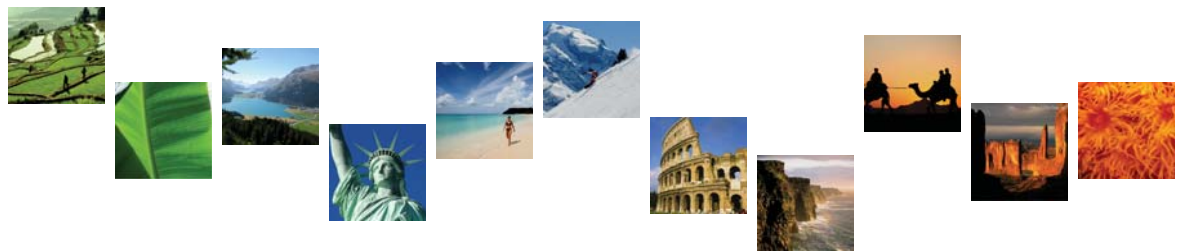


Climate Change and Tourism

Intertwined



Sabine L. Perch-Nielsen

2008

DISS. ETH No. 17758

DISS. ETH No. 17758

Climate Change and Tourism Intertwined

A dissertation submitted to

ETH Zurich

for the degree of

Doctor of Sciences

presented by

Sabine Louise Perch-Nielsen

dipl. Umwelt-Natw., ETH Zürich

born 24 March 1979

citizen of Soglio/GR, Switzerland

Accepted on the recommendation of

Prof. Dieter Imboden, examiner

Prof. Reto Knutti, co-examiner

Dr. Bas Amelung, co-examiner

2008

Summary

Climate change is occurring at a dramatic pace due to human activities and is affecting natural and human systems across the globe in a myriad of ways. Tourism is an important economic sector and is intertwined with climate change. Among the more noticeable adverse impacts of climate change on tourism are the bleaching of coral reefs in diving destinations, decreasing natural snow cover in winter sport destinations and sea level rise in low-lying tourism dependant islands. However, tourism also contributes to climate change through the emission of greenhouse gases (GHGs). This dissertation explores the dual relationship between climate change and tourism by analysing three specific topics of interest from within this subject area.

In the first part, current and future climate resources for sightseeing tourism in Europe were analysed. Climate is considered an important resource for tourism and its suitability for sightseeing tourism has been measured by the “tourism climatic index” (TCI), which summarizes and combines seven climate variables. By means of the TCI, the present climate resources for tourism in Europe and projected changes under future climate change were analysed. Daily data from five regional climate models were used to compare the reference period 1961-1990 to the SRES A2 scenario in 2071-2100. Results suggest that currently climate resources are best in Southern Europe and deteriorate with increasing latitude and altitude. Climate change entails substantial redistributions of climate resources over space and time: the latitudinal band of favourable climate is projected to shift northward improving climate resources in Northern and Central Europe in most seasons. Southern Europe’s suitability for sightseeing tourism drops strikingly in the summer holiday months but is partially compensated by considerable improvements between October and April.

Besides the effect of changing average holiday weather, climate change can influence tourism by changes in sea level rise, flora and fauna, etc. Most studies have only studied one influence climate change can have, while for policy makers and destination managers the integrated effect of these different aspects are of interest. In the second part of this dissertation, an integration method was proposed and applied. The vulnerability of beach tourism to climate change was estimated with an index approach on a country level. A vulnerability framework for the tourism sector was developed and on its basis, indicators were defined for exposure, sensitivity and adaptive capacity. A transparent index approach, including a robustness analysis with multiple transformation methods and weighting sets, yielded an assessment of the overall relative vulnerability of the beach tourism sector in 51 countries. Aggregate results on an annual level indicate that large developing countries might be among the most vulnerable, small islands states are also vulnerable, especially due to their high sensitivity, and developed high latitude countries as well as Mediterranean countries are amongst the least vulnerable.

In the third part of this thesis the perspective was changed towards the contribution of the tourism sector to climate change. For the case of Switzerland, the GHG intensity of the characteristic tourism industries was determined. The GHG intensity compares the GHG emissions of a sector to its value added and thus sets damages and benefits in context to each other. In many European countries including Switzerland, the GHG intensity of economic sectors has recently been calculated. However, tourism is missing from the list since tourism is not measured as an economic sector in the national accounts. The analysis was based on value added from an existing tourism satellite account. Along the system boundaries set out by this economic data set, GHG emissions were calculated in a detailed bottom-up approach. For comparison, the tourism sector's GHG intensity for selected European countries was also calculated using a simpler top-down approach. Results show that the Swiss tourism sector is more than four times more GHG intensive than the average Swiss economy. Of all tourism's sub-sectors, air transport stands out as the sector with by far largest emissions (84%) and highest GHG intensity. The results for other countries make similar, if not as pronounced, patterns apparent. Emission reductions necessary to prevent dangerous climate change stand in stark opposition to current and projected aviation emission growth trends.

Zusammenfassung

Das Klima verändert sich aufgrund menschlicher Aktivitäten in dramatischem Tempo und beeinflusst natürliche und menschliche Systeme weltweit auf verschiedenste Art und Weise. Tourismus ist ein wichtiger Wirtschaftszweig und steht mit der Klimaänderung in Wechselwirkung. Zu den augenfälligsten Auswirkungen des Klimawandels auf den Tourismus gehören die Korallenbleiche in Tauchdestinationen, veränderte Schneeeverhältnisse in Berggebieten und der Meeresspiegelanstieg an Badestränden. Aber der Tourismus trägt durch Treibhausgas-Emissionen auch zur Klimaveränderung bei. Diese Dissertation untersucht die Wechselwirkung zwischen Klimawandel und Tourismus durch die Analyse drei spezifischer Themen.

In einem ersten Teil wurden die gegenwärtigen und zukünftigen klimatischen Ressourcen für den Tourismus in Europa bestimmt. Um die Eignung des Klimas für Sightseeing-Tourismus zu messen, wurde der "tourism climatic index" (TCI) benützt, der sieben klimatische Variablen miteinander verbindet. Anhand des TCI wurden die gegenwärtigen klimatischen Ressourcen für den Tourismus in Europa und die projizierten Änderungen analysiert. Mit täglichen Daten von fünf regionalen Klimamodellen wurde die Referenzperiode 1961-1990 mit dem SRES A2 Szenario von 2071-2100 verglichen. Die Resultate zeigen, dass derzeit klimatische Ressourcen in Südeuropa am günstigsten sind und gegen Norden und mit zunehmender Höhe abnehmen. Der projizierte Klimawandel unter Szenario A2 verursacht erhebliche zeitliche wie geographische Umverteilungen von Klima-Ressourcen: Das Band mit günstigem Klima wird nach Norden verlagert und führt fast durchgehend zu einer Verbesserung der klimatischen Ressourcen in Nord- und Mitteleuropa. Die Eignung Südeuropas für Tourismus nimmt in den Sommermonaten deutlich ab, wird aber teilweise durch erhebliche Verbesserungen zwischen Oktober und April kompensiert.

Neben den Auswirkungen des durchschnittlichen Urlaubswetters kann der Klimawandel den Tourismus auch durch andere Mechanismen beeinflussen, wie beispielsweise durch den Meeresspiegelanstieg oder Veränderungen von Flora und Fauna, usw. Die meisten Studien haben bisher jeweils nur einen Einfluss des Klimawandels untersucht, während für politische Entscheidungsträger und Destinationsmanager die integrierte Wirkung aller Aspekte von Interesse ist. Im zweiten Teil dieser Arbeit wurde daher eine Methode zur Integration vorgeschlagen und angewendet. Die Anfälligkeit des Badetourismus gegenüber dem Klimawandel wurde anhand eines Index auf Länderebene untersucht. Ein konzeptioneller Rahmen für die Anfälligkeit des Tourismus wurde entwickelt. Davon wurden Indikatoren für die drei Anfälligkeits-Dimensionen Exposition, Empfindlichkeit und Anpassungsfähigkeit abgeleitet. Die Berechnungen, einschließlich einer Robustheitsanalyse mit mehreren Transformationsmethoden und Gewichtungen, ergaben eine Bewertung der relativen Anfälligkeit des Badetourismus-Sektors in 51 Ländern. Aggregierte

Ergebnisse auf Jahresbasis deuten darauf hin, dass große Entwicklungsländer zu den anfälligsten Ländern gehören. Kleine Inselstaaten sind auch anfällig, vor allem durch ihre hohe Empfindlichkeit, während entwickelte Länder der hohen Breitengrade und Mittelmeerländer zu den am wenigsten anfälligen gehören.

Im dritten Teil dieser Arbeit wurde die Perspektive gewechselt und der Beitrag des Tourismus zum Klimawandel ins Zentrum gerückt. Für die Schweiz wurde die Treibhausgasintensität des Tourismus-Sektors berechnet. Die Treibhausgasintensität vergleicht die Treibhausgasemissionen eines Sektors mit seiner Wertschöpfung und setzt damit Schaden und Nutzen miteinander in Beziehung. In vielen europäischen Ländern wurde in den letzten Jahren die Treibhausgasintensität der Wirtschaftssektoren ermittelt. Allerdings wurde der Tourismus jeweils nicht berücksichtigt, da er in volkswirtschaftlichen Gesamtrechnungen nicht als eigener Sektor gilt. Die hier vorgelegte Analyse stützt sich auf Wertschöpfungsdaten eines vorhandenen Tourismus-Satellitenkontos. Basierend auf den durch dieses Konto definierten Systemgrenzen wurden in einem detaillierten Bottom-up-Ansatz die Treibhausgasemissionen bestimmt. Als Vergleich wurde zusätzlich die Treibhausgasintensität der Tourismus-Sektoren ausgewählter europäischer Länder mit einem einfacheren Top-down-Ansatz berechnet. Die Ergebnisse zeigen, dass die Treibhausgasintensität des Schweizer Tourismus-Sektors mehr als vier mal höher liegt als diejenige der Schweizer Wirtschaft im Durchschnitt. Von allen Sub-Sektoren weist der Luftverkehr mit Abstand die höchste Intensität also auch den grössten Anteil der Gesamtemissionen aus (84%). Für andere Ländern sind die Resultate ähnlich, wenn auch weniger ausgeprägt. Die Emissionsreduktionen, die notwendig sind, um eine gefährliche Klimaveränderung zu verhindern, stehen im krassem Widerspruch zu den aktuellen Wachstumstrends der Luftfahrt-Emissionen.

Table of Contents

1	Introduction	1
1.1.	The Influence of Climate Change on Tourism.....	2
1.1.1	The Direct Influence: Average Weather as a Resource for Tourism.....	3
1.1.2	Indirect Effects	6
1.1.3	Integration.....	13
1.2.	Impact of Tourism on Climate Change.....	14
2	Future Climate Resources for Tourism in Europe based on the daily Tourism Climatic Index	19
2.1.	Abstract.....	19
2.2.	Introduction.....	19
2.3.	Methods and Data	21
2.3.1	The Adjusted Tourism Climatic Index	21
2.3.2	Calculations	23
2.3.3	Data.....	24
2.4.	Present Climate Resources for Tourism and the Skill of Models in Simulating their Distribution	25
2.5.	Projected Changes in TCI Distribution.....	27
2.6.	Projected Changes in the “Seasonality” of Climate Resources	31
2.7.	Discussion and Conclusion	32
2.8.	Methodological Reflections	33
3	The Vulnerability of Beach Tourism to Climate Change - An Index Approach	35
3.1.	Abstract.....	35
3.2.	Introduction.....	35
3.3.	Development of a Conceptual Framework	37
3.4.	Method and Data.....	39
3.4.1	Temporal and Geographical Scope.....	39
3.4.2	Selection of Indicators	40
3.4.3	Exposure Indicators	43
3.4.4	Sensitivity Indicators	44
3.4.5	Adaptive Capacity Indicators	45
3.4.6	Transformation of Indicators	46

3.4.7	Weighting of Indicators and Aggregation.....	47
3.4.8	Robustness Analysis and Identification of the Most and Least Vulnerable Countries	49
3.5.	Vulnerability Profiles and Patterns	49
3.5.1	Results	49
3.5.2	Discussion	52
3.6.	Robustness Analysis	54
3.7.	Limitations	57
3.8.	Conclusions.....	58
3.9.	Acknowledgements.....	58
4	The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland	59
4.1.	Abstract.....	59
4.2.	Introduction.....	59
4.3.	System Boundaries	61
4.4.	Tourism in Switzerland.....	62
4.5.	Methods and Data	63
4.5.1	Bottom-up Approach.....	63
4.5.2	Top-down Approach.....	65
4.6.	Greenhouse Gas Emissions of the Tourism Sector.....	66
4.7.	Greenhouse Gas Intensities.....	66
4.7.1	Comparison with other Sectors of the Swiss Economy	68
4.7.2	Comparison with other Countries' Tourism Sectors.....	68
4.8.	Sensitivity of the Results and Data Quality	69
4.9.	Discussion and Conclusion.....	71
4.10.	Acknowledgements.....	72
4.11.	Annex A.....	73
5	Concluding Remarks and Future Research	75
5.1.	Future Climate Resources for Tourism in Europe based on the Daily Tourism Climatic Index.....	75
5.2.	The Vulnerability of Beach Tourism to Climate Change - An Index Approach.....	76
5.3.	The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland	76
5.4.	Thoughts on Climate Change Impact Assessments.....	77
6	References	79

Acknowledgements

Many people contributed to this PhD thesis in one way or another. I would like to thank Professor Dieter Imboden for encouraging me to undertake this thesis, for giving me the freedom to follow and implement my own ideas, for the trust put in me, valuable feedback, discussions on climate, energy and research, for his strength and clear mind.

I am very grateful to my co-examiners, Reto Knutti and Bas Amelung for their support and encouragement. I very much enjoyed the exchange and the open discussions on all topics of my PhD, and appreciate their contributions from both the climate science and economic tourism perspective.

Also, I thank my roommates Michèle Bättig, Michael Kost and Jill Peloquin for simply bearing with me, listening and laughing, for discussions and feedback and help with organizing thoughts, finding the right English words and tricking Matlab into doing what I wanted it to.

My thanks go to Ana Sesartic and Matthias Stucki for their work on the GHG intensity of tourism, for not tiring to call and contact yet another source of information in Switzerland and for making me a smashingly cool marzipan cake-picture.

I thank many others for listening, supporting, discussing and providing data: Bruno Abegg, Simon Donner, Camille Gonseth, Niki Gruber, Martin Hirschi, Zouhair Lachkar, Daniel Lüthi, Carsten Nathani, Gian-Kasper Plattner, Anna Schuler, Bastienne Uhlmann, Fabian Widmann and Martin Wild.

Last but not by no means least I want to thank my parents, Fränzi, Chrigi, and Felix for their constant encouragement and support and for all they have taught me and shared with me along the way.

1 Introduction

This PhD thesis is about climate change and tourism. Climate change is occurring at a dramatic pace due to human activities and is affecting natural and human systems across the globe in a myriad of ways. Without mitigation efforts, the pace of climate change is expected to increase and lead to increasingly detrimental impacts (IPCC, 2007a, b). Like other economic sectors, tourism is affected by climate change but also contributes to it by the emission of greenhouse gases (GHGs). However, in both directions, tourism can be considered a special case:

- Climate change → tourism: Tourism is more directly linked to climate than other sectors. Average weather is a resource for tourism and thus a change in climate might reasonably be expected to affect tourist flows directly. Climate change can also influence tourism indirectly, for instance by affecting low-lying beaches, snow cover or coral reefs, which in turn influence tourism.
- Tourism → climate change: The magnitude of the contribution of tourism to climate change is less well known than that of other sectors. An important reason for this is that it is not measured as an economic sector in its own right in national accounts, leading to generally sparse statistical information on this sector.

In this thesis I explore the dual relationship between climate change and tourism by analysing three specific topics of interest from within this subject area (see Figure 1.1):

1. Direct influence of climate change on tourism: “Future Climate Resources for Tourism in Europe based on the daily Tourism Climatic Index”.
2. Both direct as well as indirect influence of climate change on tourism: “The Vulnerability of Beach Tourism to Climate Change - An Index Approach”.
3. The influence of tourism on climate change: “The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland”.

The whole subject area illustrated in Figure 1.1 is very broad and comprises work from many different fields and disciplines. In this Section, I give an overview of the scientific work in the whole area, shortly pointing out where my contributions fit in (highlighted in boxes).

This PhD is organized as a collection of three papers presented in Sections 2, 3 and 4. In the beginning of each chapter, I indicate to which journal the paper has been submitted.

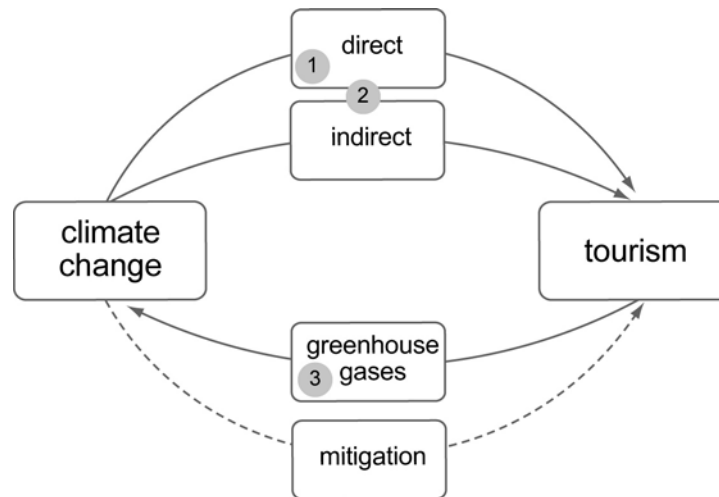


Figure 1.1: Overview of the subject area “climate change and tourism” and the position of the three contributions of this thesis.

1.1. The Influence of Climate Change on Tourism

Climate can influence tourism through different mechanisms. On one hand it exerts a direct influence by determining weather conditions at places of origin and destination. On the other hand it affects tourism indirectly, for instance by influencing natural snow cover or water supply. The high exposure of tourism to climate could be compared to agriculture, which also depends more strongly on climate than other sectors. Also the contribution of gross world product of the two sectors has similar dimensions. Despite this, tourism has received far less attention than agriculture in the climate change discussions. For instance at the time of writing, the ISI Web of Science reports 946 articles for the key words agriculture and climate change, but only 93 for tourism and climate change. One reason for this might lie in the nature of the product at stake: food belongs to the most basic physiological needs, while tourism aims at fulfilling needs on higher hierarchy levels such as belonging, esteem or self-actualization (Maslow, 1943).

What links tourism to climate are the preferences of tourists for certain conditions. Naturally, different tourism types require different climatic conditions, as is easily recognized by comparing surfing, sunbathing and skiing. Besancenot (1990) distinguishes specific requirements that vary with the type of recreational activity and personal preferences from the more fundamental climate requirements:

- *safety*, regarding extreme events, strong winds, cyclones;
- *pleasantness*, meaning sunshine and absence of rain; as well as
- *comfort or health*, referring to thermal wellbeing, and absence of skin cancer, heat shocks, etc.

In this chapter, pleasantness and comfort are reviewed first as direct effects of average weather on tourism. Then, the indirect effects are reviewed. They comprise the effects of climate change on extreme events (safety, see above) and “specific” tourism requirements such as snow cover, sea level, flora and fauna, and water. In the end, the integration of these different aspects is reviewed.

Table 1.1 shows different types of analysis that can contribute to understanding the effects of climate change on tourism. The effect of weather and climate on tourism has been analysed for many years and builds the basis for work on climate change by establishing the relationships (I). The second type (II) usually builds on the first and investigates the hypothetical effect of projected climate change on current tourism. This is the most common form of research in climate change impact assessment, also for tourism. Future scenarios for tourism (III) can be used to create future scenarios of tourism under climate change (IV). These are more seldom as they involve not only assuming global emissions trajectories for climate change but also how tourism will develop over the next decades or longer.

Table 1.1: Types of analysis regarding the influence of climate change on tourism: (adapted from Abegg, 1996; and Krupp, 1995).

	current climate	future climate
current tourism	effect of weather and climate on tourism (I)	effect of projected climate change on current tourism (II)
future tourism	tourism trends and future scenarios (III)	scenarios of future tourism under climate change (IV)

1.1.1 The Direct Influence: Average Weather as a Resource for Tourism

The Effect of Weather and Climate on Tourism

Climate appears to have played a role in travel choices for centuries. Wealthy Romans are reported to have spent their winters in the South and the summers in the cool surroundings of higher altitudes (Besancenot, 1990). In the 18th century, affluent British started frequenting the Riviera in search of mild winters because it was considered salubrious to be exposed to uniform thermal condition throughout the year. The belief in this ideal dwindled to be replaced by a new trend of seeking the sun and high temperatures in the summer months. In the USA in the 1870s, Florida, California and Cuba became popular summer destinations. After World War II, summer beach vacations and tanned skin became fashionable also in Europe (Besancenot, 1990).

It seems obvious that climate played an important role for tourism in the past and still does today. In an effort to better understand this, research in this area has dealt with two aspects: In which way and how strongly do climate and weather influence travel decisions and destination choices? And: Which climatic conditions are currently preferred (by whom, at which time and for which type of tourism)? The main methods that have been used to address these questions are to ask people directly or to observe their behaviour.

German surveys have shown that tourists consider weather and/or climate to be an important factor for destination choice, along with other factors such as landscape, access to the sea/lakes, and price (Hamilton and Lau, 2006; Lohmann and Kaim, 1999). Surveys on tourist preferences confirmed many intuitive assumptions such as the wish for long sunshine duration and the absence of rain and strong winds (Gómez Martín, 2006; Lohmann and Kaim, 1999). More specific questioning has revealed more subtle preferences, i.e. that most tourists prefer a slightly overcast sky to a blue one and a light

breeze to no wind at all (de Freitas, 1990; Scott et al., in press). The ideal temperature naturally differs depending on tourist activity: As expected, optimum temperature for beach use is considerably higher than for the mountain environments (Scott et al., in press). Also, preferences vary in function of the country of origin (Morgan et al., 2000; Scott et al., in press).

The method of directly asking tourists has its caveats. Destination choices might actually not be based on the criteria tourists think or state they are. Furthermore, it is very demanding to state perceived climatic preferences in the form of temperatures or wind speeds. Observing people's behaviour solves some of these problems. The actual climatic conditions can be measured concomitantly with the behaviour and be statistically correlated. For instance webcam observation of beach use has confirmed that rain has an overriding effect over all other variables (Moreno et al., in press). For the North coast of Germany, Krupp (1995) has shown that temperature, number of nice days, sunshine, and precipitation all contributed to explaining the number of overnight stays. Interestingly, the importance of different variables varied with season. On a larger scale, regression analyses on the basis of countries have shown that arrivals correlate positively with temperature but negatively with temperature square (or T^2), indicating an inverted U-shape relationship (Bigano et al., 2006; Lise and Tol, 2002; Maddison, 2001). For precipitation, Lise and Tol (2002) find different optimums for different nationalities. They interpret the optimum above zero as the trade-off between the wishes for both absence of rain and lush vegetation.

The method of observing tourists' travel behaviour might address some of the shortcomings of surveys. However, it also has a number of limitations – high beach attendance, for instance, need not be the result of a high preference for the prevalent conditions. It might be less unfavourable than in other parts of the country, it might be a public holiday, people might leave at lunch time not due to heat but the cultural habit of siesta (Moreno, 2007). Observations and surveys therefore complement each other very well. More studies that combine both at the same site (see de Freitas, 1990) would be a powerful contribution to improving the understanding in this field.

Indices for Favourable Tourism Climate

Published literature thus reveals that weather and climate are indeed important for destination choice and some very general preferences are persistent across different studies and methods. Many researchers have endeavoured to summarize these preferences in a single index of "favourable tourism climate". Such an index can assist investors in choosing where to develop new destinations, or help tour operators or holidaymakers to plan their activities. Since the 1960s, numerous such metrics have been developed and applied (see overviews in Besancenot, 1990; de Freitas, 2003). They can be classified in two main groups:

- elementary indices that use only basic climatic variables, assign coefficients and combine them with addition and/or subtraction; and
- complex indices that also include indicators that combine different variables. An example is an indicator for thermal comfort based on temperature and humidity together.

Despite its clear advantages, such an index has several shortcomings. Indices tend to involve some degree of subjectivity, not account for overriding effects of certain variables and only cover one type of tourist activity. As an alternative, Besancenot et al. (1990; 1978) developed a set of weather types for tourism, which classify the daily combination of basic variables in typical combinations, such as “nice with strong winds”, “fresh and sunny”, “hot and humid”, etc. The distribution of weather types across the year can be shown graphically and gives more detailed information to the interested tourist than a score on a favourability scale.

Climate Change

The literature reviewed so far all refers to the influence of weather/climate on tourism (sector I in Table 1.1). In the 1990s, the number of studies in this field grew and increasingly addressed climate change issues (Scott et al., 2005). One of the indices developed to measure “favourable climate” for sightseeing, the Tourism Climatic Index (TCI) (Mieczkowski, 1985), was used to analyse the potential impact of climate change on tourism. The studies calculated the current and potential future distribution of climate resources for tourism (sector II in Table 1.1) and showed that climate change can substantially redistribute climate resources across regions and between seasons (see Amelung et al., 2007 for a global scale; Amelung and Viner, 2006 for the Mediterranean; and Scott et al., 2004 for North America). A repeated result was a general poleward shift of favourable tourism climate and the change of “summer peak” to “bimodal shoulder peak” distributions in some regions.

Contribution 1: Future Climate Resources for Tourism in Europe based on the daily Tourism Climatic Index

These studies have two important shortcomings. One is that they calculated the TCI with monthly averages, a temporal scale that is insufficient for tourism purposes (de Freitas et al., in press). What tourists experience and react to is the weather, the integrated effect of the different climatic variables on each day (Besancenot, 1990). Another limitation is the uncritical use of climate model output. Some studies have only used one climate model, which provides no indication of the associated uncertainties (Christensen et al., 2007b). I address these issues in an assessment of the effect of future climate change on climatic resources for tourism in Europe (see Section 2). Similar to the other studies, I use the TCI to measure current and future climatic resources but use daily instead of monthly data and base my analysis on five climate models, using a simple indicator to estimate the robustness of the projected TCI changes.

Most studies looking at the effect of climate (change) on tourism focus on the two sectors I and II in Table 1.1. I found only two studies that combined future climate projections with future demographic and economic projections (sector IV) (Hamilton and Tol, 2007; Hamilton et al., 2005). In these studies, relationships were derived between current arrivals/departures and population size, national income, and climate. It was then analysed how tourism flows would change given different socio-economic scenarios and their corresponding climate changes. In the simulation, changes in patterns were larger than in aggregate numbers and in general, effects of climate change were much smaller than those from population and economic growth (Hamilton et al., 2005). Downscaling these results for Germany, Ireland and the UK, it was found that international arrivals would first decrease, as in most of Western Europe domestic tourism increased due to better climatic

conditions. With time, arrivals would increase due to visitors from increasingly rich tropical countries (Hamilton and Tol, 2007).

All these examples show how important climate and weather at the destination are for tourism. However, climate and weather at the place of origin is also relevant. Studies have shown that if conditions are favourable at the place of origin, domestic tourism is high (Giles and Perry, 1998; Hamilton et al., 2005). In addition, climate in the places of origin has also influenced tourism by means of another mechanism. By determining agricultural production and with it the harvesting season it has affected the timing of some holidays. Although the effect of weather and climate on the place of origin is acknowledged, it has received comparatively little attention.

1.1.2 Indirect Effects

Extreme Events

Under projected climate change, increases in intense tropical cyclone intensity and the frequency of heatwaves and heavy precipitation events are likely (IPCC, 2007b). It has been suggested that tourism is more exposed to extreme events than other sectors due to the attractiveness of high-risk areas: ski areas are at risk of avalanches, tropical beaches might lie in the path of tropical cyclones (Murphy and Bayley, 1989). In addition, tourists are expected to be at greater risk than residents because they are unfamiliar with the region, the potential hazards and the self-protective behaviour required (Burby and Wagner, 1996). Research has shown that not only tourists but also tourism businesses are usually not well prepared for hazards (Cioccio and Michael, 2007; Hystad and Keller, 2008). Large businesses are generally better prepared than smaller ones (Drabek, 1995), making the sector generally more vulnerable because it is traditionally dominated by small and medium-sized enterprises. Unfortunately, in some cases even the actual exposure to a hazard does not significantly increase disaster preparation among tourism businesses (Hystad and Keller, 2008).

There is a large research community concerned with hazards/disasters and the issues relevant before, during and after its onset. Studies explicitly investigating tourism therefore focus on the aspects that are specific to tourism. One of these aspects is that in communities with a high share of tourism activity, general disaster planning must include planning for tourists. Burby and Wagner (1996) interviewed hotel owners in New Orleans with respect to tropical cyclones. Many stated that to evacuate their guests they would “charter buses on the spur of the moment” (Burby and Wagner, 1996, p. 53). A quite unrealistic plan given the large quantity of residents without private means of transport trying to escape the city in the same moment. The most important aspect specific to tourism is the secondary effect disasters can have on tourism: the fact that tourists stay away not only shortly but also long after the hazard. The intense (and sometimes sensationalist) media coverage following such an event creates negative images that linger long after the tourism industry is restored. Strong communication and marketing efforts have shown to be all-important in the recovery phase (Cioccio and Michael, 2007; Faulkner and Vikulov, 2001; Huang and Min, 2002; Hystad and Keller, 2008). In many of the case studies reported upon, such marketing strategies and information campaigns made a rapid recovery possible, with destinations receiving average visitor numbers one year after the disaster (Faulkner and Vikulov, 2001; Huang and Min, 2002; Hystad and Keller, 2008; Murphy and Bayley, 1989). In some cases, visitation increased, most notably after

the eruption of Mount St. Helens in the state of Washington, USA. A national monument and a visitors' centre explaining the events led to the disaster itself becoming a new attraction (Murphy and Bayley, 1989).

