number of cars in Switzerland in 2015 (BFS, 2016). The subsequent lines show the climate impacts of *status quo* FW in FSs including and excluding the food supply chain in Switzerland and the potential reduction of climate impacts in the *base* and the *extended scenario* II. The last row shows the equivalent number of cars with the same average emissions.

Private mobility by car CH 2013 (direct emissions)	10'560	kt CO$_2$-eq	100%	*4'524'029*	*cars in CH in 2015*
Total impacts of FW in FSs including supply chain	545	kt CO$_2$-eq	5.2%	*233'684*	*cars*
Total impacts of FW in FSs excluding supply chain	341	kt CO$_2$-eq	3.2%	*146'250*	*cars*
Base reduction scenario	-138	kt CO$_2$-eq	-1.3%	*-59'268*	*cars*
Extended reduction scenario II	-239	kt CO$_2$-eq	-2.3%	*-102'384*	*cars*

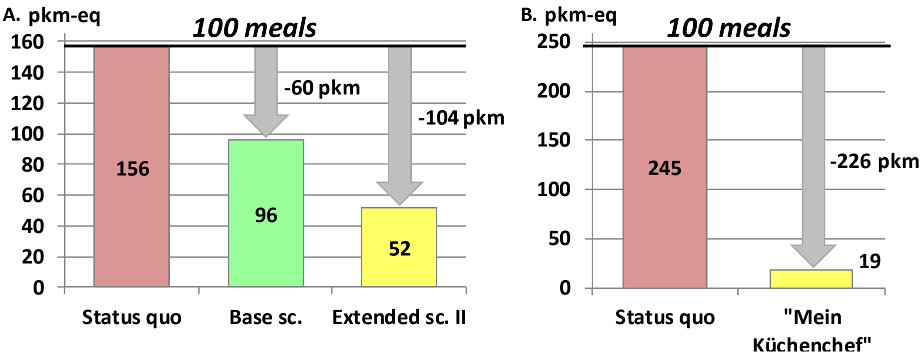


Figure C.19: (A) Average FW climate impacts of 100 meals consumed in an average Swiss FS institution, expressed in the equivalent number of person-kilometers which can be driven with an average European car, assuming 1.99 persons per car (BFS&ARE, 2012). The columns compare the *status quo* impacts with the impacts in the *base reduction scenario* achieved in the case studies and in the *extended reduction scenario II* (section C.5). The life cycle emissions of an average car (0.32 kg CO$_2$-eq/km) are based on the ecoinvent process "Transport, passenger car [RER]| processing | Alloc Rec, U" (ecoinvent, 2016). (B) Average climate impacts of FW *over the entire food value chain* caused by 100 meals consumed in an average Swiss FS institution (*status quo*) and in the *progressive restaurant* "mein Küchenchef" (section C.3.1.3.), expressed in the equivalent number of person-kilometers driven by car.

C.7 DATA QUALITY

Liquids are often disposed of separately to food and therefore not captured in all measurements. Therefore, waste of **dairy drinks, juices, and coffee might be underestimated**. Due to missing data we did **not consider other beverages,** even though some of them are environmentally relevant (e.g. alcoholic beverages).

In the extended scenario, the practicality that all FSs buy 50% of their vegetables from non-marketable origin is uncertain. Food donations are assumed to be entirely consumed. However, this should be analysed in further studies.

Some studies report FW in percentage of consumed food. The **conversion into g/meal** provides some uncertainty, since it is based on the assumption that an average meal weighs 450 g (Borstel et al., 2017). The **share of unavoidable FW** is not reported in the studies from Germany and Austria. Our deduction from the UK studies provides some uncertainty (Figure C.1 and C.2). The case studies of German school canteens and two touristic hotels did **not differentiate** plate waste **by food categories** and two business caterers did not differentiate any food categories (Table C.1). In most case studies some of the FW was categorized as “mixed” (Figure C.1). Our approximation with the average Swiss consumption mix provides uncertainty for the environmental assessment.

The highest uncertainties concerning extrapolation to larger geographical areas are related to the **relatively small sample size** and the **number of meals consumed out-of-home**. For the case of Switzerland, an estimation by Baier and Reinhard (2007) for the Canton Aargau was assumed to be representative for the whole country. The share of different subsectors was estimated in 4 countries (Figure C.6) and is therefore not representative for all countries in Europe.

The progressive restaurant “Mein Küchenchef” cooks with **sous-vide cooking** technique, where **additional plastic bags** are needed. The climate impacts of plastic bags shown in Figure C.4 are a maximum estimate based on the assumption that all meals are cooked in 5 portion sized bags. FW from surplus production could be avoided even if only some of the meals were conserved in vacuumed bags. “Mein Küchenchef” buys most of the food directly from the farmers in reusable containers and therefore causes less plastic waste than average food supply chains. However, this is not included and should be quantitatively assessed in future studies. The environmental relevance of plastic bags is discussed in section C.1.7. A further uncertainty refers to **energy consumption of sous-vide** versus conventional **cooking**. According to Mein_Küchenchef (2018) sous-vide cooking generally needs less energy than conventional cooking due to lower cooking temperatures and heat losses. This should be verified in future studies.