To sum up, tourism is particularly vulnerable to extreme events, due to hazardous locations, the unfamiliarity of tourists and the smallness of tourism businesses. Research in this field has so far focussed on disaster planning, preparation and recovery and pointed out the necessity of marketing campaigns to attract visitors after a hazard has occurred. I found no studies that have investigated the extent of damage to tourism (in comparison to other sectors) or have looked into potential effects of climate change.

Snow Cover and Snow Sport Tourism

Among the indirect influences, the effect of climate change on winter tourism is the most researched and most reported upon in the media. This is due to the evident and strong dependence on specific climatic conditions and the high value added generated by snow sport tourism. In an overview of the literature up to 1997, König (1998) shows that research started in the mid 1980s and covered Austria, Australia, Canada, New Zealand, Switzerland, and the USA. The focus lay on potential changes in snow conditions: Different models were used and combined to project changes in snow cover, the mean winter snow line or the ski season length. Invariably, the studies showed a deterioration in the conditions, be it in form of an increasing mean winter snowline or a shortening of the season. They also confirmed the expected, i.e. that the lowest lying resorts would be most affected. Since then, further studies have been published projecting shortening ski season lengths (Bürki, 2000; König, 1998). The most comprehensive effort so far has been undertaken by the OECD (2007), which analysed changes in natural snow-reliability for the European Alps, covering Austria, France, Germany, Italy, and Switzerland. Figure 1.2 shows the percentage of current ski areas still snow-reliable under different scenarios of climate change. Already today, nearly 10% of ski areas are not naturally snow-reliable. Under a warming scenario of 2°C, approximately 60% of today's ski areas would be snow-reliable. Large differences between countries are also revealed – while under a warming scenario of 2°C, 80% of Swiss stations would still be snow-reliable, only 13% of German stations would.

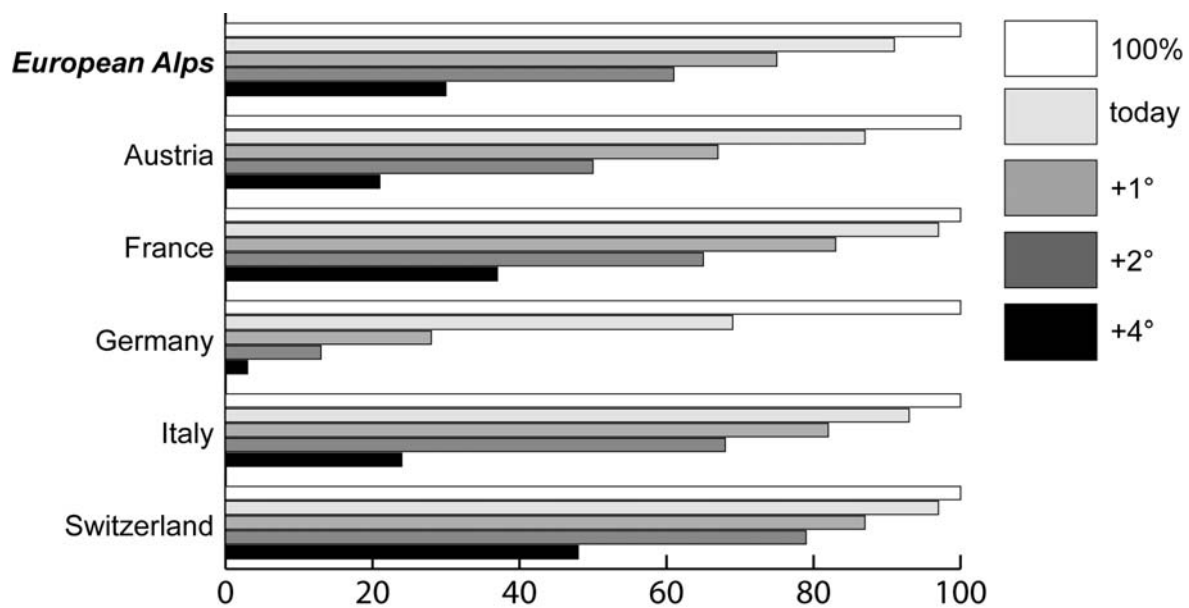


Figure 1.2: Ski areas in the European Alps and their snow-reliability in per cent today, at +1°C, +2°C and +4°C (OECD, 2007).

In the last decade, the research perspective has become broader, recognizing that the actual effects will also depend on how tourists as well as tourism providers react. In a number of surveys, tourists were asked how they would react to several snow deficient winters in a row (Behringer et al., 2000; König, 1998; Unbehaun et al., 2007). The surveys, conducted in Austria, Australia and Switzerland, show similar results: many tourists would ski in a more snow-reliable destination, some would ski less often, some would stay and a few would stop skiing all together. However, the number of people stopping to ski might actually be higher. As Elsasser et al. (2003) point out for Switzerland, not only snow conditions at the destination, but also in the places of domicile are of great importance. On the one hand, a lack of snow in the lowlands means there is no “winter atmosphere” that animates to take part in snow sports. On the other hand, it means that beginners and children cannot learn skiing cheaply and nearby “on the hill behind the house” (Elsasser et al., 2003). In addition, discrete choice experiments have shown that tourists are very sensitive to travel time (Unbehaun et al., 2007). If a more snow-reliable destination is too far away, also these people might ski less frequently.

Adaptation of tourism providers on the supply side has also received more attention from researchers in recent years. The range of potential adaptive measures is large, as shown in Figure 1.3. For North America, Scott and McBoyle (2007) have shown that all of the adaptation options presented have also been applied. By far the most important option is snow-making. Already today many ski areas rely heavily on snow-making for their operation. In a survey of tourism managers in Switzerland in the mid 1990s, Abegg (1996) found that snow-making and other technological practices were the most favoured options. More than ten years later, a survey in Austria shows similar results, with snow-making being the most preferred option, followed by moving to higher altitudes, avoiding southern exposure of the slopes and business practices such as sharing snow-making costs with the accommodation industry, joining conglomerations, and diversifying (Wolfsegger, 2005). Müller and Weber (2007) point out that climate change will increase rock flows and land

slides and will cause permafrost to thaw. This also requires adaptation to ensure protection and stabilization of infrastructure previously held by permafrost.

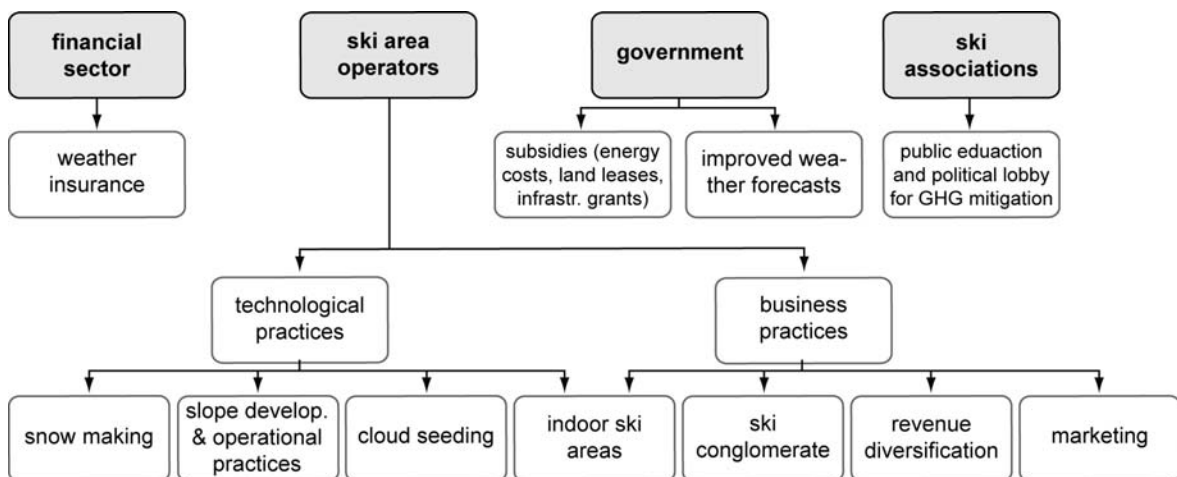


Figure 1.3: Possible adaptation options in winter sports tourism for different stakeholders (Scott and McBoyle, 2007).

Snow-making of course changes the snow reliability of ski areas. It has been shown that projected reductions in ski season length can be attenuated by additional snow-making (Müller and Weber, 2007; Scott et al., 2007a; Scott et al., 2003) and that therefore results as presented in Figure 1.2 must be carefully interpreted. However, so far, the technical feasibility (temperatures, snow gun capacities, etc.) of additional snow-making has been the focus. The high investment and running costs of snow-making might make this option uneconomical for some. Scientific research has not yet explored to what extent substantial additional snow-making is also economically feasible, in part because ski area managers are reluctant to provide the necessary financial data. In addition, snow-making requires very large amounts of energy, in many cases associated with large GHG emissions. It is a prime example for what has been called a “perverse adaptation”, where adaptation and mitigation are antagonistic.

While high lying areas are less affected and can benefit from concentration processes, research seems to agree that in low-lying areas, losses will occur despite additional snow-making. Could the propagation of alternative winter activities, all-year-tourism and the enhancement of summer tourism compensate the financial losses from snow sport tourism in these areas? Most researchers conclude that this is probably not the case (Abegg, 1996; Meier, 1998). In a comprehensive study on implications of climate change for the tourism sector of the Bernese Oberland in 2030, Müller and Weber (2007) take winter losses, adaptation costs and summer gains all into account and estimate a net loss of 4%. Reasons are that the increase in summer visitors is expected to be smaller than the decrease in winter and that daily expenditures for summer or “alternative” winter activities are lower than for skiing and snowboarding.

Despite such results, many North American ski area managers “perceive the risk of climate change to be very low” (Scott and McBoyle, 2007, p. 1426). Based on focus group discussions, Behringer et al. (2000) suggest that Swiss tourism managers downplay the possible risks, but use climate change as an argument for the expansion of snow-making.

The authors conclude that some of the lower lying ski destinations should actively retreat from ski tourism. This stands in contrast to the reported opinion of managers of *low lying* ski areas in Austria: approximately 90% find such an option (very) inappropriate (Wolfsegger, 2005). They estimate their adaptive capacity to be very high. Asked how many years they would be able to maintain an economically viable ski area (including further adaptation), 80% stated 30 years or more while slightly less than 50% expected to be able to continue for 75 years or more.

Snow sport tourism is very vulnerable to warming conditions and currently generates high value added. Climate change is projected to shorten the ski season, particularly in low lying regions. Snow-making is the most popular adaptation option, is technically feasible in many cases and can attenuate the shortening of the season. However, whether it is also economically feasible in all cases is doubtful. The vulnerability of the low lying areas is aggravated by the fact that tourism managers seem to overestimate their adaptive capacity. Enhanced summer tourism, also due to rising temperatures, is seen as an opportunity, but will probably not be able to compensate the winter losses in low lying regions.

Sea level rise

The IPCC projects sea level to further rise by 18 to 59 centimetres between 1990 and 2095 (IPCC, 2007b). Coastal regions are often intensely used by society. For instance population density along the coasts of the world is nearly three times higher than on average (Small and Nicholls, 2003). Economic activities dependent on coasts are fisheries, harbours and tourism. For tourism coastal zones are vital features – be it in the form of sandy beaches for sunbathing, covering mudflats for long walks or spectacular cliffs. The sea is by far the most popular destination of European holiday makers: approximately 63% choose the sea (other types of destinations are mountains (25%), cities (25%) and the countryside (23%)) (European Commission, 1998). In the USA, statistical analysis has shown that tourism-related earnings are highest in counties near the coast (Klein et al., 2004). Particularly in warm destinations, beaches are crucial assets (Dharmaratne and Brathwaite, 1998).

Sea level rise might affect coastal tourism in different ways. Inundation and erosion might cause damage to infrastructure such as hotels, restaurants and roads. Loss of beaches is important for visitors keen on sunbathing, and natural coastlines can be altered in their landscape and composition of flora and fauna. What makes tourism particularly vulnerable is that in many locations hotels and restaurants have been built as near to the coastline as possible to fulfil visitors' preference for proximity to the sea.

General adaptation options towards sea level rise have been categorized into three groups (IPCC Response Strategies Working Group, 1990):

- protection, including hard options such as dikes, seawalls, floodgates, but also soft options such as beach nourishment or wetland restoration;
- accommodation, comprising measures that do not prevent flooding. Vulnerable areas continue to be used. Examples are the modification of land use or building styles; and
- retreat.

In the UK, protection and retreat have been chosen in two different tourism destinations (Jennings, 2004). The author finds “that there is a threshold value of economic assets,

below which re-alignment is possible, and above which holding the line is the only politically and economically viable option” (Jennings, 2004, p. 916).

The reaction of tourists to sea level rise and adaptation measures has been investigated by Uyarra et al. (2005). A survey of tourists in Barbados showed that if beaches “largely disappeared”, 80% would not be willing to revisit for the same price. Hamilton (2007) indirectly looked at preferences for adaptation options by calculating hedonic prices for accommodation on the German coast. She found that dikes lead to lower prices, open coast to higher prices and surprisingly beaches had no influence.

Despite the apparent high vulnerability of the tourism sector along coasts, the scientific literature has only touched upon this topic. Neither global, national nor regional assessments of sea level rise impacts specific to the tourism industry were found. How exposed is the tourism sector in different countries? How would visitors react to changes in coastal landscapes? Is adaptation by tourism managers taking place and if so in which way? These are some of the questions that could be addressed in future.

Changes in flora, fauna and landscape

Nature-based tourism is an important and growing type of tourism. Fauna and to a lesser extent flora are important to tourists interested in activities such as bird watching, diving, safaris, fishing and hiking. Therefore, changes in species composition and distribution might affect tourism. A well-studied impact is the effect of higher temperatures and ocean acidification on corals. A serious decline in corals is projected for atmospheric CO₂ concentrations of 450 to 500 ppm. Above this threshold reefs become “crumbling frameworks with few calcareous corals” and “rapidly eroding rubble banks” (Hoegh-Guldberg et al., 2007, p. 1741). In southern Africa, expected changes in the expansion of its ecozones have been analysed. Climate change would render the regions less favourable for some but more favourable for other species (Preston-Whyte and Watson, 2005). While the study on southern Africa conveys an image of nearly equal winners and losers, calculations by Thomas et al. (2004) are more alarming, projecting 15–37% of species to become extinct by 2050 with a mid-range climate change scenario.

An interesting observation in this context is made by Preston-Whyte and Watson (2005). In southern Africa, they project substantial loss of the Fynbos ecozone but believe it to be “unlikely to be detrimental to tourism. Although the Fynbos ranks as one of the world’s 25 most significant biodiversity hotspots, for most tourists the allure of area has more to do with the excitement of the cable car ride up Table Mountain [...] or the challenge of a mountain climb and the vista from the top” (Preston-Whyte and Watson, 2005, p. 139). Along the same lines Gössling and Hall (2006) point out that while many divers state a preference for high biodiversity in coral reefs, many are unable to judge prevailing conditions. It seems that in some cases biodiversity is not the actual attraction, but rather the colourfulness, cleanliness or “beauty” of the landscape or the presence of specific charismatic or symbolic animals.

How will tourists react to such changes in flora and fauna? In the Caribbean island of Bonaire, 80% of surveyed tourists state they would not revisit the island for the same price if there were “severe bleaching and mortality” of corals (Uyarra et al., 2005, p. 13). This result suggests that diving and snorkelling destinations will be seriously impacted by climate change. Surveys of visitors to national parks in the Rocky Mountains reveal less

strong preferences. Most would not change their visitation behaviour given changes in climate variables as well as indirect variables such as wildlife populations. For those that would, no indirect variable was significant at the 95% level (Richardson and Loomis, 2004). A similar study by Scott et al. (2007a) showed that if glaciers and alpine tundra had disappeared and occurrences of forest fires increased, more than 50% of visitors would visit the national park less or stop visiting all together.

No scientific literature dedicated to adaptation of tourism managers to changes in flora and fauna was found. Regarding changes in national park this is understandable because environmental changes either had no effect or an effect in the most extreme scenario representing the 2080s. However, it is surprising that adaptation measures in diving areas have not been investigated, when adaptation in (similarly sensitive) winter tourism has been studied by quite a few.

Water

Climate change is projected to change water levels in lakes and streams, water temperature, and the availability of water. Changes in water levels and properties will influence a number of recreational activities associated with water such as bathing, boating, fishing, golf, ice-skating and bird watching (see overview by Jones et al., 2006). Examples are decreasing water levels with associated problems for boaters in the North American Great Lakes and decreased ice cover for ice-skating in Canada and the Netherlands (Jones et al., 2006). In addition, it has been suggested that a drying climate in some regions of the world might lead to water supply problems for tourism (Perry, 2000; Scott et al., 2004). An average tourist consumes considerably more water per day than residents do, in part because of additional water uses such as garden and golf course irrigation, cleaning, and swimming pools (Gössling, 2001). In addition, Gössling (2006, p. 184) points out that tourists often arrive in the dry season when water is scarcest and tourism tends to "shift water demand from water-rich to water-poor areas", such as from the North to the South of Europe or also from many regions to the Caribbean. It is estimated that on a global level, international tourism only consumes approx. 0.4 to 0.6 per mill of fresh water consumption (Gössling, 2006). However, for individual countries such as Barbados, Malta, Cyprus, and Spain, tourism-related water use can reach a few per cent of total domestic water use (Gössling, 2006). Perry (2000) fears that in the Mediterranean, for which a drying has already been observed and is confidently projected for the future (IPCC, 2007b), water quality and/or quantity might in future not be able to satisfy tourism's demand.

Which adaptation measures can tourism managers implement? Regarding low lake levels, adaptation strategies included dredging channels, adjusting docks, and restricting the size and location of boats (Bergmann-Baker et al., 1993; cited in Jones et al., 2006). For water shortages, Mallorca can serve as an analogue. Adaptation measures implemented there included reusing treated wastewater for irrigation as well as water transport by ship and the construction of desalination plants (Kent et al., 2002). In Namibia, a study on measures in different tourist facilities revealed a wide range of water management practices including change of garden vegetation, leak control, low-flow showers, low-flush toilets, dry sanitation, bucket showers, absence of pools, etc. (Schachtschneider, 2002).

How do tourists react to such measures? In Mallorca, reports on bad water quality in 2000 led to negative news reports in the German press resulting in a decline of German tourists

to the island. Some hoteliers feared that that “publicizing the water supply issue will tarnish the image of the island as a tourist destination” (Kent et al., 2002, p. 362).

Overall, little is known about the potential impacts changes in water levels and supply could have on tourism. While measures to reuse water and reduce water demand are many, little is known about the perception of tourists towards such measures as well as changed water levels.

1.1.3 Integration

In Table 1.2, an overview of the research focus in the field of climate change and tourism is given. It shows that the effect of climate change on all mechanisms (extreme events to water) have been well studied but not with a tourism perspective. Tourist preferences and/or reactions have been most extensively examined for average holiday weather and also for extreme events and snow cover. The picture is similar for adaptation of tourism providers where also most has been done in the case of extreme events and snow cover. Research gaps become particularly apparent in the reaction of tourists and tourism providers regarding sea level rise and changes in flora and fauna (corals).

Table 1.2: Overview of research on the direct and indirect effects of climate change on tourism. (one X represents only 1 or 2 studies, three X represents a wide array of studies for different areas and sub-topics).

	average weather	extreme events	snow cover	sea level rise	flora & fauna	water
effect of climate change	not applicable	XXX (none specific to tourism)	XXX	XXX (none specific to tourism)	XXX (not specific to tourism)	XXX (none specific to tourism)
tourist preferences/reactions	XXX	XX (not specific to climate change)	XX	X	X	-
adaptation of tourism providers	-	XX (none specific to climate change)	XX	X	-	X (none specific to climate change)

Research regarding the reactions of both tourists as well as tourism providers faces difficult challenges. The most common tool, surveys, have a number of limitations. Besides the usual issues of sampling, it is not known whether respondents really state what they think and whether they would actually behave as they think they would. Measuring revealed preferences by observing behaviour in years or seasons that are similar to projected future conditions avoid such shortcomings. However, in 10, 30 or 70 years to come, socio-economic conditions will be quite different from now. Some of the future tourists in these scenarios have not been born yet. What will their preferences be? It is impossible to tell. As Scott et al. (2007a) remark for the case of glaciers: Future tourists might not feel a “sense of loss”, not knowing that this region or park previously had glaciers. However, it must also be kept in mind that this uncertainty is not new to tourism: the sector has always been strongly exposed to fashion trends (Besancenot, 1990; Crouch, 1995; Eilat and Einav, 2004). Tourism business have had to cope with such changes for

decades and successful ones have adapted to these trends. It is a core skill of tourism managers to influence people's decisions, to sell dreams and emotions, to create wishes and yearnings in potential visitors. Along coasts where all corals have died it might be difficult, but in cases where certain type of fauna is substituted with other types, or where average weather is shifting in time, these skills will probably prove useful and important for adaptation.

Most studies investigating the effect of climate (change) on tourism have focussed on either the direct effect or one of the indirect effects of climate change on tourism (see Table 1.2). This enables an in-depth investigation of the underlying relationships. However, it is also apparent that for a destination all effects as well as adaptation are relevant. Integrating different aspects is still in its infancy. For national parks in North America, the potential effect of both climatic resources as well as environmental changes has been assessed (Richardson and Loomis, 2004; Scott et al., 2007a). Scott et al. (2007a) have shown that both direct and indirect consequences of climate change are important and can have opposing effects.

Contribution 2: The Vulnerability of Beach Tourism to Climate Change - An Index Approach

I contribute to these integration efforts with an index approach (see Section 3). The index presented estimates the relative vulnerability of the beach tourism sector towards climate change in different coastal countries. I use the concept of vulnerability, one of the key concepts in climate impact research but so far not explicitly studied for the tourism sector. I also include many of the mechanisms relevant to beach tourism, namely climate as a resource, extreme events, sea level rise, and coral reefs.

1.2. Impact of Tourism on Climate Change

Tourists cause GHG emissions during all phases of their travel: during the transport to, from and within a destination, for accommodation and for many of the activities (e.g. visiting museums, shopping, skiing, swimming, etc.). Besides these direct emissions, tourists also cause embodied emissions, as for instance emissions to grow the food they eat or to build road infrastructure they use. Questions that have been addressed in this field are: How large is the contribution of tourism to human emissions of GHGs? Are they dominated by transport, accommodation or activities? Are emissions equally distributed across a country's population or do some emit much more than others? What are the determinants of tourism emissions on an individual level?

Total Emissions of GHGs from Tourism

On a national level, total GHG emissions from tourism is not easy to determine. The national GHG inventories allow only to identify rough categories such as agriculture and transport but not more specific groups such as tourism. Another possible source are environmental accounts, in which GHG emissions are reported per economic sector (Eurostat, 2003). However, because tourism is not measured as an economic sector in its own right in national accounts (United Nations, 1993), these environmental accounts also do not include tourism. Only few studies provide some estimates of entire tourism's

contribution to GHG emissions. On a global scale the first rough approximation lies at 5.3% of global GHG emissions for leisure related tourism (Gössling, 2002). In New Zealand, tourism is responsible for roughly 5% of emissions if international flight emissions are excluded (Becken and Patterson, 2006). In Germany leisure related tourism causes only 1.6% of national emissions, also excluding international flight emissions. The figures of such studies are not comparable, as their system boundaries vary regarding the type of tourism (leisure/business, domestic/international) as well as the inclusion of aviation emissions.

Besides these figures being difficult to compare, the question arises whether 5% is a large or a small share. One approach to assess this is to compare these negative consequences (GHG emissions) of tourism to its benefits. A simple and useful concept that combines both these aspects in a ratio is environmental intensity. It denotes how much environmental damage is produced per economic value generated (Hupples and Ishikawa, 2005). In many European countries including Switzerland, the GHG intensity of economic sectors has recently been calculated. However, following the national accounts, GHG intensities for tourism are not included.

First estimates of GHG intensities in the field of tourism have been calculated by Gössling and colleagues (2005) for a number of case studies. Their work has two main shortcomings: They measure economic benefit by expenditure, which is less adequate than value added (Jones et al., 2003) and they were not able to draw from data sets in which the economic aspect (expenditures) is compatible with the environmental one (GHGs).

Contribution 3: The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland

I address these two shortcomings in an analysis of the GHG intensity of the Swiss tourism sector (see Section 4). I measure the GHG intensity in GHG emissions per Swiss franc of value added and collect the necessary data along the same consistent system boundaries. To put the results in perspective, I also calculate the GHG intensity of tourism for selected European countries.

Emission Factors

To study the composition of tourism emissions, different aspects have been investigated. From the perspective of an individual trip GHG emissions have been calculated

- per person kilometre for transport;
- per night or square metre for accommodation; and
- per visit for activities.

Emission factors for transport have long been calculated independent of tourism research and are standard data outputs of life cycle assessment databases such as ecoinvent. Figures differ depending on many factors such as on which stages of the life cycle are included, which countries the data are based on and the occupancy of the vehicle. In Figure 1.4 one example of CO₂ emissions from direct operation is presented for different vehicles.

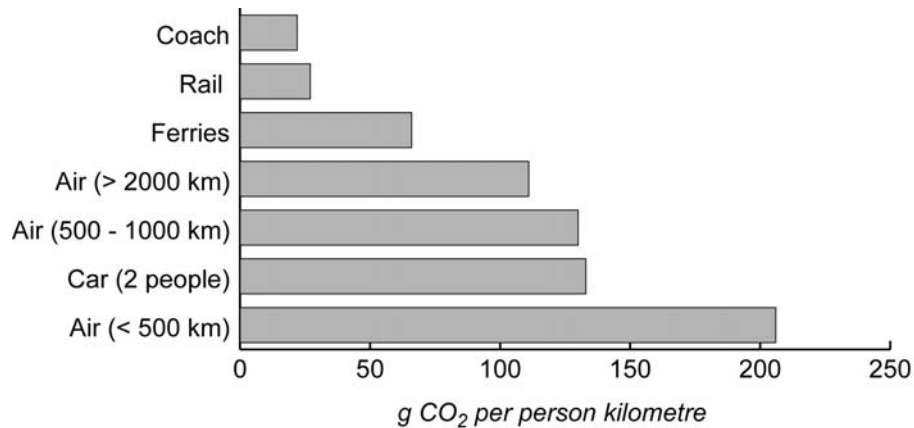


Figure 1.4: CO₂ emission factors for different vehicles in Europe (Peeters et al., 2004).

While the CO₂ emissions can be derived from fuel consumption in a relatively simple manner, the calculation of the overall effect of particularly aviation on the climate is more difficult. In addition to emitting CO₂, aviation contributes to climate change through the emission of NO_x and the formation of contrails and cirrus clouds. However, the quantification of these effects is still a subject of research and discussion (Forster et al., 2006; Penner et al., 1999; Sausen et al., 2005). The additional effect could be substantial: In 1999, the IPCC Special Report (Penner et al., 1999) proposed to multiply the CO₂ emissions with a factor of 2.7. More recent studies suggest that the multiplication factor lies closer to 1.5 (Forster et al., 2006).

For accommodation, the focus has been more strongly on energy consumption than on GHG emissions. Consumption is reported per area or guest-night. In a compilation Bohdanowicz and Martinac (2007) show that there are huge differences in energy use – from 70 up to 1000 kWh/m² year. Many determinants have proved to be relevant for energy use in accommodation facilities: hotel standard, climate conditions, presence of energy-intensive facilities, age and condition of building, energy costs, rules and regulations, awareness of owner and staff (Becken et al., 2001; Bohdanowicz and Martinac, 2007; Nepal, 2008; Trung and Kumar, 2005). In all studies, energy use per guest night increases with hotel standard. This is partially due to the presence of facilities and services (e.g. spas, laundries, pools, etc.), larger rooms and larger areas for common use. In Figure 1.5 the results of Becken et al. (2001) for New Zealand are presented. Interestingly, bed and breakfasts had a very high energy use, primarily due to the large space provided to visitors. It should also be noted that an average night in a motel, backpackers or campground consumes less energy than an average night in a New Zealand household (Becken et al., 2001).

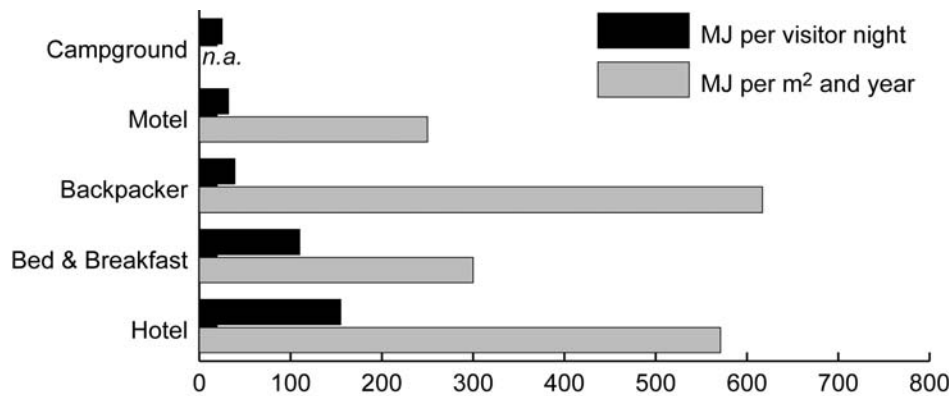


Figure 1.5: Energy use per guest night in different accommodation standards for New Zealand (Becken et al., 2001).

In comparison to the accommodation sector, a lot less data is available regarding tourist attractions and activities. The focus has also been on energy use more than on GHG emissions. As can be expected, the energy use differs widely, with activities such as hiking and visiting museums at the low end use and activities such as scenic flights and diving at the very high end (Becken and Simmons, 2002; EPA, 2000; Stettler, 1997). Below in Figure 1.6 a compilation of energy uses determined by a survey in New Zealand is presented.