C.8 EXPLANATION OF THE GRAPHICAL ABSTRACT

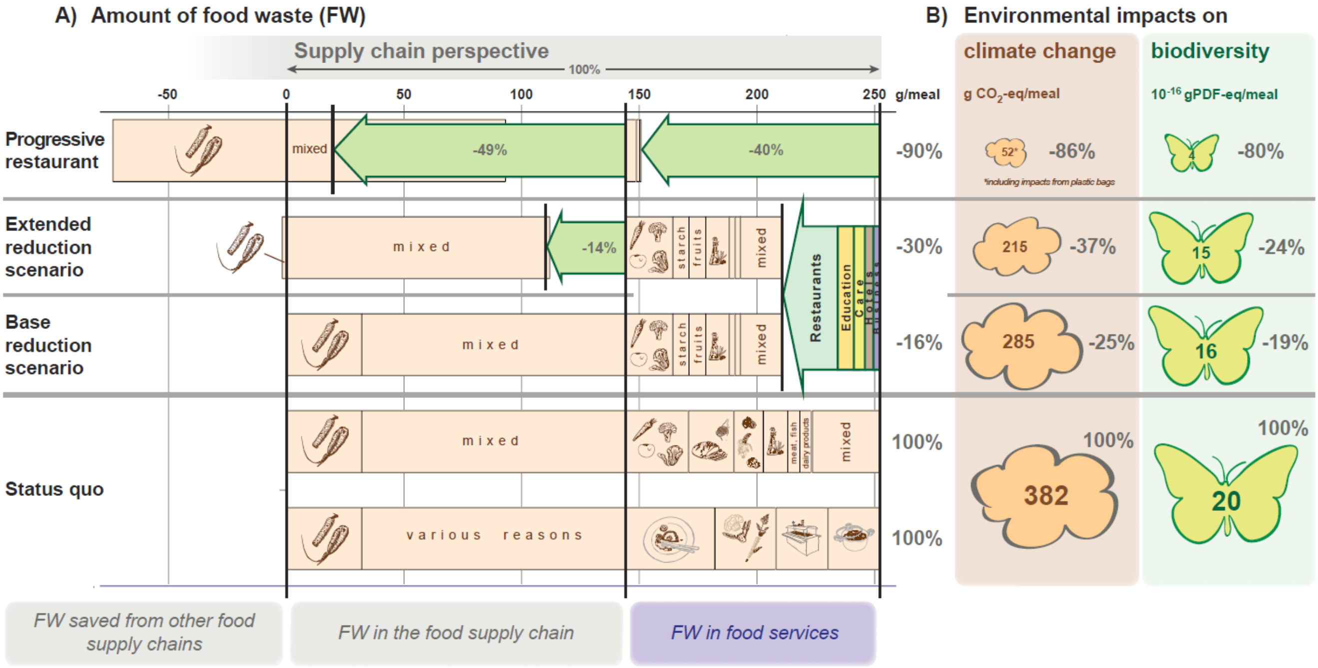


Figure C.20: Graphical Abstract: Overview of FW amounts and environmental impacts in the Swiss FS sector and potential for reduction in a supply chain perspective. Explanation in the text.

Figure C.20 and Figure C.21 are two versions of the graphical abstract of this publication. The version in Figure C.20 shows FW in a **supply chain perspective**, **including FW at all stages of the food value chain**. Part A) consists of a bar chart, which illustrates the amount and composition of FW in different scenarios arising in the food supply chain and in FSs, in g/meal. Negative values represent FW savings from FSs, which use food that would have otherwise been wasted in the food supply chain. Part B) shows the environmental impacts of FW on climate change (symbolised with a cloud and expressed in g CO$_2$-eq/meal) and biodiversity (symbolised with a butterfly and expressed in 10^{-16} gPDF-eq*a/meal).

The bar at the bottom of part A) shows **status quo FW amounts** and **reasons** (from left to right: *non-marketable or non-standard vegetables, plate waste from the guests, edible trim waste from preparation, buffet surplus, overproduction in the kitchen*). The second bar from the bottom differentiates status quo FW by **food category** (*vegetables, bread and starch, fruits, oil, meat and fish, dairy products*, and *mixed*).

The third bar illustrates the amount of FW arising in the **base scenario of FW reduction** (section 4.3.3). Food categories are shown in the same sequence in all bars. The arrow illustrates the reduction compared to status quo FW amounts and the **average contribution of the subsectors** *'restaurants', 'education', 'care', 'hotels', and 'education'*. Roughly half of the reduction is achieved in restaurants, since this is the largest subsector with 46% of the meals consumed in FSs in Europe (estimation from Figure C.6).

In-house FW in FSs is equal in the base and the extended reduction scenario. In the **extended scenario**, the FSs save additional FW by buying 50% of the **vegetables from unmarketable origin**. This is slightly more than the unmarketable vegetables arising in the status quo food supply chain. Therefore, **some of the vegetables** have to be **sourced from other food supply chains, e.g. supplying retail shops**. This makes sense, since retailers usually have higher expectations on cosmetic standards than FSs, because they do not process fresh vegetables before the customers have access to the vegetables. In FSs, however, most meals can be prepared with non-standard vegetables without difference in their appearance. Thus, FW from the entire food value chain was reduced by 16% in the base and 30% in the extended scenario.

The top bar illustrates FW in the **progressive restaurant** “Mein Küchenchef”. With 7 g/meal in-house FW and 19 g/meal net FW in the supply chain, one meal consumed in this restaurant caused 90% less FW than a meal consumed in an average status quo restaurant.

The percentages in part B) show the reduction of climate and biodiversity impacts relative to status quo FW in the whole supply chain. Climate impacts were reduced by 25% in the base scenario to 86% in the progressive restaurant, biodiversity impacts by 19-80%.

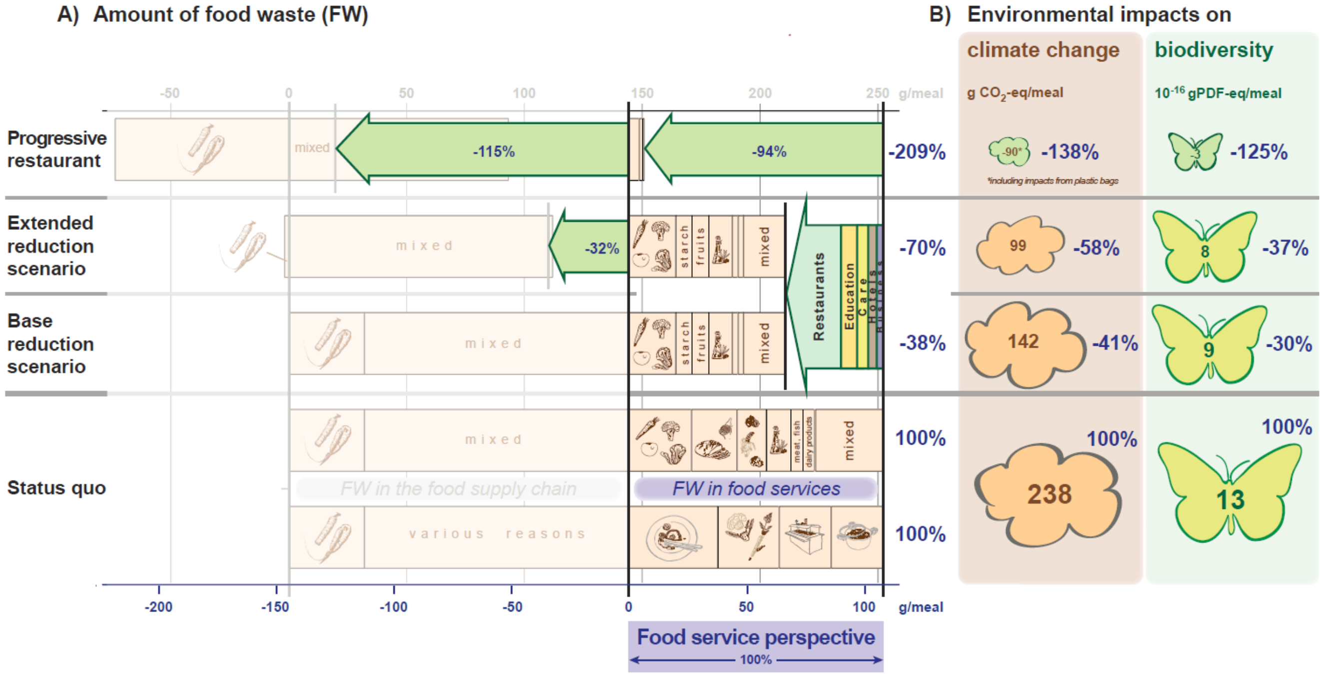


Figure C.21: Graphical Abstract: Overview of FW amounts and environmental impacts in the Swiss FS sector and potential for reduction in a food service perspective. Explanation in the text.

The second version of the graphical abstract shows FW in a **food service perspective** (Figure C.21). In this representation the **reference** defined as 100% is **status quo FW arising in FSs**. The effect of the FSs’ measures to reduce in-house FW and to save food from the supply chain which had otherwise been wasted is illustrated with arrows and quantified as percentage of status quo in-house FW in FSs. In the base reduction scenario 38% of the average status quo FW amounts in FSs were saved, corresponding to 41% of the climate and 30% of the biodiversity impacts. The progressive restaurant saved more than twice the amount of FW caused in average FSs per meal. Therewith, it saved more climate and biodiversity impacts than status quo FW in FSs cause.

C.9 ELECTRONIC APPENDIX

Tables C.7, C.8, and C.17 are provided as excel sheets in the electronic appendix.

C.10 REFERENCES

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APPENDIX D

SUPPORTING INFORMATION

ENVIRONMENTAL TRADE-OFFS IN FRESH-FRUIT COLD CHAINS BY COMBINING VIRTUAL COLD CHAINS WITH LIFE CYCLE ASSESSMENT

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D.1 METHODOLOGY

D.1.1 Virtual Cold Chain Method (VCC)

The VCC method was presented recently (Wu et al., 2018; Wu and Defraeye, 2018), where the background can be found. The simulations performed in the present publication were presented as a part of a larger simulation study on ventilated carton design and cold-chain scenarios (Wu et al., 2019), where all explicit simulation details are given. Only the key model characteristics are mentioned in this section.

Three different ventilated carton designs are evaluated: Standard box, Supervent box, and Opentop box (Figure D.1). Standard and Supervent boxes contain 64 orange fruit (diameter 75 mm, 13.57 kg), and Opentop boxes contain 60 fruit (diameter 75 mm, 12.72 kg). The cartons are palletized, holding 5120 fruit for both Standard and Supervent, and 3900 fruit for Opentop (Figure D.2).

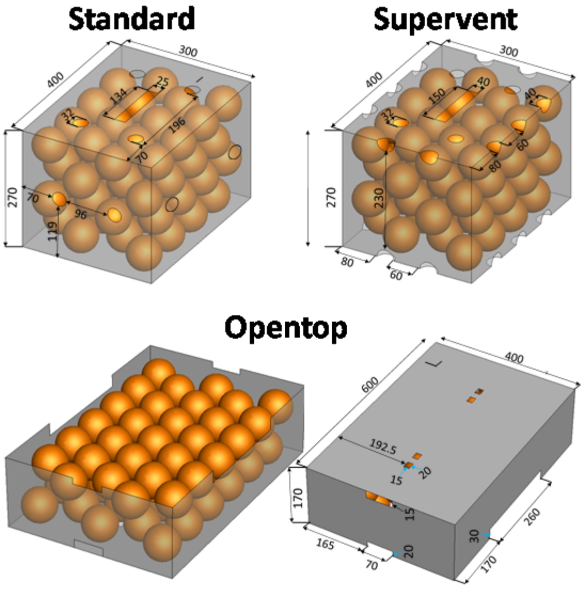

Figure D.1: Geometrical characteristics of Standard, Supervent and Opentop cartons, packed with citrus fruit. Figure adjusted from Wu et al. (2019).

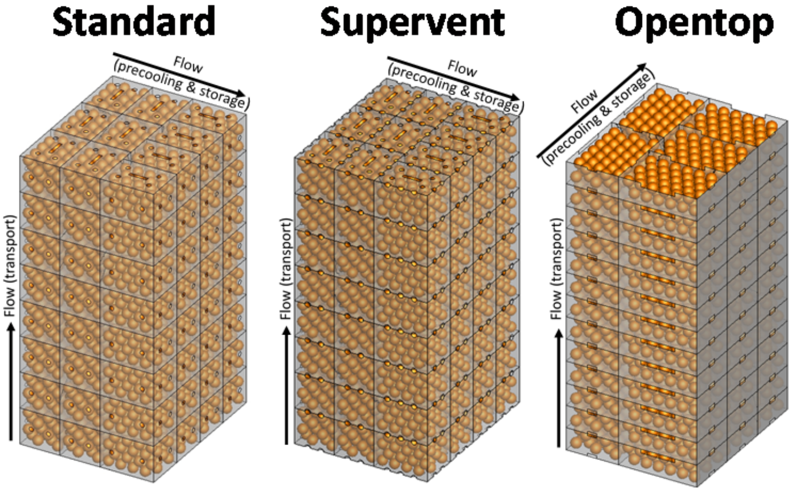

Figure D.2: Geometrical model of a pallet of Standard, Supervent and Opentop cartons. Figure adjusted from Wu et al. (2019).