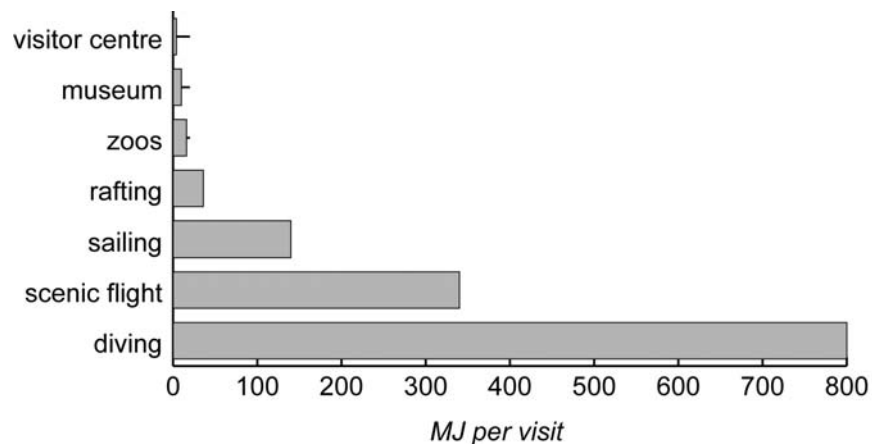


Figure 1.6: Energy use per visit for different activities in New Zealand (Becken and Simmons, 2002).

Composition of Emitters

A few studies have determined overall GHG emissions of tourism or recreation in a bottom-up approach and can therefore show which sub-sectors contribute how much to overall emissions. The three studies presented in Figure 1.7 show very similar patterns despite different foci and methods (similar results can also be found in Becken et al. (2003)). Even without accounting for the additional effect of aviation's emissions (or aviation at all in the case of Germany), transport stands out as the largest contributor to overall GHG emissions, followed by accommodation and activities.

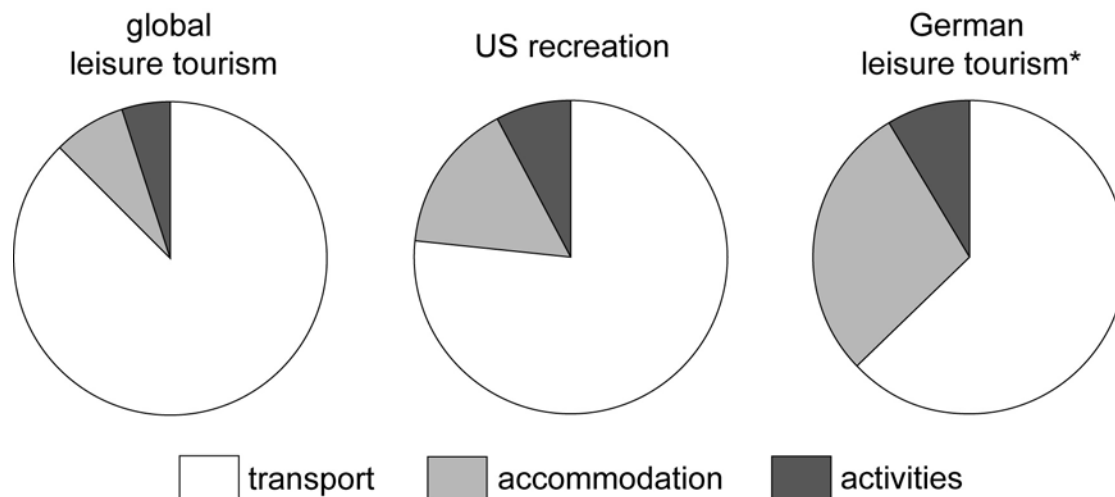


Figure 1.7: Contribution of transport, accommodation and activities to overall GHG emissions for global leisure tourism (Gössling, 2002), US recreation (EPA, 2000) and German leisure tourism (Schmied et al., 2001). Regarding global emissions, no multiplication factor was applied for aviation. *The data for German leisure tourism does not include international aviation emissions.

Other studies have investigated other distribution phenomena. They have shown that most of the emissions are caused by only very few people. On a global level, more than 80% of leisure-related transport is caused by 15% of the world's population, namely the industrialised countries (Gössling, 2002). Within such countries, again the situation is similar: For instance in Europe, 75% of the emissions from outbound transport are caused by 20% of trips (the long-haul trips) (Peeters et al., 2007). In Germany, a similar picture emerges with 80% of the climatic effect of holiday mobility being caused by only 11% of the population (Böhler et al., 2006). These 11% are characterised by high levels of education, high openness to change and are often persons between 26 and 35 or between 35 and 65 years old. Peeters et al. (2007) consider such an uneven distribution to be an opportunity for mitigation because only a small number of tourists would be affected.

Impact of Mitigation on Tourism

If current emission trends are continued, dangerous climate change will ensue. In order to prevent this, mitigation measures are being taken, most prominently on a political global level under the Kyoto Protocol. How would tourism change if mitigation efforts are strongly increased? I did not find studies that considered a range of different mitigation measures/scenarios and analysed their effect on tourism in particular. I would assume that those currently most dependent on GHG emissions would probably be losers, such as the aviation sector and destinations furthest away from important source markets. In contrast, less emitting transport modes and destinations nearer to important source markets would most likely benefit. However, this question opens a vast new field of literature of economics, psychology and policy making beyond the scope of this thesis. Suffice to refer to a number of interesting studies in this field that might serve as a starting point (Olsthoorn, 2001; Tol, 2007; UN-WTO, 2006b; Wit et al., 2002).

2 Future Climate Resources for Tourism in Europe based on the daily Tourism Climatic Index

*Submitted to Global Environmental Change on 26 February 2008
Co-authors: Bas Amelung and Reto Knutti*

2.1. Abstract

Climate is an important resource for many types of tourism. A metric for the suitability of climate for sightseeing is the “tourism climatic index” (TCI), which summarizes and combines seven climate variables. By means of the TCI, we analyse the present climate resources for tourism in Europe and projected changes under future climate change. We use daily data from five regional climate models and compare the reference period 1961-1990 to the A2 scenario in 2071-2100. A comparison of the TCI based on reanalysis data and model simulations for the reference period reveals a good fit. Currently, climate resources are best in Southern Europe and deteriorate with increasing latitude and altitude. With climate change the latitudinal band of favourable climate is projected to shift northward improving climate resources in Northern and Central Europe in most seasons. Southern Europe’s suitability for sightseeing tourism drops strikingly in the summer holiday months but is partially compensated by considerable improvements between October and April.

2.2. Introduction

Climate plays an important role for tourism. It not only codetermines a location’s suitability for different types of recreation activities but is often also responsible for the seasonality experienced in many tourism destinations (Besancenot, 1990). For tourism, a “favourable climate” can be regarded as a resource. Destinations with climate resources of better quality than others enjoy a competitive advantage. Considerable effort has therefore been put into defining a suitable metric for “favourable climate” from the tourist perspective. Such an indicator can assist investors in choosing where to develop new destinations, or help tour operators or holidaymakers to plan their activities. Since the

1960s, numerous such metrics have been developed and applied (see overviews in Besancenot, 1990; de Freitas, 2003).

One of these, the Tourism Climatic Index (TCI) developed by Mieczkowski (1985), has more recently been used to analyse the potential impact of climate change on tourism. The few studies have shown that climate change can substantially redistribute climate resources across regions and between seasons (see Amelung et al., 2007 for a global scale; Amelung and Viner, 2006 for the Mediterranean; and Scott et al., 2004 for North America). The TCI is favoured as an index because it is one of the most comprehensive metrics, integrating all three facets of climate considered relevant for tourism: thermal comfort, physical aspects such as rain and wind, and the aesthetical facet of sunshine/cloudiness. At the same time it is based on climate variables commonly available from weather stations and also climate models, making data provision and calculations fairly simple. Evidently, different tourism activities impose different climatic requirements: Sunbathing, skiing and surfing all call for quite specific and different conditions. No single index can rate the climate for all these specific activities. The TCI focuses on the common and general tourism activities of sightseeing and similar light outdoor activities.

In this study, we use the TCI to assess the effect of future climate change on climate resources for tourism in Europe. On the basis of five regional climate models we compare climate resources in the present (1961 – 1990) to those projected if the SRES scenario A2 were to be followed to the end of the century (2071-2100). From a tourism perspective, this is an horrendously long time frame, well beyond that of tourism researchers let alone entrepreneurs. However, this was the only time frame available for data in daily resolution from multiple models for Europe. In our analysis, we address two limitations of the TCI and previous applications.

A shortcoming of the TCI is that the temporal scale of the variables used – monthly averages – is insufficient for tourism purposes (de Freitas et al., in press). The choice of monthly resolution was probably the result of lacking daily data. Mieczkowski (1985) compared destinations throughout the world and was therefore dependent on the variables and temporal resolution provided by meteorological stations in developed as well as developing countries. However, what tourists experience and react to is the weather, the *integrated* effect of the different climatic variables on each day (Besancenot, 1990). What is the value of knowing, for instance, that in a given place and month it rains 120 millimetres per square metre? From a tourist perspective it is evidently critical to know whether this means permanent drizzle throughout the whole month or heavy but short rainfalls only on a few days. Also the monthly aggregation of daily values as in the “number of rainy days” or “number of windy days” is only of limited use. It is the combination of all facets for each day which is relevant to the tourist. In this study, we solve this problem by adjusting the original TCI to a daily scale and calculating it on the basis of daily climate model output data. This allows determining the number of favourable days per month instead of merely the average TCI.

Previous climate change studies with the TCI have used climate model output rather uncritically. Some studies have only used one climate model, which provides no indication of the associated uncertainties (Christensen et al., 2007b). However, a sense of uncertainty – or robustness – is particularly important for an index such as the TCI. Apart from temperature which is relatively well simulated in climate models, the TCI also includes variables such as wind, precipitation, and cloud cover, which are less well represented in

current climate models (e.g. Räisänen, 2007). We address this by basing our analysis on five climate models and using a simple indicator to estimate the robustness of the projected TCI changes. In addition, we test the quality of the models used by comparing the simulated TCI distribution for the present to the distribution calculated on the basis of reanalysis data.

In Section 2 we describe the TCI adjustments and the climate model data used. We then present the current distribution of climate resources in Europe in Section 3, along with an analysis of the skill of models in representing this distribution. In Section 4, projected changes in mean TCI and in number of favourable days per months are shown, followed by projected changes in TCI seasonality in Section 5 and a discussion and conclusion (Section 6). Finally, the TCI as an index and the applied method are reflected upon in Section 7.

2.3. Methods and Data

2.3.1 The Adjusted Tourism Climatic Index

The basis for the present analysis is the Tourism Climatic Index devised by Mieczkowski (1985). It combines five climatic aspects relevant for tourism, listed in Table 2.1: *daytime comfort (CD)*, *average (or daily) comfort (CA)*, *sunshine (S)*, *precipitation (R)* and *wind (W)*, all of which are calculated in their own specific units and then rated on a scale from -3 to 5 (or 0 to 5 for sunshine and wind).

Table 2.1: Summary of the sub-indices of the Tourism Climatic Index and the climate variables used.

sub-index	abbreviat ion	weight	variables required for adjusted TCI, all daily	availability climate model
daytime thermal comfort	CD	40 %	maximum temperature	yes
			afternoon water vapour pressure	no, mean water pressure taken (see below)
average thermal comfort	CA	10 %	mean temperature	yes
			mean water vapour pressure	no, calculated from daily dew temperature or specific humidity
sunshine	S	20 %	sunshine hours	no, calculated from cloud cover
precipitation	R	20 %	precipitation	yes
wind appreciation	W	10 %	wind speed	yes
			maximum temperature	yes

Both *daytime* and *average comfort* indices combine temperature and relative humidity to an index that reflects thermal comfort. The index used is the “(new) effective temperature” presented by ASHRAE (1972) and originally developed by Gagge et al. (1971). The *daytime comfort* uses maximum temperature and minimum humidity as they are expected to occur in the afternoon, which is when tourists are supposed to be most active. This is also why this sub-index is given most weight in the overall TCI. The *average comfort* uses

the same formula but is calculated with 24 hour averages of temperature and humidity in order to include the effects of very hot or cold night-times. In both cases, the maximum rating of 5 is given for new effective temperature between 20 and 27°C. *Sunshine* is considered a positive feature throughout and its score increases with absolute duration of sunshine per day. Equally direct, the unfavourable feature *precipitation* is measured by mean monthly amount of precipitation. In contrast to the other sub-indices *wind* is rated by means of four different scales. It is generally assumed to be an unfavourable variable, with lowest wind speeds assigned the optimum value of 5. For hot conditions the same principle applies but lowest wind speeds are assigned a maximum of 2. For very cold conditions a wind chill rating is applied. Finally there is a fourth rating system for higher temperatures where moderate wind is expected to have a pleasant effect due to evaporative cooling. By combining all sub-indices the overall TCI is then calculated: $TCI = 2 * (4 CD + CA + 2R + 2 S + W)$. As all sub-indices have a maximum score of 5, this aggregation leads to an overall maximum score of 100, with acceptable scores lying above 40, good scores above 60 and excellent scores above 80 (see Table 2). For more details we refer the reader to the original paper (Mieczkowski, 1985).

Table 2.2: Rating categories of the Tourism Climatic Index (Mieczkowski, 1985).

TCI score	category	mapping category
90-100	ideal	excellent
80-89	excellent	
70-79	very good	very good and good
60-69	good	
50-59	acceptable	acceptable
40-49	marginal	
30-39	unfavourable	unfavourable
20-29	very unfavourable	
10-19	extremely unfavourable	
< 10	impossible	

We made three small adjustments to this original index. One is necessary for the change from monthly to daily data: In the rating scheme for precipitation, the mean monthly precipitation was simply divided by 30 to obtain the precipitation amounts per day.

The two additional modifications update the indicators to reflect a more current state of knowledge. Following Scott (2004), the thermal comfort is no longer measured by the “new effective temperature” (Gagge et al., 1971) but instead by the “apparent temperature” (Steadman, 1984). In addition, the original “wind chill index” (Siple and Passel, 1945) used for one of the four wind rating schemes suffers from some serious shortcomings and was replaced by the wind chill equivalent temperature (Osczevski and Bluestein, 2005).

All climatic variables necessary to calculate the adjusted TCI are listed in Table 2.1. Three of the variables were not available from climate models in the exact format required and therefore had to be calculated: As the number of sunshine hours were not directly available from climate models, they were derived from cloud cover data as suggested by Amelung (2006). We rejected an alternative calculation method using solar radiation data (Yorukoglu and Celik, 2006), as it performed very poorly at high latitudes. Also the

humidity data was not available in the right format: mean water vapour pressure had to be calculated from the mean dew temperature with saturation formulas (over ice and over water; Murray (1967)) or from specific humidity and atmospheric pressure. Finally, the afternoon water vapour pressure was required. As this variable was not available from climate models, the mean water vapour pressure was used. For days with relatively stable weather conditions, this should not overly distort results, as vapour pressure remains quite stable (while relative humidity decreases with increasing temperatures in the afternoon).

2.3.2 Calculations

We used the daily data from regional climate models for Europe (see below) to calculate the TCI for present conditions (1961-1990) as well as for projected future conditions (2071-2100). All future simulations are based on the SRES A2 scenario (Nakicenovic et al., 2000), as this was the scenario that most available models were run with. It also has the advantage of a high signal to noise, as the warming is rather large in that scenario. Main assumptions of this A2 world are a large population growth, regionally oriented economic growth and comparatively slow economic growth and technological change, resulting in a global average surface temperature increase of above 3°C by 2100 compared to 1990 (Meehl et al., 2007b; Nakicenovic et al., 2000).

In addition, we tested the ability of the models to represent the current climate conditions relevant to tourism. The ideal way of achieving this would be to compare TCI results of the 1961-1990 model run with those calculated with observed data. However, data of observed climate on a grid is not available on a daily basis and therefore of no use in this case. Therefore, the TCI from model runs was compared to the TCI calculated with reanalysis data (see below). Reanalysis data are data generated by a long simulation with a weather forecast model, in which the atmospheric variables are continuously corrected by assimilating observational data. Therefore, the simulated weather and climate is close to observations at times and in areas and for variables where a lot of observations are available. Where no observations are present, the simulated variables are entirely determined by the model physics, and can therefore also have biases. These however are typically smaller than the biases of the regional models. As the reanalysis was only available with a lower spatial resolution, the comparison had to be carried out on this coarser grid.

In order to calculate an ensemble mean, all TCI result data were interpolated from their original (rotated) grids to a common rectilinear latitude-longitude. Two interpolations were necessary for different analyses: one onto a common high resolution grid (CRU domain) for the ensemble means of simulations runs. The second interpolation was onto the much coarser grid of the reanalysis data for the comparison of simulations to reanalysis.

Results were analysed for Europe as a whole but also for regions within Europe. The regions chosen are presented in Figure 2.1 and are adapted from Christensen and Christensen (2007). Slight adaptations were made for the Alps and Mid-Europe and for the reanalysis data, nearest neighboring cell borders were used where the grids did not coincide. Grid cell results were area-weighted for regional averages.

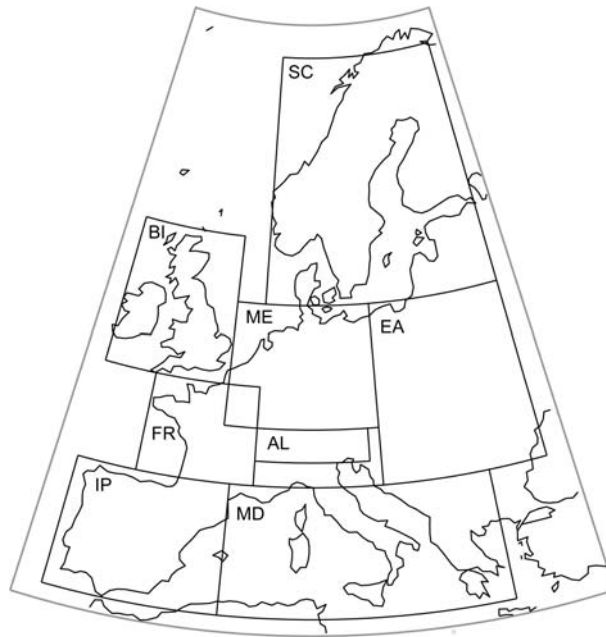


Figure 2.1: The eight regions of Europe used to analyse results: British Isles (BI), Scandinavia (SC), France (FR), Mid-Europe (ME), Alps (AL), Eastern Europe (EA), the Iberian Peninsula (IP), and the Mediterranean (MD).

2.3.3 Data

Two types of data sets were required for this study: Model simulations of present and projected future climate as well as reanalysis data for present climate. The climate model data were obtained from the EU-funded PRUDENCE project and are presented in Table 2.3. The PRUDENCE project combined different driving data with regional models, providing a series of high resolution climate change projections for Europe and allowing for a well-founded assessment of uncertainties (Christensen et al., 2007a). An important advantage of regional models is their high spatial resolution, which has shown to improve the ability of models to represent current climate (Iorio et al., 2004; Kimoto et al., 2005).

Table 2.3: Model combinations chosen for the present analysis.

SRES scenario	regional model	driving global climate model	resolution
A2	HIRHAM (Christensen et al., 1996)	ECHAM5	0.44° (50 km)
A2	HIRHAM (Christensen et al., 1996)	HadAM3H	0.44° (50 km)
A2	REMO (Jacob, 2001)	HadAM3H	0.5° (55 km)
A2	CHRM (Vidale et al., 2003)	HadAM3H	0.5° (55 km)
A2	HadRM3P (Buonomo et al., 2007)	HadAM3P	0.44° (50 km)

The HIRHAM/ECHAM5 model combination as well as the reanalysis data have a Gregorian calendar with 365/366 days per year instead of 360 days as all other models. To generate 360 days we rejected interpolation, as it would have systematically smoothed out the data set. Instead, 5 (or 6) days in regular intervals across the year were deleted every year.

For reanalysis, daily averages from the NCEP/NCAR reanalysis data set were used, as all required variables were available in daily resolution (Kalnay et al., 1996). Its horizontal resolution is approx. 210 km. For this data, precipitation is a variable completely determined by the model without assimilation of observational data (Kalnay et al., 1996). Therefore, reanalysis data for this variable are less reliable, as also revealed by a comparison with monthly precipitation data from other reanalysis sets (CMAP, see Xie and Arkin (1997) and ERA-40, see Uppala et al. (2005)).

2.4. Present Climate Resources for Tourism and the Skill of Models in Simulating their Distribution

Figure 2.2 presents the annual cycle of the TCI for each of the eight regions of Europe for the period 1961-1990 – once calculated on the basis of the reanalysis data (thick line) and five times calculated with the regional climate models (thin dashed lines). Not surprisingly, the present distribution of climate resources in Europe strongly varies across regions and between seasons. The regional average TCI can range from just above 20 (“very unfavourable”) in Scandinavian winter up to nearly 80 (“very good”) for instance in the Mediterranean in September. Most regions can be classified as “summer peak” distributions with the exception of the Iberian Peninsula and the Mediterranean that tend towards “bimodal shoulder peaks” (see Scott et al. (2004) for the typology of distributions) caused mainly by maximum temperatures rising too high in summer to be comfortable for sightseeing activities. Although all regions experience several months of “good” climate resources (TCI > 60), the differences are large: in the two southern regions there are twice as many “good” months as in the Alps or Scandinavia. If the threshold is set at “very good” conditions (TCI > 70), the Mediterranean and the Iberian Peninsula are also in the lead with six months each.

A critical test of climate model quality is to compare how well the models are able to simulate current climate. Large discrepancies between modelled and observed/reanalysis data may point out that important physical processes are not well represented. For the case of the PRUDENCE model data used, comparisons for temperature and precipitation have been carried out (Jacob et al., 2007). It is particularly important to compare simulated to reanalysis TCI results, since for some of the TCI components (in particular precipitation and cloud cover) model uncertainties are still large (Bony et al., 2006; Räisänen, 2007).

The comparison between reanalysis and simulations shows that for some regions, the models achieve a very good fit with reanalysis, as for instance for France, the Iberian Peninsula, and the Mediterranean. In other regions there are significant biases. Model simulations for the British Isles and Scandinavia for instance both show a negative bias (up to nearly 10 TCI points for the ensemble mean) throughout the year. In both cases this is mainly due to a constant positive bias in precipitation and cloud cover in all five models. Together, these two variables constitute 40 per cent of the overall index. The situation is similar in the Alps where there is a pronounced negative bias except for the summer months. Here also both cloud cover and precipitation show positive biases from autumn to spring. The five models do not agree at all on seasonal precipitation patterns. The particularly negative TCI bias in spring is caused by maximum temperatures being simulated too low. In Mid- and Eastern Europe the models are a good fit except for a

positive bias in summer. This can in both cases be attributed to summer biases in all three variables of maximum temperature, precipitation and cloud cover.

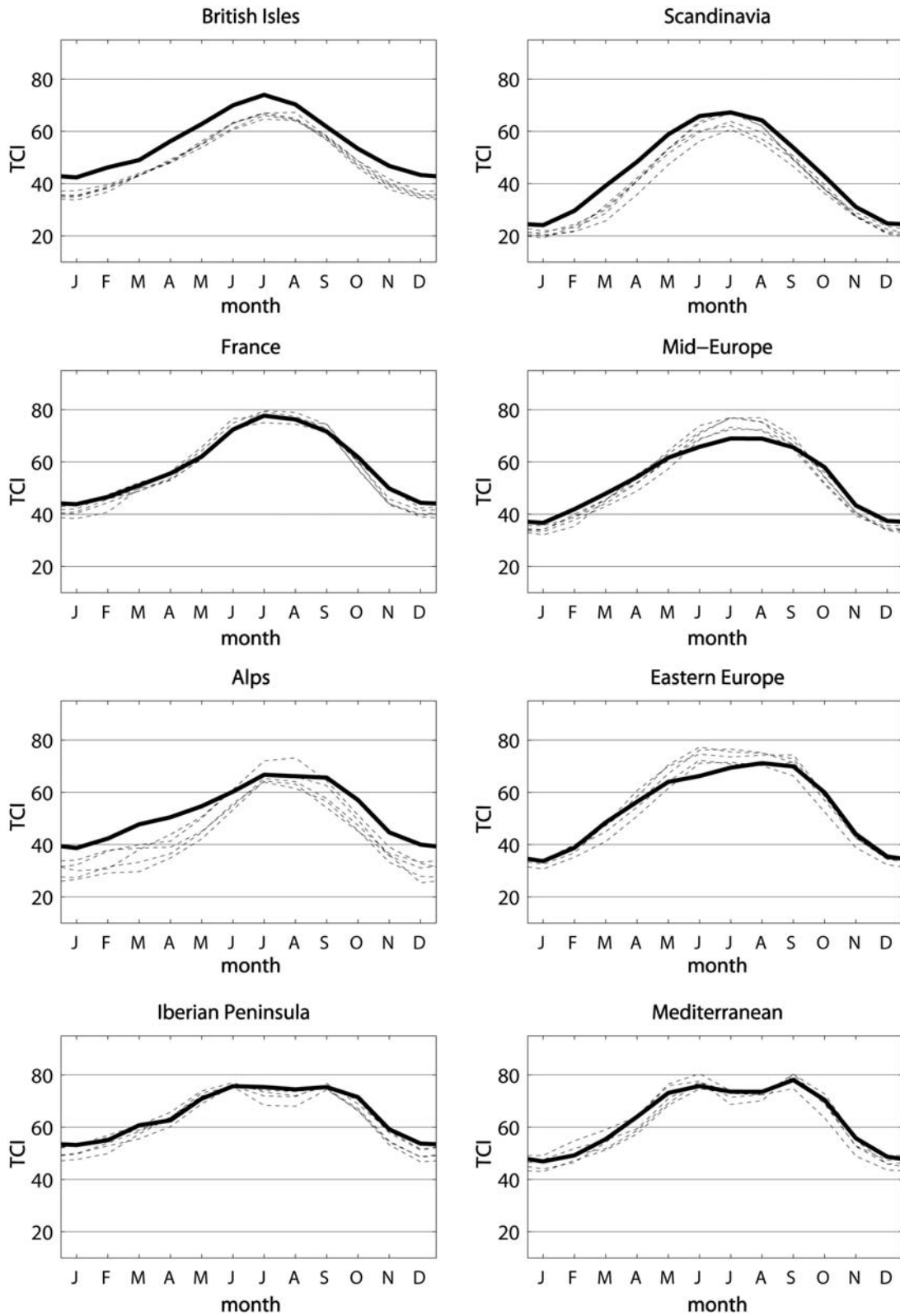


Figure 2.2: Comparison of the annual cycle of the Tourism Climatic Index calculated from reanalysis (thick line) and model simulations (thin dashed lines) for 8 European regions from 1961-1990.

Most of the biases found are related to precipitation, for which reanalysis data are less reliable as mentioned above. As a result, part of the climate model biases might actually be reanalysis biases. All in all though, the models are able to simulate the TCI in Europe reasonably well. They capture both the differences between regions as well as the annual cycle of the TCI.

2.5. Projected Changes in TCI Distribution

The simulation results for the four seasons are presented in Figure 2.3. It shows the ensemble mean of present and future TCI as well as the difference between the two. The predominant predicted change for many regions and seasons is a light increase of up to 10 TCI points. Only small changes are observed in the British Isles in winter and spring, a stretch from France to southern Sweden in winter, along the southern coast of the North and Baltic Sea in summer as well as the Mediterranean in autumn. The most striking change is the deterioration of the TCI across all Southern Europe in the summer months (June, July, and August). It is most pronounced in the most southern countries but extends up to France and Poland. This decline is primarily due to the maximum daily temperature rising too high to be comfortable for light outdoor activities. Also in the summer months, a strong increase in TCI is observed in the Alps. The general change in pattern from present to future is a northwards shift of TCI patterns.

The robustness of these projected changes in TCI is tested for each grid point by calculating the difference between present and future TCI for each model. Then, the mean of these five values per grid point is compared to their standard deviation. If the mean is higher than the standard deviation, models are said to agree on the change. In the graph on projected change, model agreement is denoted by stippling. The stippling shows that in general the five models chosen agree very well on the direction of projected changes.