The models for precooling, transport and storage are shown in Figure D.3, together with the applied boundary conditions (Table D.1). These models are a simplified representation of reality to some extent, but capture the main characteristics and differences between the different unit operations. Airflow is assumed to be horizontal for precooling and cold storage (Figure D.3a), and vertical for refrigerated transport (Figure D.3b). The upstream and downstream parts of the simulation domain were chosen sufficiently long to avoid an influence of the inlet and outlet boundary conditions on the airflow in the proximity of the pallet.

For the Opentop carton, with a reduced packing density in a pallet, the air speed is lower than with the other packages. This is counteracted partially by the cooling of Opentop pallets along their short pallet side, whereas for the other two packages, cooling along the long pallet side is performed. This reduces the inlet area so that the speed is increased a little for a certain flow rate.

The computational grids were built up with tetrahedral control volumes with a total of 40 million cells in each computational model. The wall y+ value is below 185, 6 and 3 for precooling, transport and storage, respectively. The spatial discretization error is estimated by means of Richardson extrapolation (Roache, 1994), and is 2.5% for the mass flow rate through the carton and 5% for the convective heat transfer coefficient on the citrus fruit surfaces.

Simulations are executed with the CFD software OpenFOAM 2.4.0, solving the Reynolds-averaged Navier-Stokes (RANS) equations for steady and incompressible flow with scalable wall functions, to calculate the airflow and heat transport in the region of the boundary layer. This implies that the conservation equations of mass, momentum and heat are solved using the finite volume method.

The temperature differences between adjacent fruit in the packages are relatively limited during cooling. Therefore, radiation exchange between the fruit inside the pallet and buoyancy are not modeled. The heat of respiration (50 W ton^{-1} for citrus fruit (ASHRAE, 2010)) and the moisture loss from citrus fruit in the cold chain are rather limited. As such, the respiration heat and the latent heat of evaporation are not included. The following thermal properties of citrus fruit are used in the simulations: density of 960 kg m^{-3}, thermal conductivity of 0.386 W m^{-1} K^{-1} and specific heat capacity of 3850 J kg^{-1} K^{-1}.

The second-order upwind scheme is used to discretize the advection terms of the governing equations. The first time derivative is discretized by the first-order, bounded, implicit scheme Euler. The SIMPLE algorithm and merged PISO-SIMPLE algorithm are used for steady state and transient simulations, respectively.

The grid resolution and time step size (60 s) for the transient cooling simulations were determined from a sensitivity analysis.

The cooling rate of each box was assessed by monitoring the temperature (T [K]) of the orange fruit over time, in the center of the fruit. From this data, the unaccomplished temperature change (Y) was determined:

$$Y = \frac{T - T_a}{T_i - T_a} \qquad \text{(D.1)}$$

Here, the subscripts i and a are the initial fruit temperature and the set point temperature in the unit operations. From this value, the seven-eighths cooling time (SECT, $t_{7/8}$) is determined. The SECT is the time required to reduce the difference in temperature between fruit and delivery air by seven eighths (Y = 0.125).

Table D.1: Boundary conditions for three different cold chain scenarios for each of the unit operations with respect to airflow rate (AFR), set point temperature (STP), and duration (D) of the unit operation. "-" means that the cold chain does not contain the corresponding unit operation.

Scenario	Precooling			Cold storage before shipment			Refrigerated transport			Cold storage after shipment		
	AFR	SPT	D	AFR	SPT	D	AFR	SPT	D	AFR	SPT	D
	L kg^{-1}s^{-1}	°C	days	L kg^{-1}s^{-1}	°C	days	L kg^{-1}s^{-1}	°C	days	L kg^{-1}s^{-1}	°C	days
Forced-airflow cooling	0.2	3	3	-	-	-	0.02	-1	24	0.002	4	14
Ambient cooling	-	-	-	0.002	3	5	0.02	-1	24	0.002	4	14
Ambient loading	-	-	-	-	-	-	0.02	-1	24	0.002	4	14

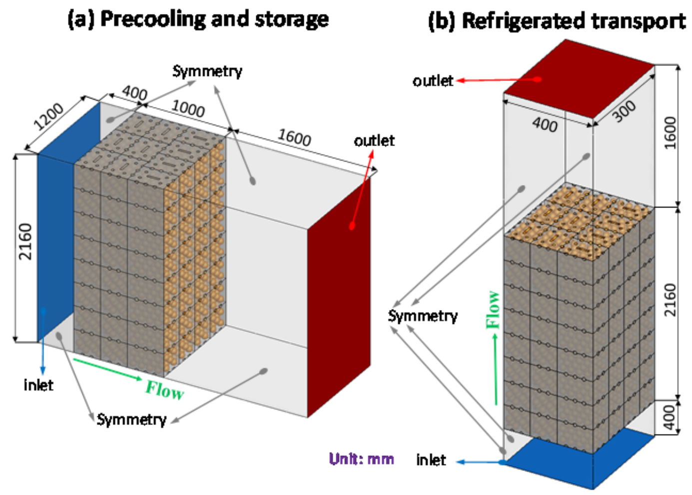

Figure D.3: Geometrical model of a pallet of Standard, Supervent and Opentop cartons. Figure adjusted from Wu et al. (2019).

A previously-developed kinetic rate-law model was applied for fruit quality evolution (Wu et al., 2018; Wu and Defraeye, 2018). This model determines the change in fruit quality, quantified by parameter *A* (Robertson, 2016; Van Boekel, 2008). To include the dependence of quality decay on the temperature, the rate constant was made a function of temperature, for which an Arrhenius relationship was used. The model parameters were calibrated on the basis of experimental data (Wu et al., 2019).

The kinetic rate-law model for fruit quality evolution was developed previously (Wu et al., 2018; Wu and Defraeye, 2018). This simple model quantifies the change in overall fruit quality, indicated by parameter *A*, and based on a kinetic rate law (Robertson, 2016; Van Boekel, 2008):

$$\frac{-dA}{dt} = kA^n \tag{D.2}$$

where *t* is the time [s], *k* is the rate constant [s^{-1}], *n* is the order of the reaction which dictates if the rate is dependent on the value of *A*. A zero-order reaction is assumed here. This implies that the temporal change of *A*, at a given temperature, is a linear curve. The magnitude of its slope equals *k*. Next to overall quality decay, which is modeled here, examples of zero-order reactions are lipid oxidation and enzymatic degradation (Robertson, 2016; Van Boekel, 2008).

If Eq. (D.2) is integrated, a linear decrease of the quality parameter is found at a constant temperature, since *k* is temperature dependent:

$$A = A_0 - kt \tag{D.3}$$

where A_0 is the quality at the start of a cold chain (t = 0 d). To include the dependency of quality decay to the temperature, the rate constant k is made a function of temperature. For this purpose, typically an Arrhenius relationship is used:

$$k(T) = k_0 e^{\frac{-E_A}{RT}} \tag{D.4}$$

where k_0 is a constant [s^{-1}], E_A is the activation energy [J mol^{-1}], R is the ideal gas constant (8.314 J mol^{-1} K^{-1}), T is the absolute temperature [K]. To calculate $k(T)$, k_0 and E_A are calibrated based on information of quality decay, and are assumed to be independent of temperature here.

However, k needs to be known at a certain temperature. Here, we assume that orange fruit can be stored for approximately 56 d at 4 ºC, according to Cantwell (2001). This means that if the fruit is kept 56 d hours at 4 °C, the quality is assumed to be entirely lost (remaining quality A_{end} = 0%). Second, information on the temperature dependency of the rate constant is needed. This information is obtained via the Q_{10} value:

$$Q_{10} = \frac{k_{T+10}}{k_T} \tag{D.5}$$

where k_T and k_{T+10} are the rate constants at temperatures T and T+10K. Van't Hoff's rule states that the rate of a biological reaction doubles or triples for every 10°C rise in temperature (Thompson, 2004). As such, the Q_{10} value is typically about 2-3 for degradation reactions in fruit (Robertson, 2016; Thompson, 2004). Here, a Q_{10} value of 2 was chosen, which means that an increase in temperature of 10°C doubles the rate constant, so halves the time until the shelf life is lost, if stored at a constant temperature. This implies that citrus fruit can be stored for approximately 28 d at 14 ºC. Based on these quantities, the rate constants at 4 ºC and 14 ºC can be derived via Eq. (D.4). Using these two rate constants and Eq. (D.5), E_a and k_0 can be calculated, which equal 4.59 x 10^4 J mol^{-1} and 7.89 x 10^6 d^{-1}, respectively. As fruit temperature varies along the cold chain, the rate constant will also vary accordingly.

The following cold chain scenarios (see Table D.1) are assessed: the forced-airflow precooling chain, the ambient cooling chain, which does not include precooling, and the ambient loading chain (Defraeye et al., 2015), where the fruit are directly loaded at ambient conditions into a refrigerated container. Ambient loading is used to shorten the supply chain and to enable postharvest cooling in regions with insufficient (pre)cooling facilities.

D.1.2 Coupling VCC to LCA

The energy coefficient (EC) is used as an input for LCA (Sanjuán et al., 2014) to quantify the energy consumption of cooling for each of the unit operations (precooling, transport and cold storage). The EC represents the heat that has to be extracted from the fruit (in kJ) per kJ of electricity that is consumed to achieve this goal, and is defined as (Thompson et al., 2010):

$$EC = \frac{Mc_p(T_i - T_f)}{E_e c} \tag{D.6}$$

where M is the mass of all produce that is cooled per month [kg mo^{-1}], c_p is the specific heat capacity of the produce [kJ $kg^{-1}K^{-1}$], T_i is the initial temperature of the product [K], T_f is the final temperature of the product [K], E_e is the electricity consumed per month to operate the cooling facility (kWh/mo) and c is 3600 kJ kWh^{-1}. In conventional LCA, the energy use is assumed constant for a specific unit operation (Stoessel et al., 2012). By combining VCC with LCA, a package-specific EC could be determined in this study, together with more accurate values for each unit operation.

The procedure to determine the package-specific EC is briefly described. Note that the EC was originally defined for entire cooling facilities. An estimation of the EC requires data on the refrigeration heat loads (e.g. heat that is stored in the fruit, building transmission heat loads, heat of lighting and fans, etc) and also the energy needed for fans, lights and lift trucks, for a typical cold storage facility. For forced-airflow precooling, the EC is typically 0.40 (Thompson et al., 2010). This value was taken as a reference point for the Standard carton in this study for forced-airflow cooling, which enabled the typical electricity use (E_e) to be quantified (Eq.(D.2)). Using this value, the EC values for Supervent and Opentop cartons were recalculated, on the basis of the method presented in (Thompson et al., 2010). The main differences between the packages originated from their different air resistance (and thus pressure drops), different residence times in the precooler (SECT) and differences in field heat due to different amounts of fruit to be precooled per pallet (e.g. for Opentop), due to the different fruit packing density. These air resistances and residence times were extracted from the VCC calculations, and other quantities are taken to be similar for all package designs. In this way, the EC of Supervent was 0.41 and that of Opentop was 0.36 for forced-airflow precooling (Table D.2).

To determine the EC for refrigerated transport, a similar procedure was applied, where the air resistances and residence times were extracted from the VCC. On the basis of that, the EC was calculated. However, the energy consumption of the container was dependent on the mode of operation as well. When fruit is still cooling, so that it has not yet reached the SECT, the package-specific EC specified in Table D.2 was used to calculate the energy use. Differences between the packages originated from different air resistances (e.g. for Opentop) and differences in amounts of fruit in the container, due to the different fruit packing density.

After the fruit reached the SECT, where the duration is different for each package and cold chain scenario, the energy consumption was calculated as being dependent on the outside temperature (see Eq.(D.3)). Since heat losses through the container walls do not depend on the package design, the same energy consumption was modeled for each package design in this stage of the cooling process.

For cold storage, the same energy coefficients as for forced-airflow cooling were assumed since the impact of the package design on air resistances and cooling times is similar. Note that the food quality information of the VCC method is not used yet as an input to LCA, but is used separately to evaluate the cold chain performance from a quality perspective.

Table D.2: Energy coefficients for cooling of orange fruit for precooling, refrigerated transport in a container, and cold storage for three package designs.