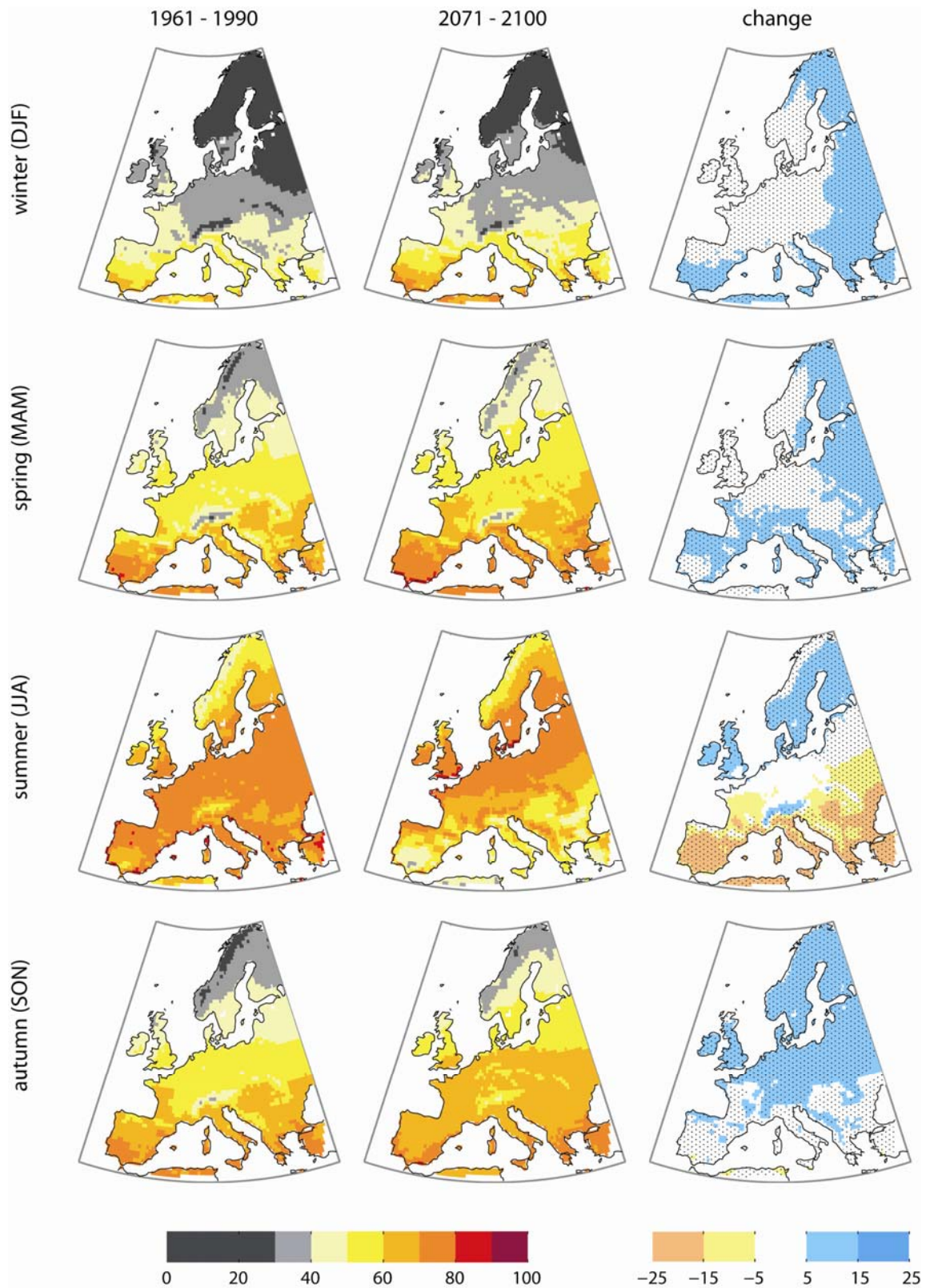


Figure 2.3: Comparison of present (1961-1990) and future (2071-2100) TCI (ensemble mean) for the four seasons. Each row presents one season and shows the present TCI, the future TCI and the difference between the two. The stippling in these latter graphs denotes regions where the five models agree on the change. Models “agree” if for the difference field the multi-model mean is higher than the multi-model standard deviation.

While the seasonally (or monthly) averaged TCI can give a general impression of climate resources in a region, it also has its shortcomings. It hides the TCI variability within a month: a TCI value of 65 can mean constant “good” conditions or very diverse conditions ranging from unfavourable to excellent. The calculation of the TCI on a daily basis allows circumnavigating this problem by simply calculating the number of “good” days per month. Figure 2.4 presents the average number of acceptable, good and excellent days per month for eight European regions for present and future conditions. The general form of the curves are very similar to those of mean simulated TCI in Figure 2.2 and the change patterns reflect those shown by the maps in Figure 2.3. A comparison of TCI change patterns with changes in the basic climate variables (not shown) reveals that the main driving force for the changes is the increase in temperature and maximum temperature across all of Europe and all seasons. Changes in cloud cover and precipitation then either amplify or dampen the temperature effects. In Scandinavia, for instance, temperature is the key cause for the increase in TCI throughout the year, as both cloud cover and precipitation hardly change. Over the British Isles, in contrast, the temperature effect is amplified in summer due to a projected increase in sunshine and decrease in precipitation, and dampened in winter due to an increase in precipitation. France, Mid-Europe, the Alps and Eastern Europe all experience similar changes: a general increase except for summer, where maximum temperature starts climbing over the optimum comfort level, leading to a drop in TCI and a shoulder peak distribution. This drop would be even more striking if it were not for slight decreases of precipitation and increases in sunshine during the summer and adjoining months. Finally, the Iberian Peninsula and the Mediterranean experience a year-through decrease in precipitation and cloud cover leading to an increase in TCI in winter and spring. In summer and the first autumn months, the increasing maximum temperature lead to the largest decreases of simulated TCI.

Our findings confirm the results of previous studies. The northward shift of favourable tourism climate as well as the “bimodal shoulder peak” distribution are changes also reported for the Mediterranean (Amelung and Viner, 2006) as well as North America (Scott et al., 2004). For Southern Europe our results are similar to those of Amelung and Viner (2006). However, they state that the region displays a “summer peak” distribution in the reference period of 1961-1990, while our calculations show an attenuated “bimodal shoulder peak” distribution (see Figure 2.2). This discrepancy is caused by different temporal resolutions: while our classification is based on monthly data, theirs is based on four seasons, which hides the small dent apparent in summer.

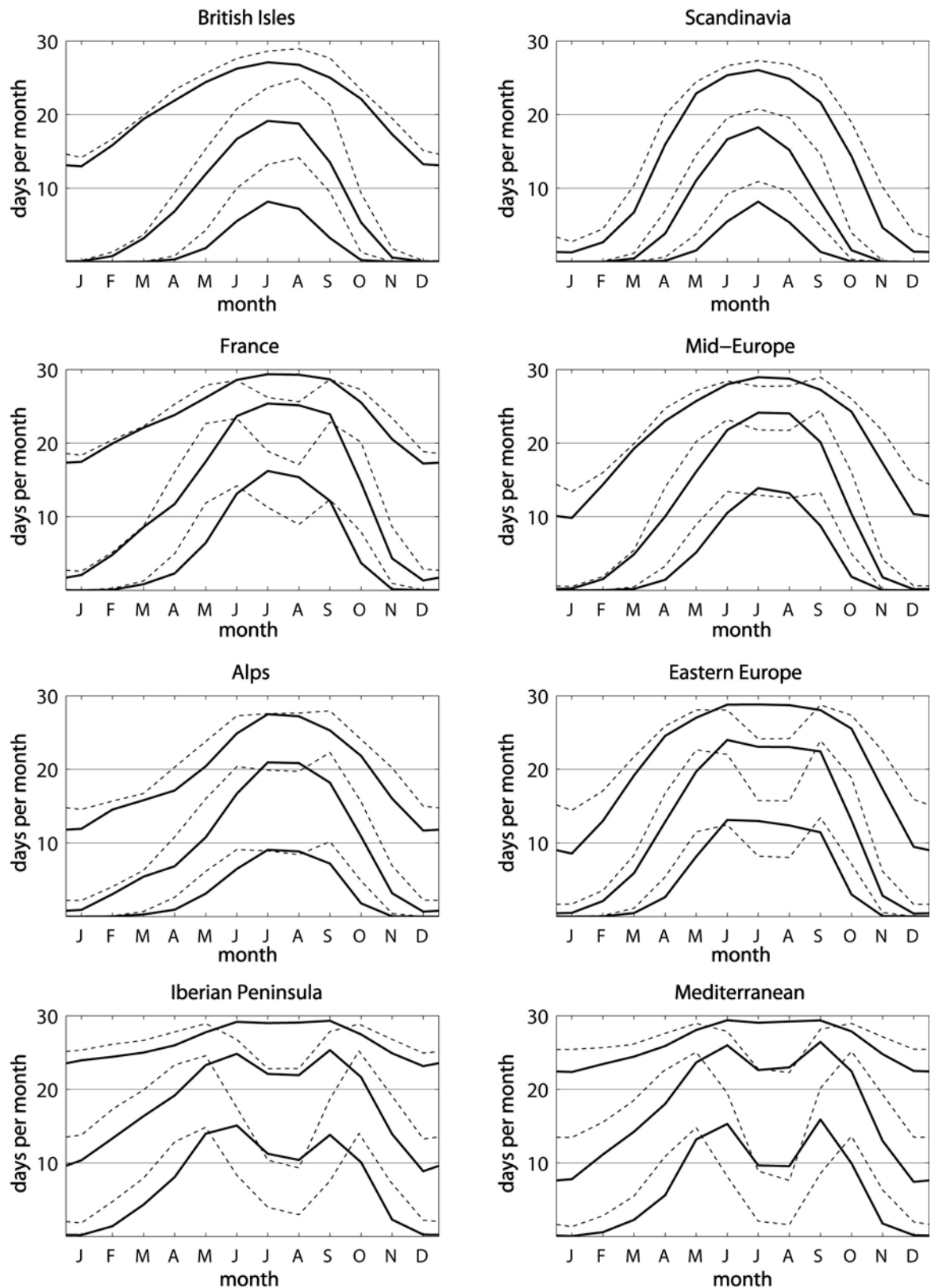


Figure 2.4: Comparison of present (1961-1990, solid lines) and future (2071-2100, dashed lines) number of acceptable, good, and excellent (top, center and bottom line pairs within each panel) days per month for the eight European regions. Acceptable, good and excellent days are defined as having a TCI above 40, 60, and 80, respectively.

2.6. Projected Changes in the “Seasonality” of Climate Resources

Seasonality is “one of the most prominent features of tourism” (Higham and Hinch, 2002, p. 76) that strongly influences the character of destinations. It is predominantly viewed as a problem, particularly from an economic point of view. It causes (tourism) facilities to be crowded in high season and under-utilized in off-season and creates seasonal (un)employment with its associated problems (Getz and Nilsson, 2004). For these reasons substantial effort has been put into reducing seasonality, albeit often with limited success (Getz and Nilsson, 2004; Higham and Hinch, 2002). In some cases seasonality has been also viewed as beneficial by allowing the resident population and environment to restore (Hartmann, 1986). It is generally accepted that seasonality is caused by climatic factors and institutional factors such as the timing of holidays (Hartmann, 1986). How “seasonal” is climate in Europe at present and how is its seasonality projected to change? There are different metrics that summarize the distributions in Figure 2.4 from the seasonality perspective (Lundtorp, 2001). We use the “seasonality ratio”, which is a simple indicator used to measure seasonality in tourism (Yacoumis, 1980). It is calculated by dividing the number of tourists per average month by the number of tourists in the month with maximum visitation. The maximum result of 1 would mean that visitors are distributed equally across all months and the lower the number, the higher pronounced is seasonality. The number of visitors is of course not proportional to the TCI, but we can apply this simple concept to the frequency of good days ($TCI > 60$) in order to determine the projected changes in the seasonality of climate resources.

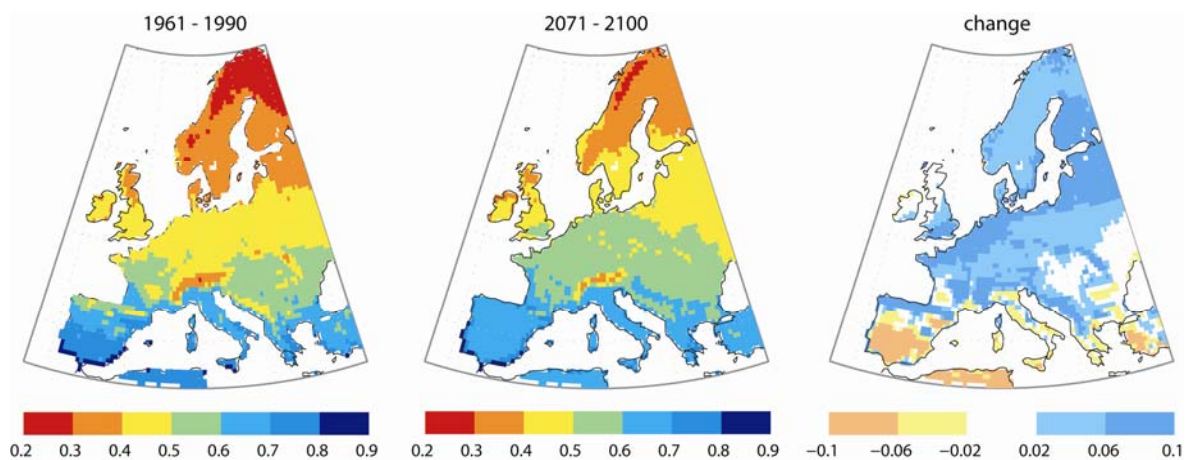


Figure 2.5: Comparison of present (1961-1990) and future (2071-2100) “TCI seasonality” (ensemble mean), measured as mean number of good days ($TCI > 60$) divided by the number of good days in the best month. A value of 1 represents equal number of good days for each month, the lower the value the stronger the seasonality.

Figure 2.5 presents climatic seasonality for the present and future as well as the change field. At present, seasonality increases with increasing latitude or height. The low seasonality of climate resources in the Iberian Peninsula and the Mediterranean, together with its overall high TCI level, explain the high suitability and attractiveness of the region for tourism. By the end of the century, tourism climate seasonality in most of Southern Europe is projected to slightly increase (decrease in ratio). This is primarily caused by a decrease in the mean number of good days, while the annual maximum remains the same or only decreases slightly. The decrease in mean is due to the strong drop in the summer

months, while the annual maximum shifts from September to October but remains the same in absolute terms. Over the rest of Europe the mean number of good days is projected to increase and seasonality to decrease (increase in ratio). In the Adriatic region, Eastern Europe, France and Mid-Europe the increase in mean is combined with a decrease or no change in the annual maximum (regions changing from a summer peak to bimodal shoulder peaks). In Scandinavia, the British Isles and the Alps the number of good days in the best month also increases, approximately by the same amount of days as the mean. Despite the increase in both mean and maximum, the seasonality declines (the ratio increases), as for seasonality to remain equal the mean and maximum would have to increase *proportionally*. In absolute terms, the maximum would thus have to increase more than the mean.

2.7. Discussion and Conclusion

By substantially redistributing climate resources for tourism, climate change produces “winners” and “losers” in different places and seasons. Most parts of Northern and Central Europe can be regarded as “winners” with an increase in mean number of good days accompanied by a decrease in seasonality. In Switzerland, for instance, mountainous regions sense opportunities to increase summer visitation by promoting their destination as an escape from the heat of the lowlands (Müller and Weber, 2007). Most parts of Southern Europe, in contrast, seem to be “losers” with the mean number of good days decreasing on average. Moreover, the sharpest drop occurs during the summer months, when holiday activity in Europe is currently at its highest. Also, southern countries are more sensitive as they are more economically dependent on tourism than the rest of Europe (WTTC, 2007). However, Southern Europe is also a “winner” – in the remaining seven months of the year, the number of good days increases. Also in absolute terms, Southern Europe still displays an overall favourable tourism climate. More than 20 days of good conditions are projected to occur in four to five months of the year. And in the winter months Southern Europe’s climate is projected to be substantially more favourable than the rest of Europe with 15 good days per month in comparison to less than 5 days. In this context, it has to be kept in mind that climate acts not only as a “pull” factor but also as a “push” factor (Giles and Perry, 1998; Hamilton et al., 2005). This means that “winners” of climate change do not only benefit from increases in their “pull” factor but might also experience more domestic tourism due to a reduced “push” factor.

The results we present indicate substantial redistributions of climate resources over space and time, which will undoubtedly influence the future distribution of tourism flows. However, in which way actual tourism flows will be changed can only be speculated upon. For the definition of “favourable climate” can change over time (Besancenot, 1990). It seems plausible that with the gradual warming Europeans would (literally) acclimatize and also prefer warmer temperatures. The definition of “favourable climate” also differs between cultures. Lin and Matzarakis (in press), for instance, showed that Taiwanese perceived thermal conditions to be neutral at 26 to 30°C (physiologically equivalent temperature), compared to 18 to 23 °C for Middle Europeans. Where will tourists in Europe come from in 2070 and what will their preferences be? It seems impossible to say. Furthermore, climate change will not only affect tourism by changing the average weather suitability for sightseeing. Depending on the region, the suitability of average weather for skiing, hiking, or lying on the beach are equally if not much more important. This might be

a key reason why currently tourism flows to the Mediterranean do not match the TCI distribution. For instance in Germany, approx. 40% of all leisure trips abroad are to Southern Europe (F.U.R., 2007). However, as apparent in Figure 2.4, Germany displays an equal amount of good days and even more excellent days than Southern Europe in the holiday months of July and August. However, for many of these trips “sand and sea” is the main purpose, for which optimal or favourable climate is naturally defined differently.

It is important to recognize that next to the suitability of average weather, climate (change) also influences tourism in other ways, such as through extreme weather events, water availability, biodiversity, snow cover and sea level rise. In addition, pivotal factors determining the effect of climate change on tourism is the current sensitivity of destinations to changes in climate as well as the adaptive capacity of tourists and service providers (Perch-Nielsen, submitted). A destination can fail to take advantage of improved climate resources by clinging to the current infrastructure and offers. Other destinations might flourish despite a decline in climate resources by means of unique attractions, weather independent activities or a great diversity of offers.

2.8. Methodological Reflections

In this paper we have addressed limitations of previous TCI applications by basing our calculations on daily data as well as multiple models. We consider the use of daily data an important improvement, as for tourism it is the integrated effect of the different climatic variables on each day that is important. To test the sensitivity of the results to different temporal resolutions, we calculated the mean monthly TCI based on both daily and on monthly data. For many regions and months differences proved to be quite small. However, precisely when maximum temperatures are near the optimum, changes between daily and monthly calculations became large (10 TCI points and above). When the mean monthly maximum temperature comes to lie in the optimal range, monthly TCI values are very high. In the daily calculations, maximum temperature obviously varies from day to day and does not permanently lie in the optimum, ultimately leading to a substantially lower mean monthly TCI. Despite its clear advantages, using daily data has its drawbacks. While temperature is represented well on a daily scale (e.g. Meehl et al., 2004; Vavrus et al., 2006), models still show great difficulty in representing daily precipitation patterns and achieve better results on a more aggregated time scale.

The use of five regional climate models has enabled us to compare simulations and provide a sense of uncertainty for the results. For most places and seasons, there is a good agreement on the direction of projected change. The results of this study can therefore be considered quite robust. However, it also has to be taken into account that the regional models available were driven with only two different global models. As regional models are strongly controlled by their driving models, actual model uncertainty is higher than documented here (Fronzek and Carter, 2007). For future research it would therefore be prudent to include a wider range of driving global models.

The TCI has proven to be a useful instrument to assess the most important facets of climate for sightseeing tourism in a single number. With this paper we have contributed to overcoming some of its limitations and render it more informative. A number of other limitations of the TCI are currently being addressed by other research. The TCI combines

its five subindices by adding them together. This addition implies that the subindices are independent of each other and that a change in one subindex can be compensated by a change in another one. However, this basic assumption does not hold true: de Freitas (1990) has shown that for beach use, rainfall events override all other aspects. A new generation of climate indices for tourism is now being developed that address this shortcoming by designing the index to integrate overriding effects (de Freitas et al., in press). An alternative is to classify weather according to a limited number of different “weather types” (Besancenot, 1990; Gómez Martín, 2006). The second limitation of the TCI is its subjectiveness and lack of verification. The rating of the variables on scales from -3 to 5 (or 0 to 5 for sunshine and wind) is to a certain extent based on biometeorological and other literature but also a large portion of expert opinion. The subsequent weighting of sub-indices for aggregation is Mieczkowski’s own expert opinion and ultimately subjective. This limitation is currently being addressed by determining preferences with surveys (Scott et al., in press) or in situ observations (Moreno et al., in press). Future research should compare different metrics for “favourable tourism” and test the sensitivity of results to different weightings.

3 The Vulnerability of Beach Tourism to Climate Change - An Index Approach

Submitted to Climatic Change 21 November 2007

3.1. Abstract

The attractiveness of a region for touristic activities depends strongly on the local weather and climate. This paper analyses the vulnerability of the beach tourism sector towards climate change by means of an index approach on a country level. A vulnerability framework for the tourism sector is developed and on its basis, indicators are defined for exposure, sensitivity and adaptive capacity. A transparent index approach, including a robustness analysis with multiple transformation methods and weighting sets, yields an assessment of the overall relative vulnerability of the beach tourism sector in 51 countries. Aggregate results on an annual level indicate that large developing countries might be among the most vulnerable, small islands states are also vulnerable, especially due to their high sensitivity, and developed high latitude countries as well as Mediterranean countries are amongst the least vulnerable. Despite several limitations of the index approach, the present study contributes to integrating the numerous direct as well as indirect effects climate change may have on beach tourism.

3.2. Introduction

Since many types of tourism depend directly on weather and climate, the current and future changes in climate have a strong potential to affect the tourism sector. In spite of this, the influence of climate (change) on tourism has only been investigated in few studies, while other affected economic sectors such as agriculture and the insurance services have received far more attention (IPCC, 2007a). Such underrepresentation is not justified. Climate and tourism are closely linked: climate has been identified as one of the most important factors in destination choice (Hamilton and Lau, 2006; Lohmann and Kaim, 1999). In addition, tourism is an important economic sector, generating approx. 3.6 per cent of the Gross World Product, and forming the very backbone of the economy in many

small island nations (WTTC, 2006). Although research on this topic has gained some momentum in recent years (Scott et al., 2005), overall the influence of climate change on tourism remains poorly understood.

It is surprising that vulnerability, as one of the key concepts in climate impact research, has so far not been explicitly studied for the tourism sector. Implicitly, the vulnerability of the tourism sector has naturally been investigated, mostly by studies on one of the three dimensions of vulnerability: exposure, sensitivity, and adaptive capacity. The exposure of the tourism sector to climate change has for instance been analysed by research on the suitability of future climate for tourism (Amelung et al., 2007; Scott et al., 2004) or on changes in snow reliability for skiing in different countries (e.g. Abegg, 1996; Harrison et al., 1999; McBoyle and Wall, 1992; Whetton et al., 1996). The sensitivity has been addressed by using statistical methods to determine how sensitive tourism demand is to climate (Bigano et al., 2006; Lise and Tol, 2002; Maddison, 2001) or by asking tourists how they would react to specific climate-related changes in a destination (Braun et al., 1999; Scott et al., 2007a). Also adaptation has been the subject of a number of studies (Becken, 2005; Behringer et al., 2000; Scott and McBoyle, 2007). Finally, a few studies have combined different vulnerability dimensions to project changes in tourism flows (Hamilton and Tol, 2007; Hamilton et al., 2005) or in ski season length (Scott et al., 2003; Scott et al., 2007b).

This paper analyses the vulnerability of the beach tourism sector towards climate change by means of an index approach. Indicators are defined for the exposure, sensitivity and adaptive capacity on a country level and the relative vulnerability of the beach tourism sectors in 51 countries is compared. The choice of beach tourism is a deliberate one. A specific type of leisure tourism is selected because different tourism activities are differently affected by climate change (e.g. skiing tourism versus beach tourism, see also Lise and Tol (2002)) and are thus difficult to aggregate for analysis. Beach tourism is selected because the associated activities of sunbathing and swimming are more strongly linked to specific weather conditions than other tourism activities.

The chosen approach of using an index to estimate relative vulnerability has a number of advantages. The notion of a relative metric – relative vulnerability – takes into account that climate change is expected to change the pattern of tourism flows rather than aggregate numbers of tourists (Hamilton et al., 2005) and therefore the relative performance is more important than the absolute one. In addition, the approach allows to explicitly address all three vulnerability dimensions and to integrate direct as well as indirect effects of climate change (e.g. changes in the suitability of climate for beach tourism as well as changes in coral reefs). This is particularly important in a comprehensive assessment, as direct and indirect consequences of climate change are both important for tourism and can have opposing effects (Scott et al., 2007a). These advantages of this approach regarding integration are however achieved at a price: indices run the risk of oversimplifying and their development is fraught with uncertainties, making a transparent and sound method an absolute necessity.

The basis for this analysis is a conceptual framework for vulnerability described in Section 2. The selection of indicators for each vulnerability dimension, their transformation and weighting, and the data used are explained in Section 3. Subsequently in Section 4, resulting countries' vulnerability profiles are presented and discussed. The robustness of the approach as well as lists of the most and least vulnerable countries are presented in

Section 5 followed by an overview of limitations in Section 6 and conclusions in Section 7.

3.3. Development of a Conceptual Framework

Vulnerability has emerged as a key concept for the human-environment interface and during the last decade, its use in the scientific literature has experienced a sharp increase (Janssen et al., 2006). Vulnerability describes the degree to which a system “is likely to experience harm due to exposure to a hazard” (Turner II et al., 2003, p. 8074). or is “susceptible to [...] adverse effects” (IPCC, 2007b, p. 883). While such broad definitions of vulnerability are by and large undisputed, the conceptualization of the term is very diverse across different research branches. A number of fields have adopted and developed the term vulnerability (see overviews and examples in Adger, 2006; Kasperson et al., 2001; Kelly and Adger, 2000; Patt et al., 2005; Schröter et al., 2005), resulting in different concepts and terminologies presented in a number of conceptual frameworks (Brooks, 2003; Cutter, 1996; Ford and Smit, 2004; Luers, 2005; O'Brien et al., 2004; Turner II et al., 2003). Which of all these is the ‘right’ conceptualization? Füssel (2007) argues that there is none, as different assessment contexts have different requirements and stresses the need to clearly specify the applied vulnerability concept.

As a basis for the present study, the conceptualization provided by the IPCC Fourth Assessment Report is adopted, which defines vulnerability as a function of a system’s exposure to climate change, its sensitivity, and its adaptive capacity (IPCC, 2007a). Sensitivity thus means “the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise)” (IPCC, 2007a, p. 861). Adaptive capacity refers to “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC, 2007a, p. 869).¹

The vulnerability concept provided by the IPCC is designed to be applicable to a large variety of assessments and is thus very broad. In order to derive indicators it is therefore necessary to elaborate the general framework and mould it on the beach tourism sector. For this purpose, the three dimensions exposure, sensitivity and adaptive capacity were combined in a matrix with different mechanisms by which climate change might affect the tourism sector directly or indirectly. In Table 3.1, the seven important mechanisms identified are presented: changes in mean climate, extreme events, sea level rise, biodiversity, water availability, snow and mitigation measures.

¹ In the terms of the framework provided by Füssel (2007), this means that two types of the four possible “vulnerability factors” are addressed in this analysis: the exposure to climate change is an external biophysical factor, the sensitivity and adaptive capacity are internal socio-economic factors.

Table 3.1: Framework for the vulnerability of the tourism sector to climate change.

	exposure	sensitivity				adaptive capacity
<i>mitigation measures</i>	policies to reduce greenhouse gas emissions	– elasticity of current tourism demand	– dependence on long-haul tourists	– extent of new potential short-haul tourists	– carbon intensity of current tourism	
<i>snow</i>	change in snow security	– dependence on tourism relying on snow	– existing snowmaking facilities	– existence of other attractions		
<i>water availability</i>	changes in precipitation, evaporation and factors that affect water consumption	– water consumption of tourism industry	– competing water consumers			
<i>biodiversity</i>	changes in composition of flora & fauna	– dependence on tourism relying on existing biodiversity	– attractiveness of new flora & fauna			
<i>sea level rise</i>	rise in sea level	– proximity of tourism infrastructure and resources to the maximum shoreline	– value of tourism infrastructure and resources at risk	– dependence on coastal tourism		
<i>extreme events</i>	change in frequency and intensity of extreme events relevant to tourism	– proximity of tourism infrastructure and resources to extreme events	– value of tourism infrastructure and resources at risk	– robustness of tourism infrastructure and resources towards extreme events (hazard resistant building, etc)	– availability of insurance and other loss sharing systems	
<i>mean climate</i>	change in suitability of climate for the type of tourism present	– dependence on tourism that relies on current climate				<ul style="list-style-type: none"> – economic resources available to tourism to adapt – innovation potential of tourism entrepreneurs – technologies available to tourism to adapt – knowledge within the tourism sector on climate change and its potential impacts – existence and effectiveness of institutions within the tourism sector

For each matrix element one or more vulnerability factors were identified and listed. The sensitivity factors regarding extreme events are based on Smith (2001) and the five general determinants of adaptive capacity were adopted from the IPCC (2001, p. 895 - 897) and are listed generically across all seven mechanisms.

The framework presented in Table 3.1 is developed for the tourism sector in general and can be used as the basis to derive indicators for different types of tourism (winter sports, nature-based tourism, coastal tourism) and different scales (destination, region, nation). For the specific case of beach tourism on a national level in this study, indicators were derived for the first four mechanisms. Snow reliability is obviously of no relevance while water availability as well as mitigation measures were very hard to quantify and thus left to future research.

3.4. Method and Data

Indices are sets of weighted and aggregated indicators. In general, their strength lies in their ability to summarize a large amount of information in a format that is simple and understandable. They have been widely applied to synthesize economic, social, environmental and technological concepts (OECD, 2003) with different purposes such as raising awareness, comparing between countries, monitoring progress and prioritizing action (Brenkert and Malone, 2005; Kaly et al., 2003). Also in the field of vulnerability, composite indices have been developed (Downing et al., 2001; UNEP, 2002).

Despite their usefulness, caution is also warranted in the use of indices. Their construction poses a number of challenges, especially the selection and weighting of indicators is fraught with uncertainties. Indices pose the risk of oversimplifying or misrepresenting the targeted process. Therefore, transparency regarding the process, the methodology and data used is of paramount importance (Eriksen and Kelly, 2007; Esty et al., 2006; OECD, 2002). In this study, the guidance issued by the OECD (2002) was generally followed and the method for each of the steps is documented transparently: the scope of the analysis, the selection of indicators, their transformation, weighting and aggregation as well as robustness analysis.

3.4.1 Temporal and Geographical Scope

The time frame chosen is two-fold and thus represents a hypothetical situation: the sensitivity and adaptive capacity of the *current* system (~2000) and *future* climate change (exposure by the 2050s) is analyzed. This is due to the very different nature of the underlying systems. While climate change can be reasonably well projected into the far future given an emission scenario, the development of the tourism sector cannot, as it underlies countless and mostly unpredictable influences such as economic and demographic growth, the global sense of security, rapidly changing trends, leisure time budgets, etc. The initial goal for sensitivity as well as adaptive capacity was to generate a time series yielding valuable insights into the past development of vulnerability. However, the lack of time series for many of the selected indicators restricted the analysis to one point in time.

Indicators were collected for a total of 177 coastal countries worldwide. However, results are presented only for the 51 countries for which all indicators were available and in which tourism is 'relevant'. 'Relevant' was defined as displaying either a high relative share or high absolute contribution of the tourism and travel industry to the gross domestic product (GDP). As a cut-off, the 50 highest scoring countries in each of these categories were selected based on data by the World Travel & Tourism Council (2004a).