	Standard box	Supervent box	Opentop box
Forced airflow cooling [kJ/kJ]	0.40	0.41	0.36
Refrigerated container [kJ/kJ]	0.40	0.41	0.27
Cold storage [kJ/kJ]	0.40	0.41	0.36

D.1.3 Life Cycle Assessment

For the life cycle inventory of agricultural production of oranges in South Africa and Spain, we use a dataset from ecoinvent, which includes, among others, the processes of planting, pesticide application, fertilization, harvesting, machine infrastructure, transport on farm, irrigation, planted trees, and direct field emissions from crop production activities (e.g. fertilizer and pesticide use). The modeled inputs and yields are shown in Table D.3. Land use changes are not considered (Ecoinvent, 2016). The climate change impacts according to this dataset are slightly higher (deviation of 10-20%) than in the corresponding datasets of the World Food LCA Database, even though the latter also includes land use changes (WFLDB, 2015).

Table D.3: Mineral fertilizer, manure, and pesticide application and yields assumed in the life cycle inventory of agricultural production in South Africa and Spain, based on FAO (2005) and Sanjuan et al. (2005).

		South Africa	Spain
Mineral fertilizer	N [kg/ha]	80	300
	P [kg/ha]	80	65
	K [kg/ha]	72	135
Manure	[t/ha]	0	3.6
Pesticides	[kg/ha]	5.3	14
Yield	[t/ha]	34.7	30

The energy consumption for cooling is calculated on the basis of Walker (2015), using the energy coefficients (EC) specified in Table D.2 (as derived above), and assuming an initial (harvesting) temperature (T1) of 21°C in South Africa (August – September, Table D.4) and of 16°C in Valencia (November - August). The resulting electricity consumption is shown in Table D.4 for all unit operations. For refrigerated container cooling, the energy consumption after reaching the SECT is calculated linearly with respect to the outside temperature, using the following equation in Fitzgerald et al. (2011):

$$y = 0.0696\, T_e + 0.9406 \tag{D.7}$$

where T_e is the outside temperature [°C] and y the average power consumption rate [kW$_{el}$/ twenty-foot equivalent (TEU) container]. This leads to an energy consumption of 2.3 kW$_{el}$/TEU at 20 °C or 3.7 kW$_{el}$/TEU at 40 °C. Note that in previous LCA studies, the power of a container was typically assumed to be constant (e.g. 3.6 kW$_{el}$/TEU (Stoessel et al., 2012)). The outside temperature is assumed to be linear between places during transportation (South River Valley – Port Gentil – Rotterdam – Zurich and Valencia – Zurich). We use the monthly average temperature of August and September for transport in South Africa, of September and October for European transport of oranges from South Africa, and of November to August for imports from Spain (Häller, 2016; Stoessel et al., 2012).

Table D.4: Calculation of energy consumption for cooling of orange fruit from ambient temperature to final storage temperature for the cold chain scenarios and packages for the life cycle inventory. A harvesting temperature of 21 °C (T_1) is assumed (conservative assumption for Port Elizabeth in July/August) and a final storage temperature of -1 °C (T_2). In the precooling facility, on the basis of Häller (2016), oranges were cooled down to 3 °C (T_{2a}) and then loaded to the container, where they were further cooled down to -1 °C. In the scenario "ambient cooling", oranges were cooled down to 16 °C (T_{2b}) in the cooling facility and then loaded to the container for further cooling.

Removing heat from products			Scenario "forced-airflow precooling"			Scenario "ambient loading"			Scenario "ambient cooling"		
			Standard	Opentop	Supervent	Standard	Opentop	Supervent	Standard	Opentop	Supervent
Precooling	T_1 (harvesting temperature)	°C	21	21	21						
	T_{2a}	°C	2.5	2.5	2.5						
	Energy removed	kJ	71.2	71.2	71.2						
	Electricity consumed	MJ	**0.178**	**0.198**	**0.174**						
Cold storage prior to shipment	T_1 (harvesting temperature)	°C							21	21	21
	T_{2b}	°C							16.1	15.7	16.7
	Energy removed	kJ							19.3	19.3	19.3
	Electricity consumed	MJ							**0.048**	**0.053**	**0.047**
Refrigerated transport in container	T_1	°C	2.5	2.5	2.5	21	21	21	16.1	15.7	16.7
	T_2 (final temperature)	°C	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Energy removed	kJ	13.5	13.5	13.5	84.7	84.7	84.7	65.5	65.5	65.5
	Electricity consumed	MJ	**0.034**	**0.050**	**0.033**	**0.212**	**0.314**	**0.207**	**0.164**	**0.242**	**0.160**

The electricity generation for container cooling is modeled with a diesel-electric generating set (*ecoinvent* process "Diesel, burned in diesel-electric generating set, 18.5 kW"; 0.262 kg CO_2-eq/MJ). For the energy consumed while the ship is staying in a harbor, the *ecoinvent* electricity mix of the corresponding country is used in the model (with a carbon impact of 0.346 kg CO_2-eq/MJ in South Africa, 0.158 kg CO_2-eq/MJ in the Netherlands and 0.132 kg CO_2-eq/MJ in Spain). For the scenario of solar precooling, we modeled electricity production from photovoltaic, 3kWp flat-roof installation, on the basis of *ecoinvent* (0.014 kg CO_2-eq/MJ).

We assume truck transport distances of 100 km from Ribera Alta/Baixa to the distribution center in Valencia and 1'400 km to Zurich. For oranges from the South River Valley (South Africa), 100 km are estimated to Port Elizabeth, 12'212 km to Rotterdam by transoceanic reefer ship, and 758 km road transport to Zurich (www.sea-distances.org and www.mappedometer.com). Average velocities and waiting times are based on Stoessel et al. (2012). The material use for packaging is modeled assuming recycla-ble corrugated cardboard with a weight of 0.074 kg/kg of fruit for the Standard and the Supervent box and 0.045 kg/kg of fruit for the Opentop box, using *ecoinvent* data (Table D.5).

Table D.5: Datasets from the *ecoinvent* database (EI) and the World Food LCA Database (WF) used for the life-cycle inventory. ("Alloc Rec, U" is a technical abbreviation used in the *ecoinvent* database for "Allocation by recycled content, unit process" (Ecoinvent, 2016; WFLDB, 2015)).

Name of the life cycle inventory dataset	Database	Functional Unit
Agricultural production		
Orange from Spain		
Orange, fresh grade (ES)| orange production, fresh grade | Alloc Rec, U	EI	1 kg
Orange, fresh grade, at farm (WFLDB 3.0)/ES	WF	1 kg
Orange from South Africa		
Orange, fresh grade (ZA)| orange production, fresh grade | Alloc Rec, U	EI	1 kg
Orange, fresh grade, at farm (WFLDB 3.0)/ZA U	WF	1 kg
Precooling (& cold storage)		
Electricity, low voltage (ZA)| electricity production, photovoltaic, 3kWp flat-roof installation, multi-Si | Alloc Rec, U	EI	1 MJ
Electricity, low voltage (ES)| market for | Alloc Rec, U	EI	1 MJ
Electricity, low voltage (ZA)| market for | Alloc Rec, U	EI	1 MJ
Packages		
Corrugated board, recycling fiber, double wall, at plant/RER U	EI	1 kg
Transport		
by ship		
Transport, freight, sea, transoceanic ship with reefer, cooling (GLO)| market for | Alloc Rec, U	EI	1 tkm
Electricity, low voltage (ZA)| market for | Alloc Rec, U	EI	1 MJ
Electricity, low voltage (NL)| market for | Alloc Rec, U	EI	1 MJ
by lorry		
Transport, freight, lorry with reefer, cooling (GLO)| market for | Alloc Rec, U	EI	1 tkm
Transport, freight, lorry >32 metric ton, EURO5 (RER)| transport, freight, lorry >32 metric ton, EURO5 | Alloc Rec, U	EI	1 tkm
Retail and cold storage in Switzerland		
Electricity, low voltage (CH)| market for | Alloc Rec, U	EI	1 MJ
Heat, district or industrial, natural gas (CH)| market for heat, district or industrial, natural gas | Alloc Rec, U	EI	1 MJ
Transport, freight, lorry 16-32 metric ton, EURO5 (RER)| transport, freight, lorry 16-32 metric ton, EURO5 | Alloc Rec, U	EI	1 tkm
Transport, freight, lorry >32 metric ton, EURO5 (RER)| transport, freight, lorry >32 metric ton, EURO5 | Alloc Rec, U	EI	1 tkm
Water Consumption, unspecified natural origin, CH, 1 m^3	EI	1 m^3

Food waste is modeled according to Table D.6. Avoidable food losses in agriculture are not considered because of the high uncertainties involved. According to interviews with a Swiss fruit importing company, most edible South African oranges that do not meet the quality standards for export are used in the domestic markets and for juicing. However, in Spain they approximately estimate that about 10% of the harvest is lost, which is then mainly fed to livestock (Freiburghaus, 2017). Including these estimates would influence the ecological comparison between Spanish and African oranges, and should therefore be based on more reliable data. The unavoidable losses in agriculture are assumed to remain in the fields in an unharvested state. The **unavoidable losses** in trade are assumed to be composted. The avoidable losses are assumed to be sent to anaerobic digestion. The impacts of anaerobic digestion and composting are calculated with the same method as in Beretta et al. (2017).

Table D.6: Avoidable (red), unavoidable (grey) food waste and food donations (green) in % of the input into the respective stages of the food supply chain. The third column defines what the references relate to, assuming this to be representative for oranges imported into Switzerland. Avoidable food waste in agriculture is not modeled due to high uncertainties.

	Reference	avoidable and unavoidable food waste	
Agricultural production	(Freiburghaus, 2017) (Beretta et al., 2017)	Oranges imported to CH Exotic fruit imports to CH	not modeled +8.1% unavoidable
Import (transport and storage)	(Freiburghaus, 2017)	Oranges imported to CH	0.05% (+0.09% donations)
Distribution centre	(Swiss_retailer, 2012) (Beretta et al., 2017)	Oranges imported to CH Exotic fruit imports to CH	0.38% +1.3% unavoidable
Retail store	(Swiss_retailer, 2012)	Oranges imported to CH	4.78% (+0.26% donations)
Households	(DEFRA, 2010) (Quested et al., 2013)	Citrus fruits in UK households	20.7%

D.1.4 Life Cycle Impact Assessment

In addition to the *global warming potential 100a* method, we analyzed the method *ReCiPe,* which translates emissions and resource extractions into 18 midpoint indicators and 3 endpoint indicators. Midpoint indicators quantify impacts on the environment with regard to impact categories, such as climate change or eutrophication. Endpoint indicators aggregate these impact categories further and represent the damage on the three areas of protection "human health", "biodiversity" and "resource scarcity". We only calculate one single endpoint score with the method "World ReCiPe H/A Single Score", which aggregates all the midpoint indicators. The result is expressed in mPt (millipoints) and is normalized with the "average hierarchist" weighing version (i.e. impacts of an average world citizen) (Goedkoop et al., 2013).