3.4.2 Selection of Indicators

The selection of indicators is the most critical step in the development of composite indicators, as it inevitably involves subjective choices. An important means of reducing overall subjectivity is robustness testing (see Chapter 3.8). However, there are also possibilities to reduce subjectivity within this first selection step by: (i) deriving indicators from a sound theoretical framework; (ii) using a proxy; and (iii) selecting indicators on the basis of a set of criteria. In this study, use was made of the first and last option to the extent possible.

Regarding the theoretical framework, the indicators were selected on the basis of the factors presented in Table 3.1, which in turn builds on the coarse vulnerability framework by the IPCC. However, this option for reducing subjectivity was limited, as so far no well-founded theory on the vulnerability of an economic sector to climate change has been developed, let alone of the tourism sector in particular.

For the second option, the possibility of using a proxy was not considered applicable to the present case. Largely, the approach consists in correlating a large number of potential indicators to a proxy variable for vulnerability and selecting those as final indicators that correlate significantly (for an application to vulnerability, see Brooks et al., 2005). The weakness of such an approach is that selecting a benchmark against which to test "is somewhat paradoxical since the very need for vulnerability indicators is because there is no such tangible element of vulnerability" (Adger and Vincent, 2005, p. 404).

Finally, a set of criteria for indicator selection was derived from the literature (see Table 3.2). It proved challenging to find indicators for all vulnerability factors listed in Table 1, due to the common problem of data availability and quality. As hardly any of the indicators considered could satisfy all of the criteria listed, the set of criteria was applied as guidance and not as a requisite for the selection of the indicators. Often, criteria were conflicting, for instance the accuracy of the indicator might conflict with its data availability or also its comprehensibility.

The indicators selected are described in the following subsections. An overview is given in Table 3.3. The second column lists the mechanism as well as the factor within this mechanism that the indicator represents.

Table 3.2: Set of criteria for the selection of indicators (based on Atkins et al., 1998; Esty et al., 2006; Kaly et al., 2003; OECD, 2002).

	criteria	explanation
validity	well-founded	based on a tested theoretical framework
	accurate	really measuring what it should
	non-ambiguous	agreement on the direction of influence between the indicator and vulnerability
use	comprehensible	relatively easy for users to understand
type	relevant	applicable to many geographic and economic conditions
	responsive to changes	can be influenced by action
	high information content	no yes/no indicators, and preferably actual performance data instead of model-based data
data	available	data that is publicly and easily available
	homogenous and periodical data	data that is collected homogeneously, making it suitable for international comparisons

Table 3.3: List of vulnerability indicators used for the analysis.

	mechanism: factor	indicator	units	years	# countries	distribution	source
exposure	mean climate: suitability of climate for the type of tourism present	change in modified Tourism Climatic Index	scale from 0 to 100	1970-1999 vs. 2041-2070	218	normal / uniform	calculated from 3 GCMs
	extreme events: frequency and intensity of extreme events relevant to tourism	change in maximum 5-day precipitation total	mm	1961-1990 vs. 2041-2070	218	none	calculated from 3 GCMs
		change in fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts	%	1961-1990 vs. 2041-2070	218	none	calculated from 3 GCMs
	biodiversity: strength of climate change that might affect flora & fauna	required adaptation of corals to increased thermal stress	°C	1980-1999 vs. 2050-2059	218	log-normal	(Donner et al., 2005)

Table continued on next page

Table 3.3 continued: List of vulnerability indicators used for the analysis.

	mechanism: factor	indicator	units	years	# countries	distribution	source
sensitivity	mean climate: dependence on tourism that relies on current climate	share of arrivals for leisure, recreation and holidays	% of total arrivals	2000-2002 (1996-2004)	158	normal / uniform	UN-WTO (UN-WTO, 2006a)
	extreme events: robustness of beach tourism infrastructure and resources towards extreme events (hazard resistant building, etc)	number of people totally affected by meteorological extreme events	% of population	1995-2004	188	none	EM-DAT (2006)
	sea level rise: proximity of tourism infrastructure and resources to the maximum shoreline	number of people additionally inundated once a year given a sea level rise of 50 cm	people per million inhabitants	2000	206	none	Hoozemans et al. (1992) ^b
		length of low lying coastal zone with more than 10 persons per km ²	km per 1000 km coastline	1990	210	none	IPCC Response Strategies WG (1990)
		beach length to be nourished in order to maintain important tourist resort areas	km per 1000 km coastline	1990	216	none	IPCC Response Strategies WG(1990)
adaptive capacity	economic resources available to tourism to adapt	GDP per capita. purchasing power parity	2000 USD per capita	2000-2002	218	normal / uniform / log-normal	CIA (2001-2003)
	technologies available to tourism to adapt	internet users	% of population	2000-2002 (1999-2004)	200	none	ITU (2006)
	knowledge within the tourism sector on climate change and its potential impacts	total gross enrolment	% of population of respective age group	2000-2002 (1999-2004)	191	none	UNESCO (2006), UNDP (2005)
	existence and effectiveness of institutions within the tourism sector	regulatory quality	-2.5 to 2.5	2000-2002	197	normal	Kaufmann et al. (2005)
	importance of tourism	GDP generated by the travel and tourism industry	% of GDP	2005	181	log-normal	WTTC (2004b)

^a Four possible distributions were tested with a one-sample Kolmogorov-Smirnov test at a significance level of 0.05: normal, lognormal, uniform, exponential.

^b Coastal population density 1990 was adjusted to 2000 by assuming same growth as average national growth.

3.4.3 Exposure Indicators

Mean Climate

The exposure indicator for mean climate should reflect the change in climate from the perspective of beach tourism. A widely used index that measures the suitability of climate for tourism is the Tourism Climatic Index (TCI) developed by Mieczkowski (1985). It combines different climatic aspects relevant for tourism: daytime comfort, daily comfort, sunshine, precipitation and wind. Each of these aspects is transformed from its specific unit onto a scale from 0 to 5. The scores are then multiplied by a weighting factor (most weight given to daytime comfort) to produce the index that ranges from 0 to 100. This index suffers from several shortcomings. The most important one is the fact that the ratings of climate variables is attributed based on expert judgement and is not verified empirically. In addition, there are many indications that tourist climate preferences are neither constant over time nor across different countries (Besancenot, 1990; Lise and Tol, 2002; Morgan et al., 2000). Nevertheless, such an index is deemed more accurate than the use of for instance temperature alone. Calculations were carried out on the basis of the original paper. However, as the original TCI is designed for light sightseeing activities, in this study two subindices have been adapted for beach tourism. Of the four different wind rating scales used by Mieczkowski the ‘normal’ system was used for all cases, as it best reflects beach visitor preferences reported by Scott et al. (in press). For sightseeing, Mieczkowski defined optimal thermal comfort between 20 and 27 °C effective temperature. Based on stated preferences (Scott et al., accepted), this optimum was shifted to 24 to 31°C effective temperature. As the number of sunshine hours were not directly available from climate models, they were derived from cloud cover data as suggested by Amelung (2006). An alternative calculation method using solar radiation data (Yorukoglu and Celik, 2006) was rejected, as it performed very poorly at high latitudes.

For the indicator, the projected average annual B-TCI for 2041-2070² was subtracted from the past average B-TCI (1970-1999). The socio-economic scenario SRES A2 was chosen as it was the only scenario for which data was available for all exposure indicators. The data processed were monthly averages from the three models GFDL_CM2.1, MIROC3.2(medres) and ECHAM5/MPI-OM, provided by the Program for Climate Model Diagnosis and Intercomparison (PCMDI).

Extreme Events

How extreme events that are relevant to tourism will change in frequency and intensity is difficult to summarize in indicators, as the spatial scale of general circulation models (GCMs) is quite coarse – too coarse for some extreme events (e.g. tropical cyclones). In addition, indicators that capture very rare events do not provide the statistical robustness needed for the analysis (Frich et al., 2002). Frich et al. (2002) thus defined ten indicators that are robust but as a tradeoff measure less extreme events such as number of frost days or growing season length. Of these ten, some are either already covered by the B-TCI while others are not relevant for beach tourism and were not included. However, two indicators stand for more extreme precipitation events and are thus chosen as flood

² For the ECHAM5/MPI-OM model, the time span was 2045-2065, as some of the necessary data was only available for these 20 years.

indicators: the relative change in the maximum 5-day precipitation total and the absolute change in the fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts. As above, data from A2 projections for 2041-2070 were used. Due to data restrictions, the comparison period was changed to 1961-1990. The three models used were GFDL_CM2.1, MIROC3.2(medres) and PCM provided by PCMDI.

Sea Level Rise

For the mechanism of sea level rise there is no exposure indicator. The obvious indicator, the projected eustatic rise for each coastline, could not be used as a result of high uncertainty: locally differentiated projections of sea level rise currently show strongly differing patterns depending on the model chosen (Meehl et al., 2007a). The alternative of using the global average rise is also of no value as an indicator, as it is naturally the same for each country.

Biodiversity

Corals are of great importance for many beach destinations (Uyarra et al., 2005) and are expected to be damaged by increasing sea surface temperatures. Donner and colleagues (2005) assessed coral bleaching globally and determined the rates of adaptation required for survival under climate change. These rates were considered a first proxy for the exposure of beach tourism to biodiversity changes as indirect effects of climate change. The specific indicator selected is the “increase in thermal tolerance required to ensure bleaching occurs only once every five years” (Donner et al., 2005, p. 2257) such that the corals can recover. The data are based on the HadCM3 model and the same scenario (A2) and similar time periods as above (2050-2059 versus 1980-1999). As grid cells could not be attributed to countries with the usual country boundaries, data of the ‘Exclusive Economic Zone’ seazone boundaries was taken from the Maritime Boundaries Geodatabase (Vlaams Instituut voor de Zee, 2005).

3.4.4 Sensitivity Indicators

For the sensitivity indicators, averages were generally calculated from the years 2000 to 2002 where possible in order to smooth out short-term effects in single years. For countries where no data was available for these years, averages were taken from those years noted in brackets in Table 3.3 that were available.

Mean Climate

As an indicator for the dependence on beach tourism, the share of arrivals visiting for leisure purposes (UN-WTO, 2006a) was selected. It is assumed that tourists visiting for business purposes or to see friends and relatives are less sensitive to changes in climate (Fagence and Kevan, 1997). It is a very coarse metric, but more specific tourism type indicators were not available on a global level.

Extreme Events

Of the four sensitivity factors listed for extreme events, only a very rough proxy could be found for the ‘robustness of beach tourism infrastructure and resources towards climatic

extreme events'. As no such specific indicators were available, it was approximated by the percent of population annually affected by meteorological extreme events (EM-DAT, 2006). This indicator provides information on how well a country can cope with extreme events in general. Unfortunately, it represents not only the country's sensitivity, but also its current exposure and these two facets cannot be separated. For this indicator, the average of 10 years was taken in order to account for the low frequency of extreme events.

Sea Level Rise

Of the three sensitivity factors listed for sea level rise, indicators were found for the 'proximity of tourism infrastructure and resources to maximum shoreline'. The 'km of beach length to be nourished in order to maintain important tourist resort areas' (Hoozemans et al., 1992) is generally a very suitable indicator for this purpose. However, as the estimation by Hoozemans and colleagues was a very rough one, conducted on country level but intended for aggregation to a regional level, the indicator is not very accurate. In addition, the data are 20 years old which seriously limits their ability to reflect tourism sensitivity today. Therefore, two additional indicators were added to make the results more robust and less dependent on a single figure. From the same study, the length of low lying coastal zone with more than 10 persons/ km² was added as a general indicator for sensitivity of the coast. Additionally, the number of people that would be additionally inundated once a year given a sea level rise of 50 cm was taken from the Global Vulnerability Assessment by Hoozemans et al. (1992). More recent assessments (Nicholls et al., 1999; Nicholls and Tol, 2006) could have been used, but these are all also based on the original work by Hoozemans et al. (1992).

3.4.5 Adaptive Capacity Indicators

The indicators for adaptive capacity (also Table 3.3) could not be adapted to the (beach) tourism sector specifically due to the lack of data but had to be chosen on a more generic level. Such generic indicators for adaptive capacity towards climate variability and change on a national level have been developed by Brooks et al. (2005). However, their set of indicators was rejected as it refers specifically to mortality due to climate-related disasters. In the following, the indicators selected for the present study are presented. The same temporal range as that of the sensitivity sector was applied to these indicators (averages from 2000 to 2002 where possible, averages from the years noted in brackets where not).

For economic resources, gross domestic product (GDP) per capita adjusted for purchase power parity (CIA, 2001-2003) was selected. A number of other indicators considered, such as debt repayments, external debt, foreign direct investment and indices for income distribution equity, proved to be less adequate as well as less available, especially for small island countries.

No indicator could be found for the factor 'innovation', as even moderately accurate and homogenous data are not available (see Volo, 2005). Many potential available indicators were considered, such as patent applications, trademarks, royalty and licensee fees, scientific journal articles etc. Apart from the fact that a number of such traditional innovation indicators are not collected homogeneously, they are not meaningful in the context of service industries. In these, innovation is often immaterial, cannot be protected and thus cannot be measured by patents or trademarks (OECD, 1996). Innovation in the

tourism industry is also often connected more to entrepreneurs than to scientists and research laboratories.

A wide variety of technologies might be useful for adapting to climate change. Indicators used for technological adaptation in other studies were rejected: ‘investment in research and development’ (Brooks et al., 2005) for reasons mentioned above regarding innovation and ‘GDP’ (Brenkert and Malone, 2005) as it already represents the economic adaptive capacity. As a first approximation, the relative number of internet users (ITU, 2006) was selected.

For the factor know-how, the indicator of total gross enrolment (UNDP, 2005; UNESCO, 2006) was preferred to the literacy rate, as the latter is not able to distinguish between most developed countries. In these, literacy rates are assumed to be 100% and thus not collected anymore.

For the existence and effectiveness of institutions in the tourism sector, the six governance indicators reported by Kaufmann et al. (2007) were evaluated as proxies: control of corruption, voice & accountability, government effectiveness, regulatory quality, political stability, rule of law. Although most of the indicators can be considered relevant in some way, regulatory quality was deemed to be the most adequate for tourism as an economic sector, as it represents “the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development” (Kaufmann et al., 2007, p. 3).

As the above indicators are not very tourism-specific, an additional indicator was included to build this bridge. The indicator represents the importance of tourism for a country. The rationale behind it is that the larger share the tourism industry contributes, the more weight and lobbying power it has to gear the adaptive capacities available towards tourism. Again, numerous indicators were screened, including number of tourists or stays divided by the population or expenditures of tourists divided by GDP. The share of GDP generated by the travel and tourism industry (WTTC, 2004b) was selected as the most adequate to depict the importance of the tourism sector and additionally was also available for a large number of countries. The factor ‘importance of tourism’ exemplifies very well how the indicators chosen depend on the perspective of the analysis. From the perspective of a country, one could argue that a very high importance of tourism is damaging, as it inevitably also stands for a high dependence on a single sector, making the country very vulnerable to changes in international tourism choices. However, from the perspective of the sector itself, this issue is much less important.

3.4.6 Transformation of Indicators

Since the individual indicators are expressed in different units (e.g. US dollars or percentage of population) they have to be transformed in order to enable comparison and aggregation. There are a number of transformation methods, each with specific advantages and disadvantages (OECD, 2003). The selected indicators are partially not very precise as data collection or calculation methods distributions (see column ‘distribution’ in Table 3.3). Therefore, a coarse transformation method was chosen that is less sensitive to such data and does not feign more accuracy than actually present. It divides the data into quintiles and assigns a score from 1 to 5 (see below tr_0 for standard method of

transformation). For robustness testing, three additional methods were selected with a general focus on robust methods (tr1 to tr3, based on OECD, 2003).

tr0 categorical scale divided into quintiles -> score 1 to 5

tr1 standardisation
(z-transformation) $x_i^{trans} = (x_i - \bar{x})/s$

tr2 adapted standardisation $x_i^{trans} = (x_i - m)/iqr$

tr3 share of sum³ $x_i^{trans} = 1000 \cdot x_i / \sum_{a=1}^n x_a$

(*s* = stand deviation, *m* = median, *iqr* = interquartile range, *n* = number of observations/countries)

The first alternative method (tr1) is standardisation, an approach commonly used in indicator construction, consisting of standardising the variables by deducting the mean and dividing by the standard deviation. The second method (tr2) applies the same principle but uses the interquartile range and the median. The third method (tr3) divides a value through the sum of all values, rendering the result less sensitive to irregular data distributions.

In order to make data comparable, transformation also needs to render values that are oriented in the same direction, meaning that higher values consistently represent better performance for each and every indicator (or worse performance for each indicator, of course, depending on the definition). However, high sensitivity and high adaptive capacity have opposing effects on vulnerability. Would both be given high values, they could not be added to each other in aggregation. In order to prevent such confusion, in this study the distinction is always made between 'favourable' and 'unfavourable'. High values are thus given to the direction that is 'favourable' i.e. representing *low* vulnerability, *low* exposure, *low* sensitivity but *high* adaptive capacity. The equations listed above achieve this goal for indicators that consist of positive values only and for which higher values represent better performance to start with. For indicators that consisted of positive and negative values and/or for which lower values represented better performance (e.g. number of people affected by extreme events), the equations were adapted.

3.4.7 Weighting of Indicators and Aggregation

Weighting is a critical step in the process for the same reason as the selection – it is nigh on impossible to avoid subjectivity. The proxy approach being ruled out (see Section 3.1), statistical methods such as principal component analysis could be used to derive weights. However, in that case the weights would simply be determined by the indicators selected – which again have been chosen subjectively. Therefore in this study alternative weighting sets were chosen to use in robustness testing (see Table 3.4).

³ The multiplication with 1000 is merely in order to make the resulting numbers more readable.

Table 3.4: Different weighting sets (in rounded percentages).

dimension	mechanism	indicator(s)	wei0	wei1	wei2	wei3
exposure	mean changes	change in B-TCI	33%	50%	25%	25%
	extreme events	maximum 5-day precipitation total fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for wet day amounts	33%	25%	25%	50%
	biodiversity	required adaptation of corals to increased thermal stress	33%	25%	50%	25%
sensitivity	mean changes	share of arrivals for leisure, recreation and holidays	33%	25%	20%	50%
	extreme events	number of people totally affected by meteorological extreme events	33%	25%	40%	25%
	sea level rise	<ul style="list-style-type: none"> – number of people additionally inundated once a year given a sea level rise of 50 cm – length of low lying coastal zone with more than 10 persons per km² – beach length to be nourished in order to maintain important tourist resort areas (all three equal weights)	33%	50%	40%	25%
adaptive capacity	economic	GDP per capita. purchasing power parity	14%	20%	14%	43%
	knowledge	total gross enrolment	14%	20%	14%	14%
	technology	internet users	14%	20%	14%	14%
	institutions	regulatory quality	29%	20%	14%	14%
	tourism importance	GDP generated by the travel and tourism industry	29%	20%	43%	14%

For exposure and sensitivity, the main weighting set ('wei0' in Table 3.4) assumes all three mechanisms to be equally important. The three alternative weightings are named wei1 to wei3 and each give most weight to one of the three factors. For the indicators for adaptive capacity, the main weighting set gives institutions and tourism importance double weight, as high tourism importance might channel all other factors towards tourism and a high regulatory quality has a similar effect by giving local as well as foreign investors the possibility to advance tourism. Alternative weighting wei1 assumes an equal set of weightings, while wei2 and wei3 gives triple weight to tourism importance and financial resources, respectively.

The last hurdle before aggregation is to define how to deal with missing values. The indicators were only aggregated to an index for countries where all indicators are available. Of the 88 countries where tourism is 'relevant', this approach yielded 51 countries with full data sets (91 of the overall 177 coastal countries).

For the aggregation to a subindex, the transformed and weighted scores can subsequently simply be summed. For the aggregation to the overall vulnerability score, the arithmetic mean of the three subindices was taken. The arithmetic mean was chosen over the geometric mean, as the latter cannot be applied to negative values as obtained by two of the transformation methods. In addition, a comparison of arithmetic and geometric mean for the two other transformation methods showed that they were very highly correlated in any case (97 – 99% depending on the weighting).

3.4.8 Robustness Analysis and Identification of the Most and Least Vulnerable Countries

The term ‘robustness testing’ is used in this study instead of the more common ‘sensitivity testing’ in order to avoid the confusions that might arise from using this latter term in connection with the vulnerability dimension ‘sensitivity’. As stated above, different transformation methods and different weighting methods were applied in order to test the robustness of the results towards different transformation methods as well as weighting choices. Calculating all possible combinations yields 256 vulnerability indices. Note that indices from different transformation methods cannot be directly compared to one another, as they have different units. In order to still be able to compare all 256 indices, all indices were transformed into simple ranks. Boxplots of these 256 indices per country give an impression on how robust the ranks are. To define the most and least vulnerable countries over all 256 indices, the approach of using quintiles applied by Brooks et al. (2005) was followed: Countries were defined as being most and least vulnerable if they were in the highest and lowest quintile in at least 100 out of 256 index variants (or 12 out of 16 variants for the individual dimensions, respectively).

3.5. Vulnerability Profiles and Patterns

3.5.1 Results

Figure 3.1 presents the results of the index calculations with the main weighting set and transformation method (categorical scale from 1 to 5). The three individual dimensions as well as the overall vulnerability index are shown. It is important to recall that the results presented do not refer to the countries’ vulnerability but to the countries’ beach tourism sectors’ vulnerability. However, in order to simplify the language, in the following reference is made to the countries.

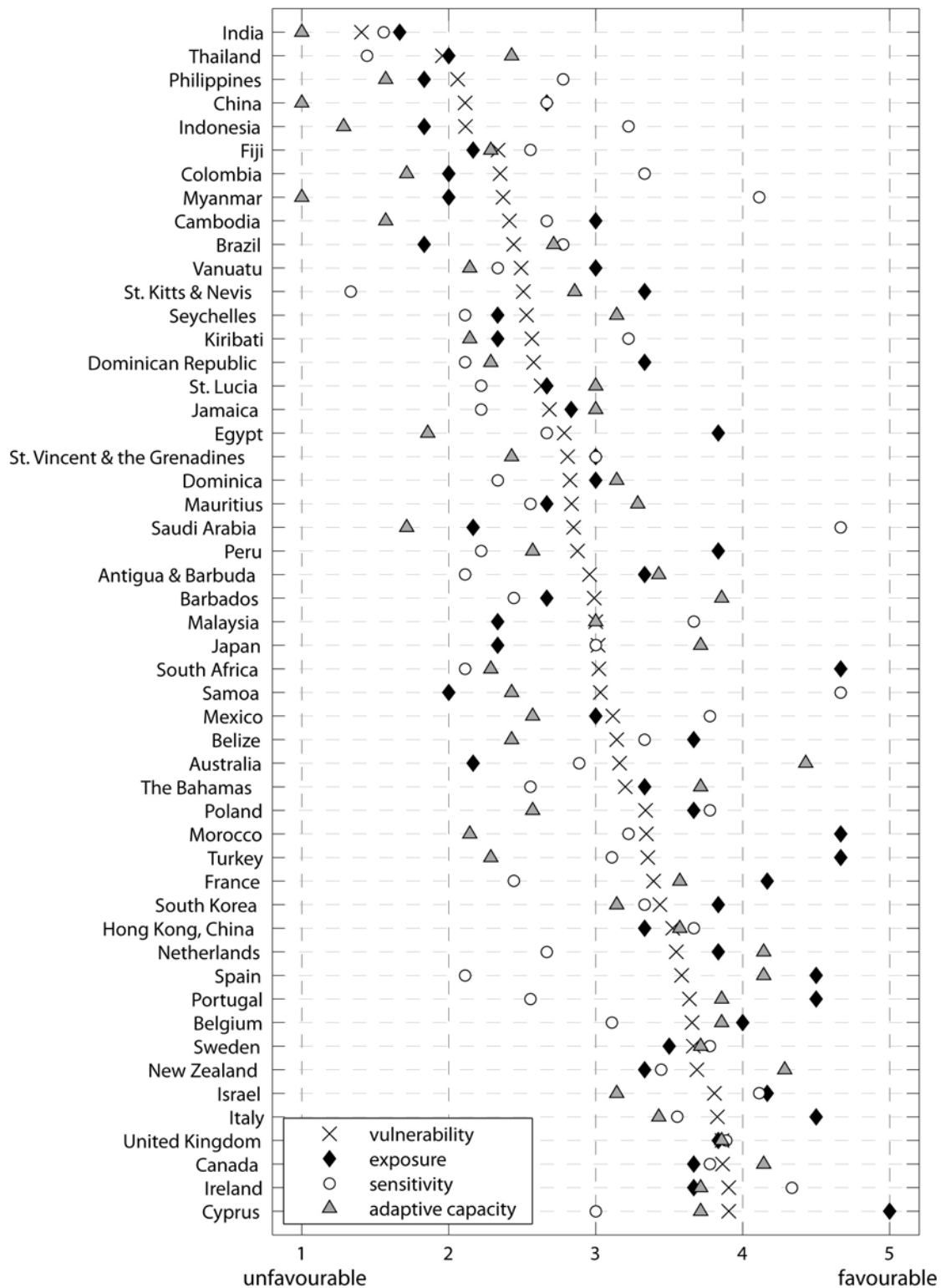


Figure 3.1: List of countries showing the the relative vulnerability of beach tourism to climate change. Results for exposure (◆) sensitivity (○), adaptive capacity (x) and all combined (◆) are shown for the standard transformation and weighting.

From a bird's eye view of Figure 3.1 it becomes apparent that nearly all vulnerability scores (marked with x) lie between 2 and 4. The fact that the extreme ranges are not occupied show that no country has very high – or very low – vulnerability in all 3 dimensions. The notable exception is India, which scores extremely low on adaptive capacity but also very unfavourable on the other two dimensions. The most of the following very vulnerable countries are – like India – of a medium development status and are also all very populous. In the range of the low to medium vulnerability many small island states are to be found, together with a heterogeneous group of countries including Egypt, Peru, Malaysia and Japan. The least vulnerable countries are developed countries of high latitudes such as Canada, New Zealand, and Ireland, as well as Mediterranean countries including Cyprus, Italy, and Portugal.

There is quite a diverse composition of vulnerability with different subindex scores producing the same overall ranking. For instance South Africa and Samoa display nearly the same level of vulnerability, whereas the sensitivity and exposure scores are diametrically opposed. Similar patterns are displayed by Belize and Australia or Mauritius and Saudi Arabia. The overall score of the most vulnerable countries is based primarily on low adaptive capacity and high exposure while the sensitivity of some countries (especially Myanmar) is comparatively favourable. Several countries have strongly opposing subindex scores such as Myanmar, Saudi Arabia, Morocco, and Spain, making their overall vulnerability result very dependent on the weight given to each dimension. Others score equally favourable or unfavourable on all dimensions such as India, Fiji, Sweden and the United Kingdom.

A more systematic way of comparing different vulnerability patterns is presented in Figure 3.2 below: Sensitivity and adaptive capacity are together (arithmetic mean) plotted against exposure. The lower left square represents overall high vulnerability (India, Indonesia, the Philippines, and Thailand), the top right one for overall low vulnerability (United Kingdom, Canada, and Ireland). The bottom right corner stands for countries that have a favourable exposure but have an unfavourable combination of sensitivity (high) and adaptive capacity (low) (South Africa and Egypt). The top left corner stands the reverse situation but contains no countries.

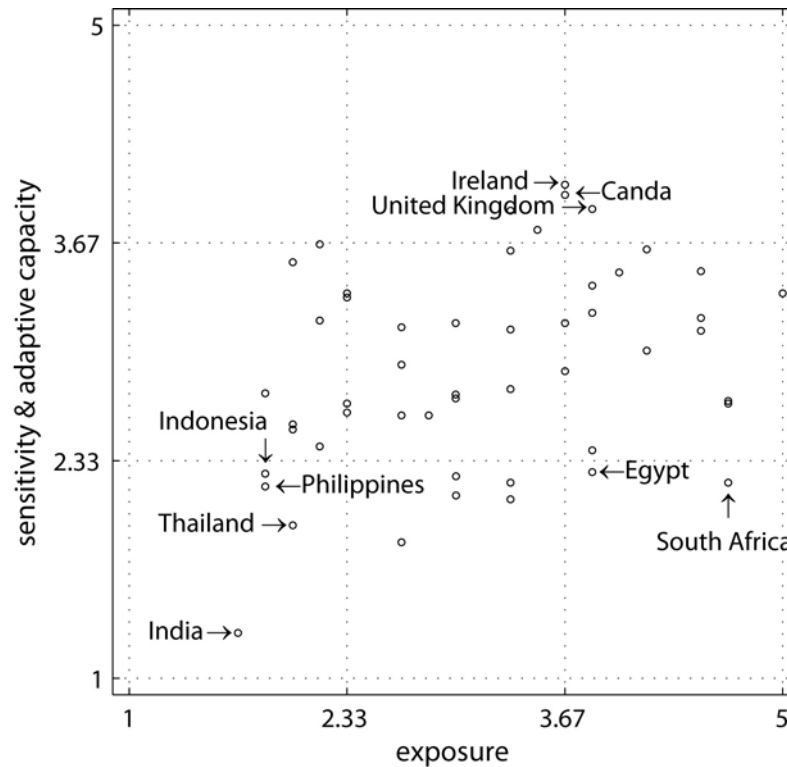


Figure 3.2: Comparison of the arithmetic mean of sensitivity and adaptive capacity versus exposure. The units used are a scale from 1 to 5 representing unfavourable to favourable, respectively.

3.5.2 Discussion

For the interpretation of the results it is crucial to keep in mind that the scores are of relative nature. The scaling between 1 and 5 does not provide any information whether the vulnerability of all countries together is very low or high on an absolute scale. This is both a weakness – it provides no notion of absolute scale – and a strength, as destination choice depends strongly on (relative) differences between competitors (Hamilton et al., 2005). For instance India scores a straight 1 for adaptive capacity, which means it has the lowest adaptive capacity score of all countries included. ‘Included’ in this case means all countries in which tourism is ‘relevant’ (see 3.1), and for which all data is available. The first criterion rules out a large number of African countries that would score lower on adaptive capacity as defined here. The average adaptive capacity of all countries included is thus probably not equal to the world average.

It is also important to remember that a comparatively low vulnerability – despite the negative connotation to the word ‘vulnerability’ – can actually denote favourable conditions for the beach tourism sector of a country. Most of the indicators for exposure allow for both improvement and deterioration: the suitability of the climate for beach tourism as well as the frequency of strong precipitation events may increase or decrease. Only the indicator for corals does not allow for improvement but only for more or less (or no) damage.

With this in mind the results can be discussed. While it is generally assumed that small island states are among the most vulnerable regarding tourism, in Figure 3.1 it is populous

countries that head the list, only then followed by small island countries in the lower and medium ranges. The populous countries' high vulnerability is not based on high sensitivities but on low adaptive capacity combined with high exposure. The small island states in contrast, display a range of adaptive capacities and exposures but all display a rather high sensitivity. However, these results have to be taken with a grain – if not rather a whole handful – of salt because the indicator approach does not lend itself well to large countries. For instance in China, the maximum 5-day precipitation is projected to increase by approx. 10 %. This number hides a very large variability within the country: on a grid basis the change projections range from -7 to + 47% (for the GFDL_CM2.1 model). Aggregating climatic, natural or socio-economic conditions over such a large area yields results that are near to meaningless on a local level.

This problem is not so relevant for the small island states. Their vulnerability scores are generally composed of a high sensitivity, although not as high as could have expected as some are not so low-lying, others not so dependent on leisure tourists and others again have not been affected by meteorological extreme events in the past. The exposure of island states is generally unfavourable with corals strongly affected and a slight decrease in climate suitability. However, in some countries this is somewhat compensated by a projected decrease in heavy precipitation events. Mostly, their adaptive capacity is in the medium ranges, which to a small degree can be ascribed to the fact that 'importance of tourism' is one of the indicators. In addition, it seems to show that a high tourism share has led to a certain level of development or, the reverse, i.e. that the growth of tourism requires a minimum level of development.

It does not come as a surprise that many developed countries of the high latitudes are amongst the least vulnerable countries. Their high development status accounts for the medium to high adaptive capacity and their sensitivity is comparatively low – with tourists visiting for leisure but also business purposes and the countries having been able to reduce sensitivity to meteorological extreme events. As there are no coral reefs in these regions, there is no potential loss; and a general increase in climate suitability has been expected (Amelung et al., 2007). In general, this assessment also holds true for the Mediterranean countries. At first sight this might seem to be in contradiction to projections of the Mediterranean becoming too hot for beach tourism (Rotmans et al., 1994). However, these refer to summer conditions whereas the present analysis uses the average suitability across the year, which is projected to increase. This points to a limitation of the indicator for climate suitability, i.e. that it is on a coarse temporal scale and does not account for institutional seasonality. Long summer holidays are standard in the most important origin countries of Mediterranean tourism, which would mean that an increase in climate suitability in summer is worth more than an increase in, for instance, winter. Another weakness is the fact that a 10-point increase of the suitability indicator is always equally rated. However an increase from 60 to 70 (from 'good' to 'very good') could be considered more favourable than one from 20 to 30, where both ratings are quite unfavourable and would probably mean that beach tourism is still not possible for the masses in any month of the year. In this context it is important to keep in mind that the present analysis is only concerned with beach tourism. An increase in climate suitability for beach tourism can go hand in hand for instance with an increase or a decrease of the suitability for more active types of tourism such as sightseeing. The index does not provide any information on that.

Regarding the diverse composition of vulnerability, it can be instructive to compare two countries in more detail. South Africa and Samoa are nearly equally ranked but have very

different profiles. Samoa is ranked as one of the least vulnerable small island states, which is primarily due to its extraordinarily – and maybe somewhat surprising – low sensitivity. Only 33% of arrivals to Samoa visit for ‘leisure, recreation and holidays’, most are for ‘other reasons’. This is due to the fact that many Samoans live in New Zealand and return for weddings and other celebrations and to visit friends and relatives. Moreover, its sensitivity to extreme events is estimated to be low as no meteorological disasters were reported in the time span considered (1995 – 2004). However, if the investigated time span would have been 1991-2000, the percent of population affected once in 10 years would have been 49% instead of 0%, yielding a transformed score of 1 instead of 5. This highlights the sensitivity of this particular indicator to the time period chosen. Samoa’s exposure, on the other hand, is quite high especially regarding coral bleaching and climate suitability. In contrast, climate suitability in South Africa increases, heavy precipitation events do not increase and as there are no coral reefs, they cannot be negatively affected by bleaching. In turn, South Africa has a high sensitivity, as it has been strongly affected by extreme events (mostly droughts) and most tourists visit for leisure purposes.

It is difficult to compare overall findings with other research. Comparisons with other global-scale assessments (Amelung et al., 2007; Hamilton et al., 2005) are of limited value as these do not focus on beach tourism and in addition include only one aspect of climate change (changes in temperature or a tourism climate index). A verification with studies carried out on national level (Becken, 2005 for Fiji; Céron and Dubois, 2005 for France; and Uyarra et al., 2005 for Bonaire and Barbados) is also futile, as these relate to absolute changes and the present study analyses countries only from a relative perspective.

3.6. Robustness Analysis

The results of the robustness testing are presented in Figure 3.3. For each country, its 256 possible rankings (see method section) are displayed in the form of a boxplot. In general, the possible rankings per country are very wide. While individual countries like India may have very low ranges (3 ranks), the average range lies at approx. 21 ranks – a very high value when compared to the total of 51 countries investigated. There are also cases, in which the range is extremely wide as for instance the Seychelles, Antigua & Barbuda, or the extreme case of Belgium, which nearly spans the complete width of ranks. The average interquartile range, which comprises 50% of observations, is 6 ranks.

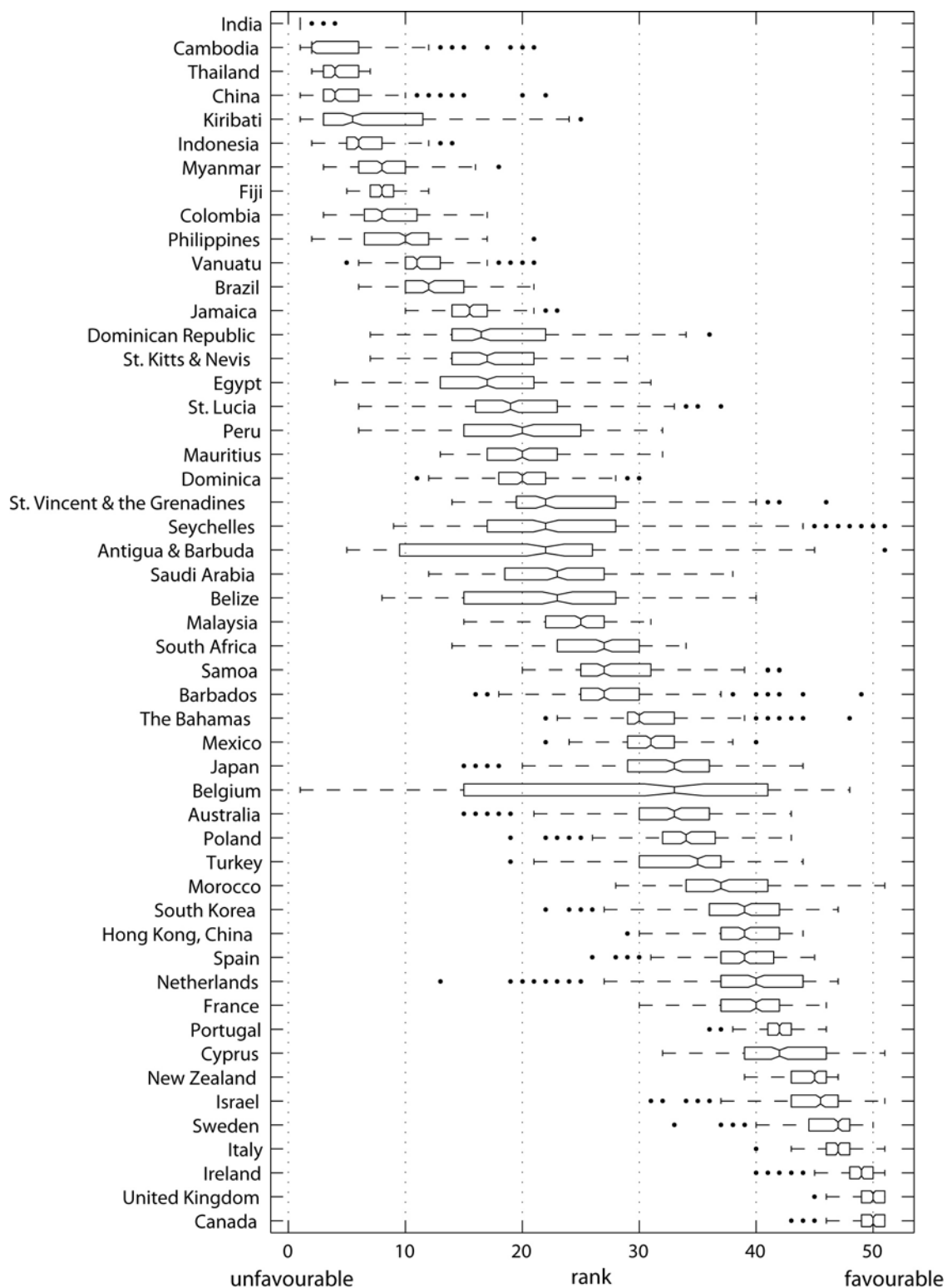


Figure 3.3: Robustness analysis of vulnerability country ranking: Boxplot for each country based on the 256 country rankings. Boxes denote lower and upper quartiles and have notches at the medians. Maximum whisker length is 1.5 times the interquartile range. Outliers are shown with points. High ranks denote higher vulnerability.

These analyses show that the general features are robust while the exact rankings are not. However, the question must be raised whether a higher robustness is unambiguously a favourable feature of the index. A comparison of the subindices exemplifies this issue: the subindex for adaptive capacity is more robust (ranks varies less) than that for exposure.

This is due to the fact that the indicators for adaptive capacity correlate quite highly with each other, which makes them less sensitive to different weighting sets. However, this does not necessarily make this subindex better than the other – it simply reflects the fact that correlating (i.e. in this case similar) aspects are being measured. In the exposure subindex, the different indicators correlate less or not at all, as for instance coral bleaching and 5-day precipitation maxima. However, both these indicators represent important aspects of the overall vulnerability. Kaly et al. (2003) emphasize this point in their work on the Environmental Vulnerability Index and select indicators that are as uncorrelated as possible in order to reduce redundancy. In this sense a very robust index could indicate that only one aspect is being repeatedly measured. It is evident that in an index approach if i) different aspects are measured and ii) different weighting sets are applied, aggregated results inevitably vary. In the present case, it is precisely the aim of the vulnerability index to capture and combine several and different aspects of vulnerability. The variety of possible ranking then partially reflects how differently vulnerability can be perceived depending on individual priorities.

Figure 3.3 also underlines the importance of analysing the robustness of the results: In the case of Belgium it shows that results vary so widely that it presumably makes most sense to compare this country to others by using the indicators themselves and not the aggregated indices. Relying on the result of one specific transformation and weighting would be unsound. But how does such a large variability come about? A contributing factor is the combination of very unfavourable and very favourable aspects within the same subindex that are each given high weight in one of the weighting sets: Belgium has a high GDP but a low ‘importance of tourism’ and each of these indicators is in one weighting set given triple weight. A second important reason are data outliers that produce different results depending on the transformation method chosen. Outliers are smoothed by categorization from 1 to 5 but can have very strong effects in the standardisation methods: Belgium has a much higher share of inhabited low lying coastal zone than all other countries investigated, it lies approx. 19 interquartile ranges away from the median of the distribution. This value is so extremely unfavourable that it can compensate all other (rather favourable) sensitivity indicators, yielding an unfavourable overall score. Finally, the calculation of many possible rankings allows to identify the most and least vulnerable countries in a more robust way (see method section). They are listed in Table 3.5 below.

Table 3.5: Least and most vulnerable countries. Determined as resulting in the lowest/highest quintile in at least 12 out of 16 index variants (for individual dimensions), resp. 100 out of 256 index variants for all combined.

	vulnerability	exposure	sensitivity	adaptive capacity
unfavourable	India, Thailand, Fiji, China, Cambodia, Indonesia, Myanmar, Colombia, Kiribati, Philippines, Vanuatu	India, Colombia, Brazil, Marshall Islands, Maldives, Nauru, Tuvalu, Thailand, Indonesia, Bahrain, Micronesia, Philippines, Myanmar	India, Thailand, Antigua & Barbuda, St. Kitts & Nevis, Cambodia	India, China, Cambodia, Indonesia, Myanmar, Colombia, Iran, Russia, Philippines, Morocco, Kiribati, Saudi Arabia
favourable	United Kingdom, Canada, Italy, Ireland, Sweden, New Zealand, Israel, Portugal, Cyprus, Netherlands	Cyprus, Morocco, Turkey, South Africa, Greece, Israel, Jordan, Italy, Portugal, France, Germany, Malta, Belgium, Croatia, Virgin Islands	United Kingdom, Ireland, Myanmar, Mexico, Malaysia, Saudi Arabia, Samoa	Netherlands, Australia, Denmark, Finland, Iceland, United States, Canada, New Zealand, Sweden

3.7. Limitations

The interpretation and discussion of results as well as the robustness analysis have revealed a number of difficulties and limitations to the index approach. An important limitation is the subjective selection and weighting of indicators. This was to the extent possible addressed by basing it on a framework, carrying out a robustness analysis and above all reporting all steps transparently. A number of additional shortcomings are related to data constraints. The limited availability of data lead to (i) the scale of the analysis being national, with a consequently strongly diminished relevance of results for large countries; (ii) some vulnerability factors not being very accurately represented by their indicators (see limitations of individual indicators in the method section); (iii) some vulnerability factors not being represented at all, as for instance issues of water availability; and (iv) the exclusion of certain poorly documented countries leading to a bias, which is particularly relevant in a relative analysis as the one presented here. An aspect that went beyond the scope of this study are the relationships between the indicators (Eriksen and Kelly, 2007). The simple averaging of (transformed and weighted) indicators has a very important implication: it means that the different aspects can compensate each other: more suitable climate can compensate for sea level rise, less GDP can be compensated by less heavy precipitation events. Tol and Yohe (2007) have shown that this assumption is valid for some but by no means all types of vulnerability. From a conceptual perspective, the resulting exposure indicators have raised doubts whether the notion of vulnerability is indeed suitable for the tourism sector. While sensitivity includes the possibility of a system to be beneficially affected and adaptive capacity comprises the ability to take advantage of opportunities, the concept of vulnerability allows only for damage, not for benefit or gain. For the analysis in the tourism sector – and perhaps others as well – it would be valuable to devise a broader concept and terminology.

3.8. Conclusions

This paper has presented a beach tourism vulnerability index on a national level as a new method of looking at the possible effects of climate change on tourism. A framework of the vulnerability of the tourism sector towards different aspects of climate change has been developed. Based upon this an index approach has been applied transparently, including a robustness analysis with multiple transformation methods and weighting sets. The analysis was carried out for 177 coastal countries worldwide but aggregated results are presented for 51 countries in which tourism is most important and for which full data sets were available. Aggregate results on an annual and national level indicate that, regarding beach tourism, large developing countries might be among the most vulnerable due to high exposure and low adaptive capacity. Small islands states are also vulnerable, especially due to their high sensitivity towards climate change. Developed high latitude countries as well as the Mediterranean are amongst the least vulnerable countries. However, the aggregated index should not be seen as a country ranking set in stone but rather as a starting point for a more detailed comparison of subindices or individual indicators. This caution in interpretation is warranted due to a number of limitations of the index approach. An important drawback is the fact that for large countries, results on a national scale have very little relevance on the specific local level because a national indicator hides all geographical variability present. This could be addressed in subsequent research by using the general framework developed to derive indicators on a destination level and for instance compare competing beach destinations. Future research should also investigate the relationships between the different indicators and scrutinize the implicit assumption that a favourable rating in one indicator can compensate for an unfavourable rating in another.

The effect of climate change on tourism is not a simple one-dimensional relationship but involves complex interactions of direct and indirect effects as well as possibilities of responding to these. The merit of the presented approach lies in the integration of direct as well as indirect effects as well as explicitly addressing all three vulnerability dimensions, exposure, sensitivity and adaptive capacity. National level vulnerability assessments such as the one presented are still in a pioneering phase (Eriksen and Kelly, 2007). It is hoped that this assessment has contributed to the development in this field and will encourage further exploration of methods to integrate different elements of the climate change – tourism interface.

3.9. Acknowledgements

The author would like to thank Simon Donner and colleagues for generously providing their data on coral bleaching. Thanks go to Bas Amelung, Dieter Imboden, and Reto Knutti for helpful feedback. The author also acknowledges the modeling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model output, and the JSC/CLIVAR Working Group on Coupled Modelling (WGCM) for organizing the model data analysis activity. The multi-model data archive is supported by the Office of Science, U.S. Department of Energy.

4 The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland

*Submitted to Ecological Economics on 14 March 2008
Co-authors: Ana Sesartic and Matthias Stucki*

4.1. Abstract

In recent years, many countries have calculated the greenhouse gas (GHG) intensity of their economic sectors as a basis for policy making. The GHG intensity of tourism, however, has not been determined since tourism is not measured as an economic sector in the national accounts. While for tourism-reliant countries it would be useful to know this quantity, a number of difficulties exist in its determination, in particular with respect to the consistency of system boundaries. In this paper, we present an analysis of GHG intensity of the characteristic tourism industries in Switzerland based on a detailed bottom-up approach. For comparison, we calculate the tourism sector's GHG intensity for selected European countries using a simpler top-down approach. Our results show that the Swiss tourism sector is more than four times more GHG intensive than the average Swiss economy. Of all tourism's sub-sectors, air transport stands out as the sector with by far largest emissions (84%) and highest GHG intensity. The results for other countries make similar, if not as pronounced, patterns apparent. We discuss these results and possible mitigation options against the background of the goal to prevent dangerous climate change.

4.2. Introduction

Climate change is projected to impact tourism in various ways. Among the more noticeable adverse impacts are the bleaching of coral reefs in diving destinations, decreasing natural snow cover in winter sport destinations and sea level rise in low-lying tourism dependant islands (IPCC, 2007a). However, tourism also contributes to climate change through the

emission of greenhouse gases (GHGs). As a result, the tourism industry has a growing self-interest and is under increasing pressure to act on climate change.

It has become clear that the goal of preventing “dangerous anthropogenic interference with the climate system” (United Nations, 1992) requires considerable reductions of global GHG emissions over the next decades. The challenge this poses for the economy is to find ways to provide income and employment while emitting very low levels of GHGs. In this context, environmental intensity is a simple and useful concept that combines both these aspects in a ratio. It denotes how much environmental damage (in our case GHG emissions) is produced per economic value generated (Huppel and Ishikawa, 2005). In many European countries including Switzerland, the GHG intensity of economic sectors has recently been calculated by expanding the national accounts with environmental satellite accounts to generate a “National Accounting Matrix including Environmental Accounts” (NAMEA) (BfS, 2005). This matrix juxtaposes the monetary information of the national accounts and environmental physical flow data and produces key indicators such as GHG emissions per gross value added or per employee (Eurostat, 2003). The NAMEAs have enabled a comparison across sectors and countries as well as the identification of best practices (BfS, 2005).

Tourism, however, is not measured as an economic sector in its own right in national accounts because it is not an output-defined but mainly demand-defined industry. Consequently, the NAMEAs do not include GHG intensities for tourism. First estimates of GHG intensities in the field of tourism have been calculated by Gössling and colleagues (2005). They calculated the GHGs emitted per Euro of tourist spending (which they termed “eco-efficiency”) for five case studies: inbound tourism to Rocky Mountain National Park, Amsterdam, Val di Merse in Italy, France and the Seychelles. The focus on a group of tourists instead of a nation enabled them to calculate the GHG intensity as a function of the origin country or the trip purpose. A weakness of the approach is that the economic benefit is measured by expenditure, which is less adequate than value added (Jones et al., 2003). More importantly, their case studies revealed the difficulty of generating data sets in which the economic aspect (expenditures) is compatible with the environmental one (GHGs). In most of their case studies they were able to calculate the GHG emissions of the transport from origin to destination. However, most of the tourist spending surveys they used did not include expenditures for this transport. Such inconsistencies can severely limit the validity and comparability of the resulting ratios.

Here we look at the GHG intensity of tourism’s value added with a focus on consistent system boundaries. We calculate GHG intensity on a national level for the case of Switzerland and measure it in terms of GHG emissions per gross value added. The economic data for this task is available from an existing tourism satellite account (TSA) for Switzerland (Gaillard et al., 2003). Our main contribution consists in collecting GHG data in a bottom-up and a top-down approach along the system boundaries set out by the TSA. By this means, the GHG intensity of tourism can be calculated in a consistent way and can be compared to that of the standard economic sectors reported in the Swiss NAMEA (BfS, 2005). In addition, the emissions and GHG intensities of tourism sub-sector can be compared and assessed. To put the results in perspective, the GHG intensity of tourism was also calculated for selected European countries in a top-down approach.

4.3. System Boundaries

The GHG intensity indicator sets an economic quantity in relation to an environmental one. In order for the resulting ratio to be meaningful, the same system boundaries have to be applied to both quantities consistently. However, this is often not accomplished (Pedersen and de Haan, 2006). The eco-efficiency study by Gössling et al. (2005) shows that it can be difficult to obtain consistent data sets. In general, economic data such as value added refer to all economic activities of resident producers while environmental data are defined geographically and refer to national territories (Pedersen and de Haan, 2006). In some cases, this difference is not relevant. It would for instance seem unproblematic to compare the value added of all hotels resident in Switzerland with the emissions of all hotels located within Swiss borders. However, in other cases, different boundaries can be very relevant. Emissions of aviation, for instance, can be allocated according to many criteria, e.g. the point of fuel sale, the residence of the transporting company, the country of departure or that of arrival, etc. The CO₂ emissions of “Swiss” aviation in 1999, for instance, vary by a factor of more than six depending on which allocation principles are chosen (Kaufmann et al., 2000).

In principle, there are three options for system boundaries: the adoption of the boundaries applied to either the available economic or the environmental data set or the creation of a new set of system boundaries. As in this study we want to compare the GHG intensity of the tourism sector to that of other sectors, the economic system boundaries are chosen. The targeted system boundaries are thus set by the Swiss TSA (Gaillard et al., 2003) and are listed in the following:

Tourism definition: Tourism is defined according to the official definition provided by the UN World Tourism Organization as “the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited” (Eurostat/OECD/WTO/UNSD, 2001, paragraph 1.1). It is important to note that business travel, which is not perceived as tourism in the general public, is included in this official definition.

Tourism sector: In this study, the term “tourism sector” only encompasses the “characteristic tourism industries” (see Annex 1), which account for the lion’s share of the gross value added and emissions (Gaillard et al., 2003). The “connected” tourism industries are not considered (e.g. retail trade, schools, hospitals, banks).

Units of analysis: The units of analysis are institutional units resident in Switzerland. This boundary differs from the geographical approach often used for GHG and specified by the Intergovernmental Panel for Climate Change for the national greenhouse gas inventories (IPCC, 1996). These generally cover the emissions within Swiss territory, thus including (transport) emissions of non-resident units on the territory and excluding the emissions of resident units abroad.

Level of analysis: As the Swiss TSA only includes the direct and not the indirect or induced economic impacts, the same level of analysis is applied to the GHG calculations. This means, for instance, that the consumption of electricity entails no emissions. The TSA guidelines (Eurostat/OECD/WTO/UNSD, 2001) specify a noteworthy exception to this general rule that is also applied in the Swiss TSA. In the case of travel agencies and tour

operators, not only the services provided by these entities themselves, but also the embodied tourism services are considered to be directly purchased by the visitor. It is considered more appropriate for tourism services provided in a package (flight, accommodation, etc.) to appear as final consumption (by the visitor) than as intermediate consumption (by the travel agency/tour operator).

Greenhouse gases: For the standard calculation, all GHGs listed in the Kyoto Protocol are included: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. These are measured in CO₂-equivalents on the basis of global warming potentials. In a sensitivity analysis, all additional radiative forcing agents of aviation are included as well (see Section 3.1).

Time: The targeted time frame is the year 1998. It is the most recent (and as yet only) year for which the Swiss TSA currently provides data.

4.4. Tourism in Switzerland

Tourism is an important economic sector for Switzerland, generating approx. 3.4 % of gross domestic product (Gaillard et al., 2003) and 13% of export receipts (STV, 2007). Main attractions of tourism in Switzerland are the mountains, for both summer and winter, and Swiss cities (STV, 2007). The most important source markets for Switzerland are Germany, France, the UK and the USA (BfS, 2003). In Table 4.1, it is compared to the tourism sectors of other selected European countries. With international tourism constituting nearly half of overnight stays, Switzerland lies in the intermediate ranks.

Table 4.1: Comparison of the tourism in Switzerland with other selected European countries (data source: average for 2000-2002 from UN-WTO (2006c)).

country	tourism's share of GDP [%]	source for share of GDP	share of international overnight stays [%]	# of tourists per annum [1000]	# of tourists per inhabitant
Sweden	2.7	Statistika centralbyrån (2008c)	22	5878	0.7
Germany	3.2	(Ahlert, 2003)	12	18271	0.2
Switzerland	3.4	(Gaillard et al., 2003)	47	7381	1.0
United Kingdom	3.8	(Jones et al., 2004)	27	n.a.	n.a.
France	4.9	WTTC (2004b)	37	76468	1.3
Italy	4.9	WTTC (2004b)	42	40181	0.7
Austria	6.7	(Statistik Austria and WIFO, 2003)	71	18258	2.3
Spain	6.8	(Instituto Nacional de Estadística, 2008b)	67	50106	1.2
Greece	7.2	WTTC (2004b)	75	13778	1.3
Croatia	9.0	WTTC (2004b)	88	6440	1.4
Cyprus	10.4	WTTC (2004b)	96	2600	3.3

4.5. Methods and Data

In their study on GHG emissions of tourism in New Zealand, Becken and Patterson (2006) advocate applying both a bottom-up as well as a top-down approach to estimate a country's tourism CO₂ emissions. We follow this general suggestion and present both approaches in the following two subchapters. The presented bottom-up approach is specific for Switzerland; the top-down approach can and is applied internationally.

4.5.1 Bottom-up Approach

The Swiss TSA provides results for 13 specific tourism sectors that are composed of 44 sub-sectors of the official Swiss classification of economic activities. As all economic information in Switzerland is collected according to this classification, GHG emissions are first estimated at the level of these 44 sub-sectors and in the end aggregated to the 13 TSA sectors.

For most economic sectors in Switzerland, the Federal Statistics Office determines value added by estimating the average value added per employee from company surveys and multiplying it with the number of employees in a sector. To be consistent with the economic data, it would thus be useful to obtain emissions on a "per employee" basis. For the Swiss case, such a calculation method was possible for most sub-sectors and is presented in the following equation and Table 4.2.

$$\frac{GHG}{sub-sector} = \frac{employees}{sub-sector} \times \frac{stationary\ fuel}{employee} \times \frac{CO_2}{fuel} \times \frac{total\ CO_2}{stationary\ CO_2} \times \frac{GHG}{CO_2}$$

a)
b)
c)
d)
e)

Table 4.2: Data sources, time frame and references for the main method to calculate GHG emissions per sub-sector.

term	Indicator	source	year data refer to	reference
a	employees / sub-sectors	census of Swiss enterprises	1998	(BfS, 1998)
b	stationary fuel/ employee	energy survey among resident companies	2002-2004	(BfE, 2006)
c	CO ₂ / fuel	Switzerland's Greenhouse Gas Inventory 1990-2005. National Inventory Report 2007	-	(BAFU, 2007a)
d	transport shares	Swiss pilot NAMEA	2002	(BfS, 2005)
e	GHG / CO ₂	Swiss pilot NAMEA	2002	(BfS, 2005)

The main source is an energy survey carried out in resident companies by the Swiss Federal Office of Energy (BfE, 2006). It provides raw data on companies' consumption of stationary energy sources per employee. For each sub-sector, the number of employees per sub-sector (a) in 1998 (BfS, 1998) were multiplied with the averages stationary fuel consumption per employee (b). For those sub-sectors in which no or only very few companies had answered the survey, results were taken from similar substitute sectors.

Stationary CO₂ emissions were then calculated by means of CO₂ conversion factors (BAFU, 2007a). As the energy survey excluded all use of transportation fuels, emissions from transport had to be added (d). Transport emissions are available as percentages of total CO₂ emissions per economic sector from the Swiss NAMEA (BfS, 2005) and were usually below 15%, except for the transport sectors (see below). In the specific cases of railways and water transport, the transport emissions were available and thus added in absolute numbers (BAFU, 2007a). In a next step, non-CO₂ GHGs were added by means of multiplication factors (e) that could also be drawn per economic sector from the NAMEA (BfS, 2005).

For some of the sub-sectors, alternative calculation methods had to be used. In the passenger transport sub-sectors, applying the above method is imprudent. Emissions were thus mostly calculated by means of the travel behaviour microcensus, which provides the amount of kilometres travelled per mode of transport by the Swiss population in the year 2000 (ARE/BfS, 2001). The total of person kilometres was multiplied with CO₂ emission factors (Ecoinvent, 2006) and converted into GHG emissions with multiplication factors derived from the Swiss NAMEA (BfS, 2005) as above. It has to be noted that this calculation method is unable to provide results along the defined system boundaries. GHG emissions are calculated from the demand instead of the supply side. In addition, the calculations do not include distances travelled by visitors within Switzerland but instead include distances travelled by Swiss residents abroad.