D.2 ADDITIONAL RESULTS

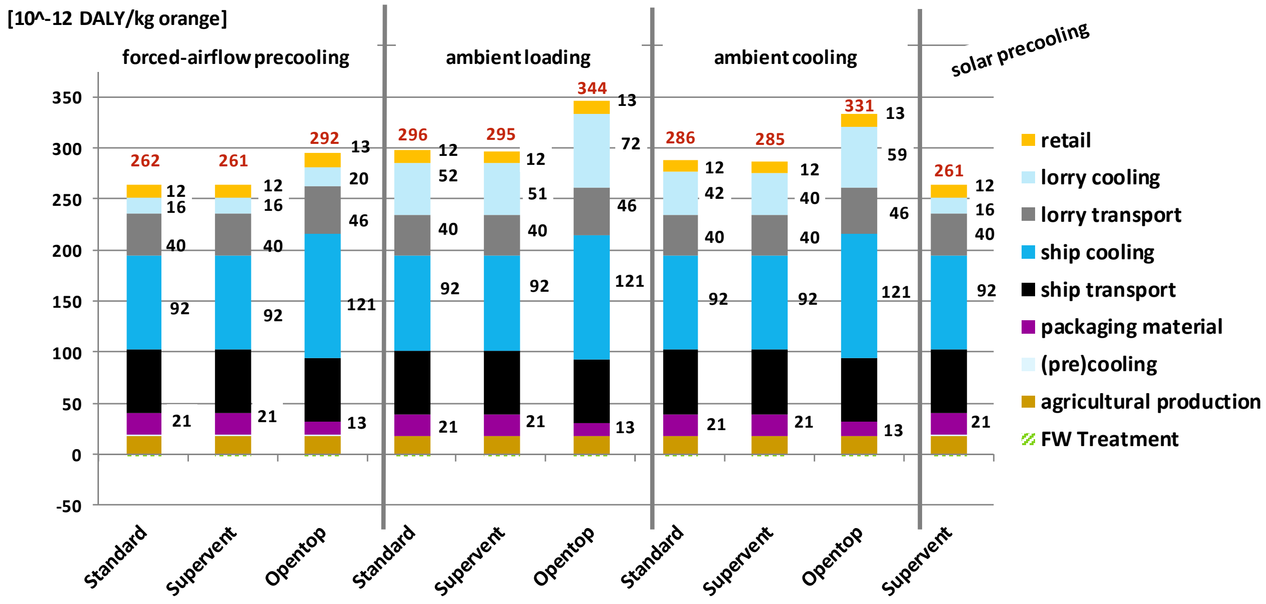

Figure D.4: Human health impact from stratospheric ozone depletion analyzed with the *ReCiPe* method in *DALY* (disability adjusted life years), per kg of fruit (Goedkoop et al., 2013) for all package designs and cold chain scenarios, split up into the different processes of the supply chain.

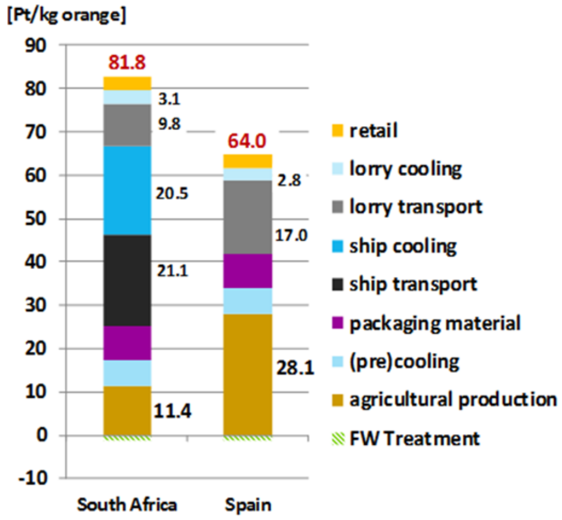

Figure D.5: Environmental impact (*ReCiPe* Pt per kg of fruit) of the Supervent packaging for two different fruit sourcing regions, split up into the different processes of the food supply chain and food waste treatment.

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CURRICULUM VITAE

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EDUCATION

2014 – 2018		PhD on the environmental impact of food losses in Switzerland and strategies for reduction	ETH Zurich, ESD
2012-2013		Scientific Assistant at the Institute of Environmental Engineering; publication of my master thesis "Quantifying Food Losses and the Potential for Reduction in Switzerland"	ETH Zurich, ESD
2011-2013	1 semester	Didactic Certificate in environmental education	ETH Zurich
2009-2011	2 years	Master Studies in Environmental Sciences *Main Subject "Forest and Landscape Management"* *Minor in "Sustainable Energy Use"*	ETH Zurich
		Master Thesis in "Food Recycling and Recovery options in Switzerland"	ETH Zurich and ZHAW Wädenswil
2008	7 weeks	Internship in scientific research: *herb-chronology, plant ecology, eco-physiology, scientific imaging*	University of Arizona, Laboratory of Tree-Ring Reasearch, Tucson
2007	3 months	Language School	Bristol, UK
2004-2007	3 years	Bachelor Studies in Environmental Sciences *Main Subject "Forest and Landscape Management"*	ETH Zurich
1996-2003	7.5 years	High School, *Main Subject "Modern Languages"*	Möhlin and Muttenz (Switzerland, German part)
1991-1996	5 years	Elementary School	Tenero (Switzerland, Italian part)

PRACTICAL EXPERIENCE

2012 – 2018		President of *foodwaste.ch* and project leader	foodwaste.ch, Berne
2016	1 month	Ecovillage Design Education "Creating a transformative culture", by Gaia Education	Schloss Glarisegg (Switzerland)
2012		Co-foundation of the association *foodwaste.ch,* destined to prevent food losses and food waste	foodwaste.ch, Berne
2009	3 months	internship in renewable energy projects, focus on biomass energy	Berne: sol-E Sustainable Energy Solutions
2008-2009	6 months	internship in environmental communication and care	Lucerne: Locher, Schmill, Van Wezemael & Partner AG, Foundation Nature & Economy

FURTHER EDUCATION

2017	“Learning to teach” program for doctoral teaching assistants at ETH	ETH Zürich Lehrentwicklung
2015	“Expand the box” training in Possibility Management	Jura, CH
2015	"The power of your voice - Voice training for lecturers"	Didactica (Uni and ETH Zurich)
2014	Scientific colloquium „Alternatives to Economic Growth“ (wissenschaftl. Kolloquium “Wege aus der Wachstumswirtschaft”)	Forum für Verantwortung, Akademie Otzenhausen (DE)
2014	Presentation with theatre techniques (Präsentation mit Theatertechniken)	Didactica (Uni and ETH Zurich)
2014	National conference on „Nutrition and Sustainability“ (Nationale Fachtagung “Nachhaltigkeit und Ernährung”)	SGE (Schweizerische Gesellschaft für Ernährung)
2014	Visualisation techniques for teaching (Visualisieren von Lerneinheiten)	Didactica (Uni and ETH Zurich)
2013	Member of the project group for a new energy concept of ETH (Arbeitsgruppe zur Erarbeitung des Energieleitbildes der ETH)	ETH Zurich
2012	Enterpreneurship course „venture challenge“	University of Zurich
2011	Course in „Personal communication and public relations“ (Kaderkurs “Persönliche Kommunikation und Öffentlichkeitsarbeit”)	Federal Office for the Environment (FOEN)

POLITICAL ACTIVITIES

2011-2018	Actuary and Board Member of the Green Party, Section of the district of Rheinfelden
2009-2018	Swiss Delegate of the Green Party for the Canton of Aargau
2011	Participation in the “promotion of young politicians program” (Nachwuchsförderungsprogramm der Grünen Partei)

LANGUAGES

Deutsch	Mother Tongue
English	Cambridge Advanced Certificate (CAE)
Italian	colloquial – Elementary School in Italian, 7.5 years of lectures at High school (Main Subject)
French	basic – 7.5 years of lectures at school; Test d’Evaluation de Français etef, Level B2-C1
Spanish	basic – 3.5 years of lectures at school, 1 semester at the Sprachenzentrum der Uni ZH
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