For aviation as a large emitter of GHGs in Switzerland, it is particularly important to determine emissions along the correct system boundaries. Unfortunately, it proved impossible to achieve this goal in the scope of this study. Emissions of “Swiss” aviation in 1998 are available according to five different allocation principles (Kaufmann et al., 2000) with largely varying results. However, none of these distinguishes between emissions from resident and non-resident airlines. Further enquiries revealed that neither the airports nor the Swiss Federal Office of Civil Aviation record the country of residence of the flights’ airlines in their statistics. Given the lack of better data, emissions from aviation fuel sold in Switzerland were thus chosen as a first approximation. It (incorrectly) includes fuel bought in Switzerland by non-residential airlines and (incorrectly) excludes purchases of residential airlines abroad. The calculation of aviation’s contribution to climate is also difficult for another reason. In addition to emitting CO₂, aviation contributes to climate change through the emission of NO_x and the formation of contrails and cirrus clouds. However, the quantification of these effects is still a subject of research and discussion (Forster et al., 2006; Penner et al., 1999; Sausen et al., 2005). For this reason and to keep calculations consistent with the Swiss NAMEA, calculations in this study have primarily been carried out under the assumption that aviation’s GHG to CO₂ ratio (1.013) is equal to that of the transport sector (BfS, 2005). In a sensitivity analysis of the results towards this assumption, the key indicators of this study are calculated and presented assuming the overall impact of aviation to be 1.5, 2 or 2.7 times as high as that of CO₂ alone.

For the calculation of value added for “Holiday Home Use and Renting by Owner”, the Swiss TSA follows the international guidelines (Eurostat/OECD/WTO/UNSD, 2001) and includes the imputed rent on owned second homes. However, since it does not explain the underlying calculations and the applied system boundaries are therefore not known, it is impossible to determine the GHG emissions along the same boundaries. In addition, the Swiss TSA assumes that the tourism share of second homes is only 4%, which seems an

implausible estimate for Switzerland. For these two reasons, this category has been excluded from the present study.

A full list of all these sectors and the applied calculation methods is provided in Annex 1.

The calculations presented here are specific to Switzerland, and for other countries the bottom-up approach will depend on available statistics. What can be drawn from this case for other countries is that consistency is improved if emissions are calculated on the same basis as value added (in this case per employee). Also, IPCC greenhouse gas inventories generally do not provide data on the level necessary, especially for accommodation, restaurants, travel agencies, and cultural services. However, in the passenger transport sector it is well worth looking into the methods and results of the inventory report.

4.5.2 Top-down Approach

Given a TSA as well as a NAMEA, a simple top-down approach can be applied in order to obtain an estimate of the tourism sector's GHG intensity. First, the tourism sector's overall GHG emissions can be calculated by multiplying the gross values added per sub-sector provided by the TSA with the GHG intensities of the corresponding (more aggregated) sectors determined in the NAMEA. Then the emissions are divided by the overall gross value added to give the GHG intensity. This estimate relies on the assumption that the GHG intensities are identical within an economic sector.

The top-down approach was applied to Switzerland as well as a number of selected European countries. For this study, comparison is restricted to Europe, since countries compile NAMEAs following the same guidelines (Eurostat, 2003). TSAs and NAMEAs were collected and investigated for 14 European countries. In order to ensure a minimum standard of accuracy, GHG intensity of tourism was only calculated if calculations for transport could be made on a disaggregated level (i.e. land, water and air transport separately). This excluded the Czech Republic, Denmark, Netherlands, Finland and Portugal. Germany was excluded because GHG emissions allocated to aviation were only over German territory and Norway, Belgium, France and Italy because tourism value added was not available. The data sources for the remaining 4 countries and Switzerland are presented in Table 4.3 below. To maintain consistency, the private use of second homes and non-tourism industries were excluded for those countries that report these items.

Table 4.3: Data sources for the calculation of the GHG intensity of tourism with a top-down approach for Switzerland and selected European countries.

country	tourism value added	GHG emissions of sectors	gross value added of sectors
Austria	Statistik Austria and WIFO (2003)	Statistik Austria (2008)	Statistik Austria (2008)
Spain	Instituto Nacional de Estadística (2008b)	Instituto Nacional de Estadística (2008c)	Instituto Nacional de Estadística (2008a)
Sweden	Statistika centralbyrån (2008c)	Statistika centralbyrån (2008b)	Statistika centralbyrån (2008a)
United Kingdom	Jones et al. (2004)	Office of National Statistics (2008)	Office of National Statistics (2008)
Switzerland	Gaillard et al. (2003)	BfS (2005)	BfS (2005)

4.6. Greenhouse Gas Emissions of the Tourism Sector

Based on the bottom-up approach, the Swiss tourism sector's emissions in 1998 are estimated at 3.45 million t CO₂-eq. This corresponds to approx. 6.1% of overall Swiss GHG emissions including international aviation emissions (BAFU, 2007b). This figure can be set in perspective by tourism's contribution to the gross domestic product (GDP). The TSA estimates it at 2.5% of GDP in 1998 for the system boundaries of this study. The top-down approach estimates tourism emissions at 2.62 million t CO₂-eq. (4.4% of total), at more than 20% below the bottom-up estimate. However, this estimate is judged to be a lot less accurate (see Section 6).

Table 4.4: Estimated GHG emissions of Swiss tourism (1998) broken down by sub-sector.

Sub-sector	GHG emissions [1000 t CO ₂ -eq.]	% of total emissions
Accommodation	274	8%
Foods and Beverages	52	2%
Culture, sports, entertainment	22	1%
Travel agencies	6	<0%
Other transport	209	6%
Air transport	2'865	84%

In Table 4.4, overall GHG emissions are broken down by sub-sector. Tourism's GHG emissions are clearly dominated by the emissions from air transport (including supporting activities), which account for 84% of total emissions. Other important sub-sectors are accommodation with 8% and other transport (6%), which consists of all land and water transport, including supporting activities. It might be surprising that other transport modes constitute such a small share of total emissions. On the one hand, this is due to the fact that the entire Swiss railway system is electrified, generating no *direct* GHG emissions in operation. On the other hand, these figures are small as they do not include the use of private vehicles such as cars since these do not generate direct value added. Direct GHG emissions from travel agencies, catering services, cultural activities, sports and entertainment represent an insignificant share of total emissions.

A comparison with the GHG emission distribution for tourism in countries (see Becken and Patterson (2006) for New Zealand and Schmied et al. (2001) for Germany) is not possible as these apply different system boundaries, including emissions of private households (i.e. car driving) and excluding international flight emissions. The results from the top-down approach for selected European countries show that air transport is dominant in most cases, contributing approx. 70% of emissions of tourism in Sweden and the UK and 50% in Spain, where land transport plays a larger role (25%).

4.7. Greenhouse Gas Intensities

The Swiss tourism sector's GHG intensity is estimated at 370 g CO₂-eq./CHF of gross value added (CHF are Swiss francs. In 1998 a Swiss franc represented a value of 0.63 EUR and 0.69 USD.). The estimate from the less accurate top-down approach is 281 g CO₂-eq./CHF. Figure 4.1 below presents the GHG intensities and emissions of the different sub-

sectors. The sub-sectors presented are those for which value added is provided in the TSA (Gaillard et al., 2003). The clearly highest GHG intensity is displayed by air transport, which in this case includes the supporting activities of all transport sectors. It is followed by water transport and land transport. The latter is comparatively low since it includes trams, which are all electrified, and coaches, which have high capacity utilisation rates. Sports facilities and activities also display a fairly high GHG intensity, which might be attributed to emission intensive facilities such as indoor swimming pools.

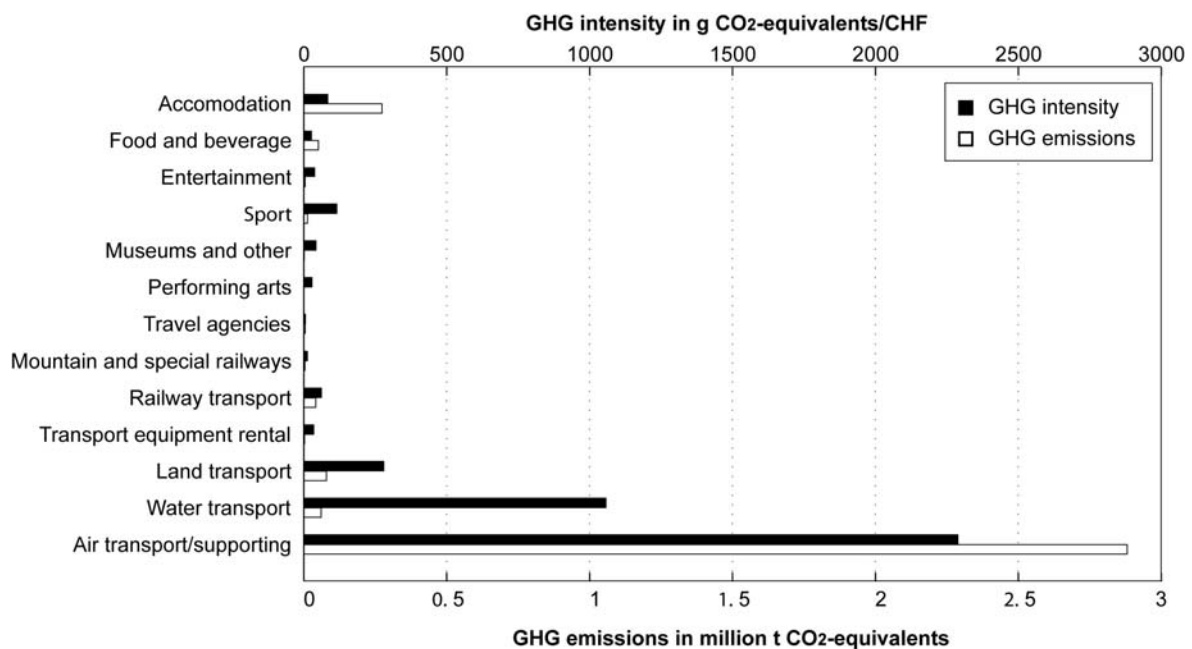


Figure 4.1: The Swiss tourism sub-sectors' GHG emissions (in t CO₂-eq.) and GHG intensity (in g CO₂-eq./CHF gross value added).

A sector's relevance can be assessed by either its absolute emissions or its GHG intensity. If both criteria are applied, air transport is undisputedly the most important sector with very high emissions and a very unfavourable GHG intensity. Far behind follow water and land transport with very unfavourable GHG intensities but low absolute emissions as well as accommodation with considerable absolute emissions but low intensity. The pivotal role of air transport is also illustrated by the fact that if aviation were disregarded, the tourism GHG intensity would drop to 70 g CO₂-eq. /CHF. This is approx. 40 times lower than that of air transport alone.

Comparisons with other GHG intensities can set that of the Swiss tourism sector into perspective. The only intensities of tourism available from literature are those by Gössling and colleagues (2005). However, they are calculated with tourism expenditures and not value added and can therefore not be compared. In the following, the GHG intensity is compared to that of other sectors of the Swiss economy as well as tourism sectors of selected European countries.

4.7.1 Comparison with other Sectors of the Swiss Economy

Figure 4.2 presents an economy-wide comparison of GHG intensities of Swiss sectors. With a GHG intensity more than 4 times higher than the average, the tourism sector ranks among the most intense sectors. Only few economic sectors display even less favourable GHG intensities: the disposal industry with low value added but high emissions from incineration, agriculture with high methane and nitrous oxide emissions and the transport sector. Of the sectors included in “manufacture of energy intensive products”, only metal working and cement production are less favourable than tourism.

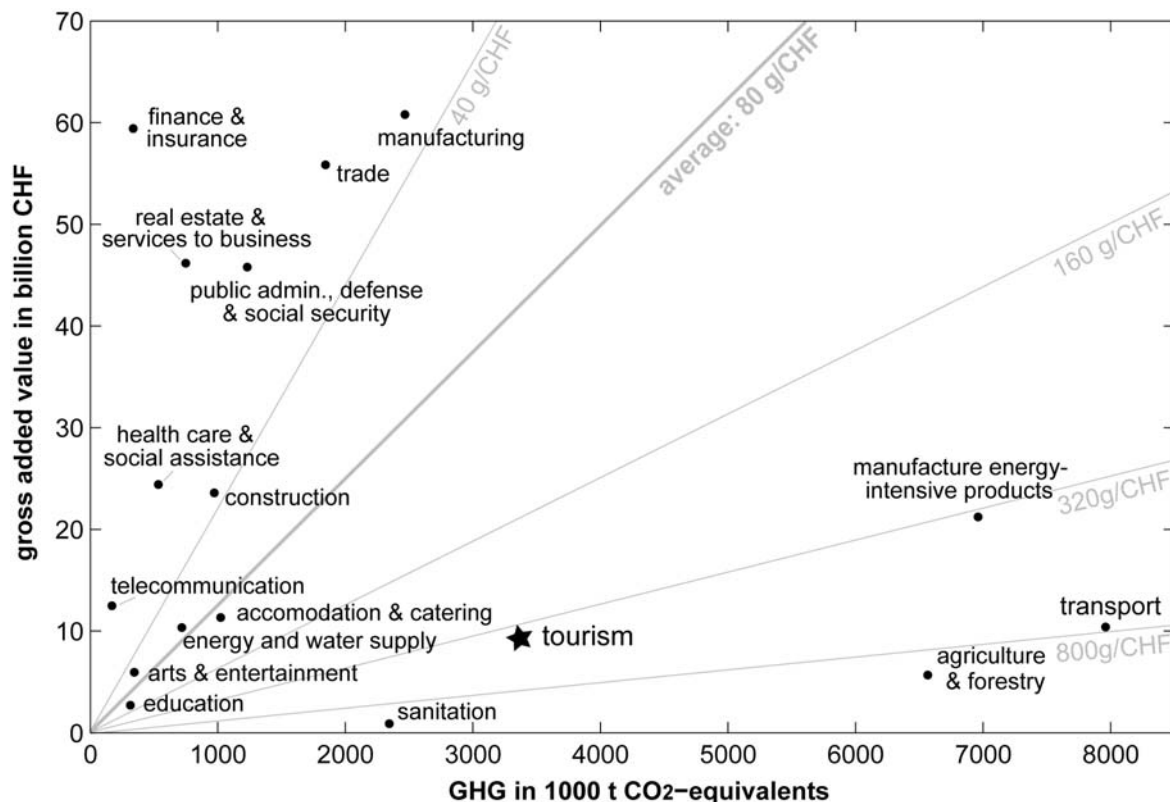


Figure 4.2: Comparison of the GHG intensities of tourism (this study) and selected economic sectors in Switzerland (BfS, 2005). The gross value added of the sectors is plotted against their GHG emissions. The grey diagonal lines represent different GHG intensities as examples.

4.7.2 Comparison with other Countries' Tourism Sectors

The GHG intensities calculated for selected European countries with the top-down approach are presented in Figure 4.3. While the GHG intensities of the tourism sector vary strongly, the very low value for Austria is conspicuous. It is partially caused by the calculation that only 8% of air transport's value added is due to leisure and business tourism (Statistik Austria and WIFO, 2003). It is difficult to conceive that 92% of value added is due to freight, cargo and other special cases of travel not related to leisure or business. In addition, a very low GHG intensity reported for air transport: GHG emissions of resident airline companies were assumed to be 50% of all aviation bunker fuel sold in Austria. In contrast, in Switzerland and in Sweden 100% is taken. The Austrian value is very probably a considerable underestimation, as also stated by the authors (Statistik Austria, 2008).

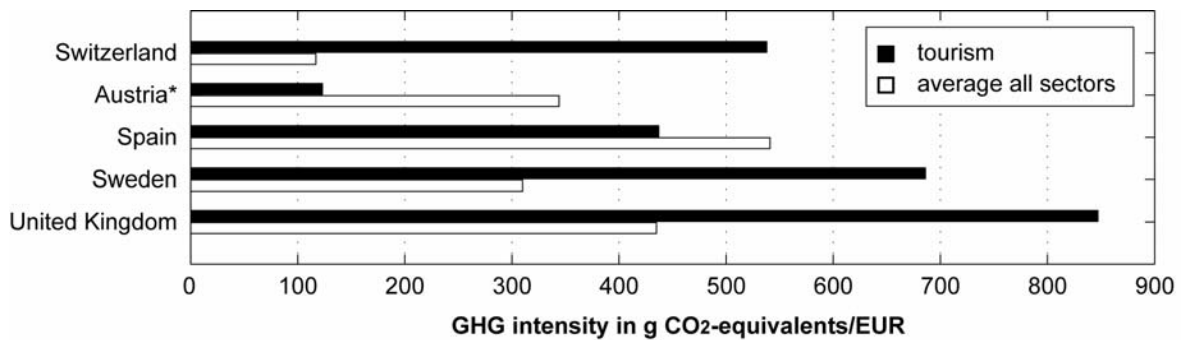


Figure 4.3: GHG intensities (g CO₂-eq./EUR) of the tourism sector and all sectors in selected European countries. Only characteristic industries excluding private use of second homes are shown. Results for Switzerland are taken from the bottom-up approach. * Results for Austria are assumed to be substantially underestimated (see text).

Thus disregarding Austria, the GHG intensity of tourism ranges from 440 to 850 g CO₂-eq./EUR. With the exception of Spain, tourism is more GHG intensive than the average of all sectors. Like in Switzerland this is due to a high share and a high GHG intensity of air transport. In Spain, the share of air transport is lower and less GHG intensive land transport plays a more important role. In addition, 70% of tourism value added is from accommodation and catering services with very low GHG intensities. In Sweden and the UK, water transport displays even higher GHG intensities than air transport and constitutes 12 and 17% of tourism GHG emissions, respectively. Overall, the Swiss tourism sector's GHG intensity is similar to that of other countries. The large difference between tourism and the average economy seems however to be extraordinarily pronounced in Switzerland. This is not due to the value for tourism but to the very low GHG intensity of the average Swiss economy. This is caused by lower intensities in most economic sectors, and exceedingly lower intensities for electricity supply due to nuclear and water power (BfS, 2005). Presumably the most important reason is the composition of economic sectors. As can be seen in Figure 4.2, overall value added in Switzerland is dominated by services with high value added and low emissions, as for instance the financial and insurance services.

In this context it is important to note that the above GHG intensities cannot be compared to many of the reported GHG intensities of economies (Bataille et al., 2007; Raupach et al., 2007). This is because these are calculated by dividing total end-use emissions by GDP. In contrast to the approach used in the NAMEAs, they thus include household emissions in addition to the industries' emissions.

4.8. Sensitivity of the Results and Data Quality

The sensitivity of key indicators towards different assumptions in air transport's radiative overall effect on climate change is presented below in Table 4.5. Air transport's share of tourism GHG emissions is not overly sensitive to the different assumptions and remains high throughout. In contrast, the GHG intensity of the tourism sector as a whole is highly sensitive to these assumptions. As air transport constitutes the main share of tourism's emissions, the GHG intensity of tourism increases nearly linearly with the aviation GHG multiplication factor. Assuming the often cited factor of 2.7 originally proposed by the IPCC Special Report in 1999 (Penner et al., 1999), the overall GHG intensity jumps from 370 to 880 g CO₂-eq./CHF and tourism's share of total Swiss emissions increases from 6.1

to 12.8%. However, more recent studies suggest that the multiplication factor lies closer to 1.5 (Forster et al., 2006).

Table 4.5: Changes in key indicators, assuming that the overall impact of aviation is 1.5, 2 or 2.7 times as high as that of CO₂ alone.

aviation GHG multiplication factor	1.013	1.5	2	2.7
GHG intensity of the tourism sector in g CO ₂ -eq./CHF	370	520	670	880
tourism's share of Swiss GHG emissions in %	6.1%	8.2%	10.3%	12.8%
air transport's share of tourism GHG emissions (including air transport supporting activities) in %	84%	88%	91%	93%

The quality of the results presented here depends on three factors: the accuracy of the value added calculated in the TSA, the accuracy of the GHG emission data and the consistency of system boundaries between the two. Regarding the first component, the authors of the TSA estimate the value added to be of high quality for the aggregate sector and of variable quality for individual sub-sectors (Gaillard et al., 2003). Regarding the other two components, data quality differs between sub-sectors. For those sub-sectors calculated with the standard method, the system boundaries are consistent because both value added and GHG emissions are based on the number of employees within a sub-sector. In this case, data quality is determined by the representativeness of the underlying energy survey. For sub-sectors with large samples the results are of a high quality, while for those with small samples (or substitute samples) results are less accurate. For those sub-sectors where GHG emissions were calculated by means of the microcensus, we judge the figures to be quite accurate but system boundaries not to be completely consistent. For air transport, system boundaries are also inconsistent and due to its large share this might have a large effect on overall results. In addition, as seen above, air transport's emissions depend very strongly on the as yet uncertain total effect on climate change. This makes air transport the weakest point to be addressed in order to improve data quality.

As mentioned in Section 4, we estimate the accuracy of the top-down approach for Switzerland to be quite low. One reason is the high aggregation level and uncertain accuracy of the underlying data. Unfortunately, the GHG intensity of air transport is not reported separately but only averaged with that of (less GHG intensive) land and water transport. This high level of aggregation distorts the results in favour of tourism GHG emissions and intensity. In addition, the underlying data of the Swiss NAMEA is only assumed to be accurate on an aggregated level but preliminary on the sector level (BfS, 2005). However, for the countries in which a TSA and a reliable and less aggregated NAMEA are both available (see Figure 4.3), we judge the top-down calculation a simple yet adequate approach to calculate the GHG intensity of tourism. In most of these cases, an important uncertainty arises from reported aviation emissions, as these are often derived from bunker fuel sold within the territory and do thus not refer to the fuel used by resident companies.

Regardless of small possible changes in the detailed numbers due to the uncertainties, the ensuing discussion and conclusions are robust and remain valid.

4.9. Discussion and Conclusion

We have shown that the GHG intensity of Swiss tourism is more than four times higher than the average of the Swiss economy. Also, we have identified air transport to be by far the largest emitter of GHGs as well as the most GHG intensive sub-sector in Swiss tourism. Calculations for selected European countries make similar, if not as pronounced, patterns apparent. The central role of air transport is not an unexpected result and confirms the outcome of other studies (Gössling, 2002; Gössling et al., 2005; Peeters et al., 2007; Schmied et al., 2001). However, we believe that the implications of this result have yet to be integrated into research and policy making. Especially studies on sustainable tourism often restrict their analyses to the destination level (Hoyer, 2000; Hunter, 2002), thus disregarding the single most important aspect from a climate change perspective. Also in practice, this tendency can be observed: In Switzerland, for instance, a national program is targeted towards increasing the energy efficiency in hotels, while the national marketing organization has defined the strategic growth source markets to be China, Russia, India, Korea and the Gulf States (Schweiz Tourismus, 2007).

The prevention of dangerous climate change requires worldwide GHG emissions to be cut in half by 2050 compared to 1990. For developed countries with more responsibility and capability, the reduction goal lies at 80% (UNDP, 2007). Given the fact that in the analysed countries 50 to 85% of tourism emissions are caused by air transport, the tourism sector can only achieve this reduction goal with a major cut of emissions in air transport. Focussing on transport emissions, there are four options to reduce the GHG emissions of tourism (based on Peeters and Schouten, 2006):

1. Reducing GHG emissions per person kilometre travelled;
2. Shifting towards transport modes with less GHG emissions (i.e. from air and water to land transport);
3. Reducing travel distances by promoting domestic and short-haul markets; and
4. Extending the length of stay.

All options contribute to reduction of both emissions and GHG intensity. While in the first, emissions are reduced within each sub-sector, the other three change the overall emissions by changing the composition of sub-sectors within transport (2) or the tourism sector as a whole (3 and 4). This makes these options more difficult to implement, as shifts between sub-sectors inevitably generate winners as well as losers: For instance, destinations have continuously put effort into encouraging longer stays, while on the other side airlines have been propagating more frequent flights and trips. Despite implementation difficulties, these composition changes are indispensable to achieve substantial reductions of absolute emissions in the tourism sector. Technological and operational improvements alone (1) have been shown not to suffice: For instance in Germany, the GHG emissions per long-haul trip are projected to decline by 25% from 1999 to 2020 primarily due to technical innovations. However, this is more than offset by an increase of 167% in demand in the same time period: Total emissions from long-haul trips are projected to double from 30 to over 60 million t CO₂-eq. (Schmied et al., 2001). Then how could tourism look like if the required emission reductions are reached? In a backcasting analysis, Céron and Dubois (2007) present a picture for a “sustainable mobility” in France in 2050, in which GHG emissions are reduced by 75% and the holiday participation rate is increased. Surprisingly, the resulting scenario allows an overall increase in kilometres travelled. “Long distance” trips are reduced and compensated with outings and short distance leisure mobility. Interestingly, the amount of “very long distance” trips by air does not decrease, but

remains at 0.1 trips per individual and year. In total, air and especially car transport are drastically reduced and substituted with trains and coaches. While the assumed increased efficiency of this scenario is taking place, most other assumptions are in direct contradiction to the current trend towards shorter trips and a modal shift to air travel.

In this context the current distribution of GHG emissions among travellers is of interest. A study in Germany revealed that 80% of the climatic effect of holiday mobility is caused by only 11% of the population (Böhler et al., 2006). Peeters (2007, p. 92) sees this uneven distribution as an “opportunity to reduce emissions significantly, while affecting only a relatively small part of all tourism and tourism economy”. This is a point where further research regarding GHG intensity would be useful – how much per cent of value added is generated by these 11% of population and 80% of emissions? GHG intensities could be calculated as a function of source markets or socio-demographic groups targeted by national marketing organizations (Gössling et al., 2005). Further development in this field should also involve adopting a life cycle thinking: including indirect value added as well as the corresponding “embodied” emissions could change the overall picture considerably. Restaurants, for instance, would presumably display a higher GHG intensity due to the large share of intermediate inputs from the GHG intensive agricultural sector. Also, the GHG intensity of the tourism sector could be compared to that of tourism as an activity by adding emissions of private households for tourism purposes (particularly the use of cars).

The merit of GHG intensity as an indicator lies in combining the economic benefit and environmental damage in one number. If in the next decades wealth and employment are to be maintained or increased while GHG emissions are to be cut sharply, GHG intensity is a very valuable indicator. However, it also has to be kept in mind that a reduction of GHG intensity does not necessarily mean a reduction in absolute emissions as it can be offset by increases in value added or total output. Therefore, if the prevention of dangerous climate change is set as primary goal, GHG intensity must only be interpreted in conjunction with additional information on absolute emission levels.

4.10. Acknowledgements

The authors would like to thank Dieter Imboden, Bas Amelung and Reto Knutti for feedback and the Swiss Federal Office of Environment for providing unpublished data of the energy survey.

4.11. Annex A

Table 4.6: Tourism sub-sectors according to the Swiss TSA (Gaillard et al., 2003) and the corresponding sub-sectors according to the Swiss classification of economic activities. The last column lists the deviations from the main calculation method.

TSA Switzerland	Swiss classification of economic activities	Method
Accommodation		
Hotel industry	Hotels with restaurant	
	Hotels without restaurant	
Non-hotel accommodation	Youth hostels, accommodations	
	Campground	
	Guest houses and tourist homes	
	Group accommodation (without lodges)	
	Other accommodation establishments	
Holiday home use and renting by owner	Holiday Home Use and Renting by owner	not included
Catering industry		
	Restaurants, Tea-Rooms, etc.	
	Bars	
	Caterers	
Passenger transport		
Railways	Railway transport	transport emissions from (BAFU, 2007a)
Mountain railways and other special railways	Mountain railways and other special railways	microcensus
Land transport	Passenger transportation, short distance	microcensus
	Passenger transportation, long distance	microcensus
	Taxi	microcensus
	Other passenger land transport	microcensus
Water transport	Inland water transport of passengers	transport emissions from (BAFU, 2007a), share of commercial water passenger transport from (BUWAL, 1996)
Air transport	Scheduled air transport	(BAFU, 2007b)
	Non-scheduled air transport	(BAFU, 2007b)
Auxiliary transport activities	Supporting and auxiliary land transport activities	
	Supporting and auxiliary water transport activities	
	Supporting and auxiliary air transport activities	
Renting of transport vehicles	Renting of automobiles	
	Renting of other land transport vehicles	

Travel agencies And tour operator		
Travel agencies And tour operator	Travel agencies and tour operators	
Culture	Entertainment, culture and sport	
Visual arts	Theatre and dance productions	
	Orchestras, bands and musicians	
	Individual fine artist	
	Other artistic activities or writing activities and presentations	
	Operation of concert and theatre halls	
	Operation of auxiliary arts facilities	
Museums and other cultural activities	Museums	
	Botanical and zoological gardens and nature reserves activities	
Sport and entertainment		
Sport	Operation of facilities for outdoor or indoor sports events	
	Other sports related activities	
Entertainment	Cinemas	
	Fairground and amusement parks	
	Other cultural and entertainment activities (e.g. Dancing schools)	
	Discotheques, ballrooms, night clubs	
	Libraries and archives	
	Gambling and betting	
Other entertainment/recreation/leisure services		

5 Concluding Remarks and Future Research

Climate change and tourism are intertwined. Climate change can affect tourism directly or indirectly and tourism contributes to climate change through the emission of greenhouse gases. In this thesis, I have addressed three aspects of interest in this field.

5.1. Future Climate Resources for Tourism in Europe based on the Daily Tourism Climatic Index

Summarized Results

Currently, climate resources for sightseeing tourism are best in Southern Europe and deteriorate with increasing latitude and altitude. Climate change entails substantial redistributions of climate resources over space and time, which will undoubtedly influence the future distribution of tourism flows. Generally, favourable climate is projected to shift northward improving climate resources in Northern and Central Europe. In Southern Europe, the suitability for sightseeing tourism also increases between October and April but drops strikingly in the summer holiday months due to maximum temperatures rising too high to be comfortable for sightseeing.

Approach

The use of daily data enabled to determine the number of favourable days per month instead of a monthly mean. This form of representation is meaningful as well as simple, making it useful for communication with tourism stakeholders.

Future Research

Besides improving the index itself, future research could calculate present and future suitability of climate for different types of tourism. An EU-wide survey has shown that European holiday makers choose the sea (63%), the mountains (25%), cities (25%) and the countryside (23%) as destinations (European Commission, 1998). For each region one could calculate the number of days favourable for beach tourism, hiking, and sightseeing in each month. Also, research into climate as a push instead of a pull factor would be very interesting, as it has so far been neglected. How does climate in the source country influence the extent and timing of holiday making? How important is climate in

comparison to other factors such as price and income? A possible analysis would be to calculate the *difference* in favourable climate (Δ TCI) between a source and the possible destination for each month and compare it to the tourist flows.

5.2. The Vulnerability of Beach Tourism to Climate Change - An Index Approach

Summarized Results

A vulnerability index for beach tourism is developed that integrates different aspects of climate change: change in average weather, extreme events, sea level rise and coral reefs. By means of the three vulnerability dimensions exposure, sensitivity, and adaptive capacity, the index estimates the relative vulnerability of beach tourism sectors of different countries. Aggregate results on an annual level for 51 coastal countries indicate that large developing countries might be among the most vulnerable, small islands states are also vulnerable, especially due to their high sensitivity, and developed high latitude countries as well as Mediterranean countries are amongst the least vulnerable.

Approach

The main contribution of this analysis is the integration of the different mechanisms by which climate change can influence tourism. The approach has shown that if many of these influences are included, overall results are quite different than if only the direct changes in average weather are investigated.

Future Research

Future research can adjust the indicators presented to a local level and compare a number of competing beach destinations. This change of scale would make the results more relevant to tourism stakeholders and address some of the limitations revealed by the analysis. On a methodological level, different ways of integrating direct and indirect impacts should be assessed. What integration methods exist and which are most suitable in this context? What is the role of quantitative and qualitative approaches? Finally, the concept of vulnerability should be reconsidered. While the use of the vulnerability framework proved very useful to think of all relevant aspects, its major shortcoming is that it allows only for damage, not for benefit or gain. For the analysis in the tourism sector – and perhaps others as well – where there are losers but also winners, it would be valuable to devise a broader concept and terminology.

5.3. The Greenhouse Gas Intensity of the Tourism Sector: The Case of Switzerland

Summarized Results

In Switzerland, the characteristic tourism industries generate 2.5% of the gross domestic product, but cause 6.1% of GHG emissions. This makes it more than four times more GHG intensive than the average Swiss economy. Of all tourism's sub-sectors, air transport stands out as the sector with by far largest emissions (84%) and highest GHG intensity. The

results for some other EU countries are similar, if not as pronounced. The UNDP (2007) estimates that in order to prevent dangerous climate change, GHG emissions in developed countries must be reduced by 80% from 1990 to 2050. To achieve such a large reduction the tourism will have to change as drastically in the next 50 years as it has in the past 50 years. Assuming an 80% reduction for the tourism sector and given the fact that in the countries analysed aviation causes 50-85% of emissions, it has become clear that the goal cannot be reached without a major cut in emissions from air transport. This is in stark opposition to current aviation growth trends. The International Air Transport Association reports a 7.4% growth of international passengers per year for 2002-2006 and forecasts a growth of 5.1% for 2007-2011 (IATA, 2007). Assuming an average increase of 5% from 1990 to 2050 would result in an increase of more than 1800%. Worldwide GHG emissions should concomitantly be reduced by 50%.

Future Research

Future research on GHG intensity calculations should include indirect effects, both for value added and GHG. In addition, emissions of aviation must be investigated in-depth, as it is not only the most important contributor, but also the sub-sector with largest uncertainty, both because of current statistics collection and the non-CO₂ effects of aviation. The simple top-down approach presented could currently only be applied to 3 European countries. However, the necessary data are under development in many countries. In some years' time and given access to disaggregated transport data, a broader comparison can be achieved.

In addition, emission data of tourism should be used for more scenario backcasting: Given specific emission reduction goals - what type of future tourism scenarios are possible? In this context it must be recognised that if strong mitigation efforts are undertaken soon, some destinations will be more impacted by this than they would have been by changing climate. Further questions should thus be: Which of these options have most additional benefits or would least impact the economy?

From a broader perspective, the results raise another type of questions. The choice of holiday destination is one of the most environmentally important decisions of individuals (BAFU, 2006). What can travel motivation researchers contribute to this topic? What is the main motivation for long-haul travel? In which way is holiday satisfaction related to the destination distance and length of stay? Income elasticity of holiday demand is generally high, especially for long-haul travel, showing that it is still considered a luxury good (Crouch, 1996). The elasticities are different between countries – why so and what are the trends?

5.4. Thoughts on Climate Change Impact Assessments

On a more fundamental level, one may ask what the main goal of climate change impact assessments is? I would say to help decision making under uncertainty by reducing some of this uncertainty. Then which are the most important decisions? One vital question our society is facing regarding climate change is how much to mitigate. An ideal basis for such a decision would be to know a) the cost of mitigation and b) that of climate change, both ideally in monetary terms, and c) how much mitigation prevents how much climate

change. One could then choose the exact level of mitigation that renders minimal overall costs. After this, another question immediately follows: Given a certain mitigation goal, how can we best cope with, prepare for and take advantage of the climate change we are prepared to accept? Although for both these questions an assessment of climate change impacts is of use, the focus is quite different in both.

How can the “climate change – tourism” research community best contribute to answering these questions? Previous research has shown that in some cases all the linkages connecting climate change to tourism are quite clear as well as strong. I would name the dying of corals for diving tourism, declining snow cover in low-lying areas for snow-sport tourism and sea level rise for beaches and coastal tourism infrastructure. In these cases *all* linkages are “well” established, as for instance the impact of higher temperatures on corals *as well as* the absence of corals on diving tourists. For such effects I would say that both approaches make sense: measuring the magnitude of the net effect as well as exploring the mechanisms to support adaptation – and ideally exploring mitigation options at the same time (a good example is given by the report by Müller and Weber (2007)).

Many other effects are less clearly defined and more speculative. This can result from any of the linkages between climate change and tourism being weak. Examples may be the effect of climate change on changes in precipitation on regional/local level or on tropical cyclones. Other examples typical for tourism are derived from the fact that tourism is dependent on tourists that base their decision on personal preferences that can change comparatively rapidly. Where the effect of climate change on tourism depends on the subjective appreciation of gradual changes (biodiversity, average weather), the linkages are weak. The Alps, for instance, used to be perceived as dangerous and only to be passed if absolutely necessary. Today, they are the main asset of many important tourism destinations. How will Europeans react to rising temperatures? Will they feel thermal comfort at the same temperatures as today? Or acclimatize, meaning that the effect of changing temperatures across Europe has quite a different effect? How will tourists react to changes in flora and fauna? It might have no effect because they do not even notice, it might have serious effects in case of the loss of a charismatic or symbolic animal of a region. Or will visitors even increase, visiting the worldwide last population of a certain species? How can a net impact reasonably be measured in such a case? I would argue that where the linkages between climate change and tourism are weak, a concentration of research on the second question asked above would make sense: What might happen and how can we prepare (as well as mitigate)? A good approach would seem regional assessments of the different effects of climate change, developed and assessed by an interdisciplinary research team together with tourism stakeholders.

On a last note, a quote on socio-economic climate change impact assessment from more than 10 years ago that is still very important to be kept in mind today:

“The results of socio-economic climate change impact assessment are subject to many uncertainties. These do not only result from scientific methods, theories, models and data sets but also from the fundamental limits to predictability, from complexity and value judgements involved in underlying research questions. [...] results the dilemma of climate change impact assessment. Researchers are asked questions that reflect a societal need, but cannot be definitely answered. A gap remains between question and answer that can be tightened but can never be closed.”

(freely translated by me from Krupp, 1995, p. 176 and 177)

6 References

- Abegg, B.: 1996, *Klimaänderung und Tourismus: Klimafolgenforschung am Beispiel des Wintertourismus in den Schweizer Alpen*, vdf Hochschulverlag, Zürich, p. 222.
- Adger, W.N.: 2006, 'Vulnerability', *Global Environmental Change-Human and Policy Dimensions* 16, 268-281.
- Adger, W.N. and Vincent, K.: 2005, 'Uncertainty in adaptive capacity', *Comptes Rendus Geosciences* 337, 399-410.
- Ahlert, G.: 2003, 'Einführung eines Tourismussatellitensystems in Deutschland', *GWS Discussion Paper 2003/2004*, Gesellschaft für wirtschaftliche Strukturforchung mbH, Osnabrück, p. 74.
- Amelung, B.: 2006, *Global (environmental) change and tourism: Issues of scale and distribution*, Amelung Publishers, Maastricht, p. 211.
- Amelung, B., Nicholls, S. and Viner, D.: 2007, 'Implications of global climate change for tourism flows and seasonality', *Journal of Travel Research* 45, 285-296.
- Amelung, B. and Viner, D.: 2006, 'Mediterranean tourism: Exploring the future with the Tourism Climatic Index', *Journal of Sustainable Tourism* 14, 349-366.
- ARE/BfS: 2001, 'Mobilität in der Schweiz, Ergebnisse des Mikrozensus 2000 zum Verkehrsverhalten.' Bundesamt für Raumentwicklung, Bundesamt für Statistik, Bern and Neuenburg, p. 96.
- ASHRAE: 1972, *ASHRAE Handbook of Fundamentals* American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., New York, p. 688.
- Atkins, J., Mazzi, S. and Ramlogan, C.: 1998, 'A study on the vulnerability of developing and island states: A composite index. Final report.' Prepared for the Commonwealth Secretariat, London.
- BAFU: 2006, 'Umweltbewusster Konsum: Schlüsseleentscheide, Akteure und Konsummodelle', Bundesamt für Umwelt, Bern, p. 115.
- BAFU: 2007a, 'Switzerland's Greenhouse Gas Inventory 1990-2005. National Inventory Report 2007', Bundesamt für Umwelt, Bern.
- BAFU: 2007b, 'Switzerland's Greenhouse Gas Inventory: Emissions since 1990 per year', Bundesamt für Umwelt, Bern, p. 16.
- Bataille, C., Rivers, N., Mau, P., Joseph, C. and Tu, J.J.: 2007, 'How malleable are the greenhouse gas emission intensities of the G7 nations?' *Energy Journal* 28, 145-169.
- Becken, S.: 2005, 'Harmonising climate change adaptation and mitigation: The case of tourist resorts in Fiji', *Global Environmental Change* 15, 381-393.
- Becken, S., Frampton, C. and Simmons, D.G.: 2001, 'Energy consumption patterns in the accomodation sector - the New Zealand case', *Ecological Economics* 39, 371-386.
- Becken, S. and Patterson, M.: 2006, 'Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism', *Journal of Sustainable Tourism* 14, 323-338.

- Becken, S. and Simmons, D.G.: 2002, 'Understanding energy consumption patterns of tourist attractions and activities in New Zealand', *Tourism Management* 23, 343-354.
- Becken, S., Simmons, D.G. and Frampton, C.: 2003, 'Segmenting tourists by their travel pattern for insights into achieving energy efficiency', *Journal of Travel Research* 42, 48-56.
- Behringer, J., Bürki, R. and Fuhrer, J.: 2000, 'Participatory integrated assessment of adaptation to climate change in Alpine tourism and mountain agriculture', *Integrated Assessment* 1, 331-338.
- Bergmann-Baker, U., Brotton, J. and Wall, G.: 1993, 'Non-riparian recreational baoter study: Canadian section, implications of water level scenarios', MI: International Joint Commission, Detroit.
- Besancenot, J.-P.: 1990, *Climat et tourisme*, Masson, Paris, p. 223.
- Besancenot, J.-P., Mounier, J. and de Lavenne, F.: 1978, 'Les conditions climatiques du tourisme littoral: une méthode de recherche compréhensive', *Norois* 99, 357-382.
- BfE: 2006, 'Energieverbrauchsstatistik der Industrie und des Dienstleistungssektors. Survey raw data.' Bundesamt für Energie, Bern.
- BfS: 1998, 'Eidgenössische Betriebszählung 1998', Bundesamt für Statistik, Bern and Neuenburg.
- BfS: 2003, 'Statistik der Hotel- und Kurbetriebe und der Parahotellerie', Bundesamt für Statistik, Bern and Neuenburg.
- BfS: 2005, 'Pilot-NAMEA für die Schweiz 2002', Bundesamt für Statistik (Swiss Federal Statistical Office), Neuchâtel, p. 74.
- Bigano, A., Hamilton, J.M. and Tol, R.S.J.: 2006, 'The impact of climate on holiday destination choice', *Climatic Change* 76, 389-406.
- Bohdanowicz, P. and Martinac, I.: 2007, 'Determinants and benchmarking of resource consumption in hotels - Case study of Hilton International and Scandic in Europe', *Energy and Buildings* 39, 82-95.
- Böhler, S., Grischkat, S., Haustein, S. and Hunecke, M.: 2006, 'Encouraging environmentally sustainable holiday travel', *Transportation Research Part a-Policy and Practice* 40, 652-670.
- Bony, S., Colman, R., Kattsov, V.M., Allan, R.P., Bretherton, C.S., Dufresne, J.L., Hall, A., Hallegatte, S., Holland, M.M., Ingram, W., Randall, D.A., Soden, B.J., Tselioudis, G. and Webb, M.J.: 2006, 'How well do we understand and evaluate climate change feedback processes?' *Journal of Climate* 19, 3445-3482.
- Braun, O.L., Lohmann, M., Maksimovic, O., Meyer, M., Merkovic, A., Messerschmidt, E., Riedel, A. and Turner, M.: 1999, 'Potential impact of climate change effects on preferences for tourism destinations. A psychological pilot study.' *Climate Research* 11, 247-254.
- Brenkert, A. and Malone, E.: 2005, 'Modeling vulnerability and resilience to climate change: A case study of India and Indian States', *Climatic Change* 72, 57-102.
- Brooks, N.: 2003, 'Vulnerability, risk and adaptation: a conceptual framework.' Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.
- Brooks, N., Adger, W.N. and Kelly, P.M.: 2005, 'The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation', *Global Environmental Change* 15, 151-163.
- Buonomo, E., Jones, R., Huntingford, C. and Hannaford, J.: 2007, 'On the robustness of changes in extreme precipitation over Europe from two high resolution climate change simulations', *Quarterly Journal of the Royal Meteorological Society* 133, 65-81.
- Burby, R.J. and Wagner, F.: 1996, 'Protecting tourists from death and injury in coastal storms', *Disasters* 20, 49-67.
- Bürki, R.: 2000, *Klimaänderung und Anpassungsprozesse im Wintertourismus*, St. Gallen.
- BUWAL: 1996, 'Schadstoffemissionen und Treibstoffverbrauch des Offroad-Sektors', *Umweltmaterialien* Nr. 49: Luft, Bundesamt für Umwelt; Wald und Landschaft, Bern, p. 243.
- Céron, J.-P. and Dubois, G.: 2005, 'The potential impacts of climate change on French tourism', *Current Issues in Tourism* 8, 125-139.

- Céron, J.P. and Dubois, G.: 2007, 'Limits to Tourism? A Backcasting Scenario for Sustainable Tourism Mobility in 2050', Routledge, pp. 191 - 209.
- Christensen, J., Carter, T., Rummukainen, M. and Amanatidis, G.: 2007a, 'Evaluating the performance and utility of regional climate models: the PRUDENCE project', *Climatic Change* 81, 1-6.
- Christensen, J. and Christensen, O.: 2007, 'A summary of the PRUDENCE model projections of changes in European climate by the end of this century', *Climatic Change* 81, 7-30.
- Christensen, J.H., Christensen, O.B., Lopez, P., van Meijgaard, E. and Botzet, M.: 1996, 'The HIRHAM4 regional atmospheric climate model. DMI Technical Report 96-4. Available from DMI, Lyngbyvej 100, Copenhagen Ø', Danish Meteorological Institute.
- Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. and Whetton, P.: 2007b, 'Regional climate projections', in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.), *Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, pp. 847-940.
- CIA: 2001-2003, 'Gross Domestic Product - Purchasing Power Parity per Capita', *The World Factbook*.
- Cioccio, L. and Michael, E.J.: 2007, 'Hazard or disaster: Tourism management for the inevitable in Northeast Victoria', *Tourism Management* 28, 1-11.
- Crouch, G.I.: 1995, 'A meta-analysis of tourism demand', *Annals of Tourism Research* 22, 103-118.
- Crouch, G.I.: 1996, 'Demand elasticities in international marketing : A meta-analytical application to tourism', *Journal of Business Research* 36, 117-136.
- Cutter, S.L.: 1996, 'Vulnerability to environmental hazards', *Progress in human geography* 20, 529-539.
- de Freitas, C.: 1990, 'Recreation climate assessment', *International Journal of Climatology* 10, 89-103.
- de Freitas, C.R.: 2003, 'Tourism climatology: Evaluating environmental information for decision making and business planning in the recreation and tourism sector', *International Journal of Biometeorology* 48, 45-54.
- de Freitas, C.R., Scott, D. and McBoyle, G.: in press, 'A second generation climate index for tourism (CIT): specification and verification', *International Journal of Biometeorology*.
- Dharmaratne, G.S. and Brathwaite, A.E.: 1998, 'Economic Valuation of the Coastline for Tourism in Barbados', pp. 138-144.
- Donner, S.D., Skirving, W.J., Little, C.M., Oppenheimer, M. and Hoegh-Guldberg, O.: 2005, 'Global assessment of coral bleaching and required rates of adaptation under climate change', *Global Change Biology* 11, 2251-2265.
- Downing, T.E., Butterfield, R.E., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y. and Stephen, L.: 2001, *Vulnerability indices: Climate change impacts and adaptation*, UNEP, Nairobi.
- Drabek, T.E.: 1995, 'Disaster responses within the tourist industry', *International Journal of Mass Emergencies and Disasters* 13, 7-23.
- Ecoinvent: 2006, 'ecoinvent database v1.3', Swiss Centre for Life Cycle Inventories.
- Eilat, Y. and Einav, L.: 2004, 'Determinants of international tourism: A three-dimensional panel data', *Applied Economics* 36, 1315-1327.
- Elsasser, H., Müller, H., Messerli, P. and Sherly, F.: 2003, 'Wintertourismus: Können die Folgen der Klimaerwärmung mit Investitionen kompensiert werden?' *Climate Press* 15, 1-3.
- EM-DAT: 2006, 'The OFDA/CRED International Disaster Database', Université Catholique de Louvain, Brussels.

- EPA: 2000, 'A method for quantifying environmental indicators of selected leisure activities in the United States', Environmental Protection Agency, p. 100.
- Eriksen, S. and Kelly, P.: 2007, 'Developing credible vulnerability indicators for climate adaptation policy assessment', *Mitigation and Adaptation Strategies for Global Change* 12, 495-524.
- Esty, D.C., Levy, M.A., Srebotnjak, T., de Sherbinin, A., Kim, C.H. and Anderson, B.: 2006, 'Pilot 2006 Environmental Performance Index', Yale Center for Environmental Law & Policy, New Haven, p. 367.
- European Commission: 1998, 'Facts and figures on the Europeans on holidays 1997-1998 (Eurobarometer survey)', European Commission Directorate General XXIII, p. 19.
- Eurostat: 2003, 'NAMEA for air emissions compilation guide, draft version', Eurostat, p. 105.
- Eurostat/OECD/WTO/UNSD: 2001, 'Tourism satellite account: recommended methodological framework', Eurostat, OECD, WTO and UNSD, Luxembourg, Madrid, New York, Paris, p. 148.
- F.U.R.: 2007, 'Erste Ergebnisse der 37. Reiseanalyse 2007', Forschungsgemeinschaft Urlaub und Reisen, Kiel, p. 10.
- Fagance, M. and Kevan, S.: 1997, 'Migration, recreation and tourism: human responses to climate differences', in Auliciems, A. (ed.), *Advances in bioclimatology*, Springer, Berlin, pp. 133-160.
- Faulkner, B. and Vikulov, S.: 2001, 'Katherine, washed out one day, back on track the next: a post-mortem of a tourism disaster', *Tourism Management* 22, 331-344.
- Ford, J.D. and Smit, B.: 2004, 'A framework for assessing the vulnerability of communities in the Canadian Arctic to risks associated with climate change', *Arctic* 57, 389.
- Forster, P.M.D., Shine, K.P. and Stuber, N.: 2006, 'It is premature to include non-CO2 effects of aviation in emission trading schemes', *Atmospheric Environment* 40, 1117-1121.
- Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Klein Tank, A.M.G. and Peterson, T.: 2002, 'Observed coherent changes in climatic extremes during the second half of the twentieth century', *Climate Research* 19, 193-212.
- Fronzek, S. and Carter, T.R.: 2007, 'Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs', *Climatic Change* 81, 357-371.
- Füssel, H.-M.: 2007, 'Vulnerability: A generally applicable conceptual framework for climate change research', *Global Environmental Change* 17, 155-167.
- Gagge, A.P., Stolwijk, J.A. and Nishi, Y.: 1971, 'Effective temperature scale, based on a simple model of human physiological regulatory response', *Ashrae Transactions* 77, 247-262.
- Gaillard, G.A., Rütter, H. and Berwert, A.: 2003, 'Satellitenkonto Tourismus der Schweiz: Grundlagen, Methodik und Ergebnisse', Bundesamt für Statistik, Neuchâtel, p. 89.
- Getz, D. and Nilsson, P.A.: 2004, 'Responses of family businesses to extreme seasonality in demand: the case of Bornholm, Denmark', *Tourism Management* 25, 17-30.
- Giles, A.R. and Perry, A.H.: 1998, 'The use of a temporal analogue to investigate the possible impact of projected global warming on the UK tourist industry', *Tourism Management* 19, 75-80.
- Gómez Martín, B.: 2006, 'Climate potential and tourist demand in Catalonia (Spain) during the summer season', *Climate Research* 32, 75-87.
- Gössling, S.: 2001, 'The consequences of tourism for sustainable water use on a tropical island: Zanzibar, Tanzania', *Journal of Environmental Management* 61, 179-191.
- Gössling, S.: 2002, 'Global environmental consequences of tourism', *Global Environmental Change* 12, 283-302.
- Gössling, S.: 2006, 'Tourism and water', in Gössling, S. and Hall, C.M. (eds.), *Tourism and global environmental change: ecological, social, economic and political interrelationships*, Routledge, London, pp. 180-194.

- Gössling, S. and Hall, C.M.: 2006, 'An introduction to tourism and global environmental change', in Gössling, S. and Hall, C.M. (eds.), *Tourism and global environmental change: ecological, social, economic and political interrelationships*, Routledge, London, pp. 1-34.
- Gössling, S., Peeters, P., Ceron, J.-P., Dubois, G., Patterson, T. and Richardson, R.B.: 2005, 'The eco-efficiency of tourism', *Ecological Economics* 54, 417-434.
- Hamilton, J. and Tol, R.: 2007, 'The impact of climate change on tourism in Germany, the UK and Ireland: a simulation study', *Regional Environmental Change* 7, 161-172.
- Hamilton, J.M.: 2007, 'Coastal landscape and the hedonic price of accommodation', *Ecological Economics* 62, 594-602.
- Hamilton, J.M. and Lau, M.A.: 2006, 'The role of climate information in tourist destination choice decision making', in Gössling, S. and Hall, C.M. (eds.), *Tourism and global environmental change: ecological, social, economic and political interrelationships*, Routledge, London, pp. 229-250.
- Hamilton, J.M., Maddison, D. and Tol, R.S.J.: 2005, 'Climate change and international tourism: A simulation study', *Global Environmental Change* 15, 253-266.
- Harrison, S., Winterbottom, S.J. and Sheppard, C.: 1999, 'The potential effects of climate change on the Scottish tourist', *Tourism Management* 20, 203-211.
- Hartmann, R.: 1986, 'Tourism, seasonality and social change', *Leisure Studies* 5, 25-33.
- Higham, J. and Hinch, T.: 2002, 'Tourism, sport and seasons: the challenges and potential of overcoming seasonality in the sport and tourism sectors', *Tourism Management* 23, 175-185.
- Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A. and Hatziolos, M.E.: 2007, 'Coral Reefs Under Rapid Climate Change and Ocean Acidification', pp. 1737-1742.
- Hoozemans, F.M.J., Pennekamp, H.A. and Marchand, M.: 1992, 'Sea level rise: A global vulnerability assessment: Vulnerability assessment for population, coastal wetlands and rice production on a global scale', *Delft Hydraulics, Rijkswaterstaat, Delft*, p. 178.
- Hoyer, K.G.: 2000, 'Sustainable tourism or sustainable mobility? The Norwegian case', *Journal of Sustainable Tourism* 8, 147-160.
- Huang, J.-H. and Min, J.C.H.: 2002, 'Earthquake devastation and recovery in tourism: the Taiwan case', *Tourism Management* 23, 145-154.
- Hunter, C.: 2002, 'Sustainable Tourism and the Touristic Ecological Footprint', *Environment, Development and Sustainability* 4, 7-20.
- Huppes, G. and Ishikawa, M.: 2005, 'Eco-efficiency and its terminology', *Journal of Industrial Ecology* 9, 43-46.
- Hystad, P.W. and Keller, P.C.: 2008, 'Towards a destination tourism disaster management framework: Long-term lessons from a forest fire disaster', *Tourism Management* 29, 151-162.
- IATA: 2007, 'IATA economic briefing: passenger and freight forecasts 2007 to 2011', *International Air Transport Association*, p. 4.
- Instituto Nacional de Estadística: 2008a, 'Contabilidad Nacional de España: Tabla 1: Valor añadido bruto a precios básicos', Instituto Nacional de Estadística.
- Instituto Nacional de Estadística: 2008b, 'Cuenta satélite del turismo de España (online)', Instituto Nacional de Estadística.
- Instituto Nacional de Estadística: 2008c, 'Cuentas satélites sobre emisiones atmosféricas. Serie 1990 y 1995-2003', Instituto Nacional de Estadística.
- Iorio, J.P., Duffy, P.B., Govindasamy, B., Thompson, S.L., Khairoutdinov, M. and Randall, D.: 2004, 'Effects of model resolution and subgrid-scale physics on the simulation of precipitation in the continental United States', *Climate Dynamics* 23, 243-258.
- IPCC: 1996, 'Revised 1996 IPCC guidelines for national greenhouse gas inventories - greenhouse gas inventory reporting (Volume 1)', in Houghton, J.T., Meira Filho, L.G., Lim, B., Treanton, K., Mamaty, I., Bonduky, Y., Griggs, D.J. and B.A., C. (eds.), *IPCC/OECD/IEA*.

- IPCC (ed.): 2001, *Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of working group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.
- IPCC: 2007a, 'Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', in Parry, M., Canziani, O.F., Palutikof, J., van der Linden, P.J. and Hanson, C. (eds.), Cambridge University Press, Cambridge, United Kingdom p. 976.
- IPCC: 2007b, 'Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', in Solomon, S., Quin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B. and LeRoy Miller, H. (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 996.
- IPCC Response Strategies Working Group: 1990, 'Strategies for adaptation to sea level rise. Report of the Coastal Management Subgroup of the Intergovernmental Panel on Climate Change.' Ministry of Transport and Public Works, The Hague, p. 131.
- ITU: 2006, 'Internet users', ICT Statistics Database.
- Jacob, D.: 2001, 'A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin', *Meteorology and Atmospheric Physics* 77, 61-73.
- Jacob, D., Bärring, L., Christensen, O., Christensen, J., de Castro, M., Déqué, M., Giorgi, F., Hagemann, S., Hirschi, M., Jones, R., Kjellström, E., Lenderink, G., Rockel, B., Sánchez, E., Schär, C., Seneviratne, S., Somot, S., van Ulden, A. and van den Hurk, B.: 2007, 'An inter-comparison of regional climate models for Europe: model performance in present-day climate', *Climatic Change* 81, 31-52.
- Janssen, M.A., Schoon, M.L., Ke, W.M. and Borner, K.: 2006, 'Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change', *Global Environmental Change-Human and Policy Dimensions* 16, 240-252.
- Jennings, S.: 2004, 'Coastal tourism and shoreline management', *Annals of Tourism Research* 31, 899-922.
- Jones, B.E., Scott, D. and Gössling, S.: 2006, 'Lakes and streams', in Gössling, S. and Hall, C.M. (eds.), *Tourism and global environmental change: ecological, social, economic and political interrelationships*, Routledge, London, pp. 76-94.
- Jones, C., Munday, M., Bryan, J. and Roberts, A.: 2004, 'UK tourism satellite account - first steps project', Department for Culture, Media and Sport, p. 44.
- Jones, C., Munday, M. and Roberts, A.: 2003, 'Regional tourism satellite accounts: A useful policy tool?' *Urban Studies* 40, 2777-2794.
- Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R. and Joseph, D.: 1996, 'The NCEP/NCAR 40-year reanalysis project', *Bulletin of the American Meteorological Society* 77, 437-471.
- Kaly, U., Pratt, C., Mitchell, J. and Howorth, R.: 2003, 'The demonstration Environmental Vulnerability Index (EVI)', p. 136.
- Kasperson, R.E., Kasperson, J.X. and Dow, K.: 2001, 'Vulnerability, equity, and global environmental change', in Kasperson, J.X. and Kasperson, R.E. (eds.), *Global Environmental Risk*, United Nations University Press, Tokyo, pp. 247-272.
- Kaufmann, D., Kraay, A. and Matruzzi, M.: 2005, 'Governance Matters IV: Governance Indicators for 1996-2004'.
- Kaufmann, D., Kraay, A. and Matruzzi, M.: 2007, 'Governance Matters VI: Governance Indicators for 1996-2006', The World Bank, p. 93.
- Kaufmann, Y., Meier, R. and Ott, W.: 2000, 'Luftverkehr - eine wachsende Herausforderung für die Umwelt: Fakten und Trends für die Schweiz', Nationales Forschungsprogramm Verkehr und Umwelt, NFP 41, Materialienband M25, Bern, p. 71.

- Kelly, P.M. and Adger, W.N.: 2000, 'Theory and practice in assessing vulnerability to climate change and facilitating adaptation', *Climatic Change* 47, 325-352.
- Kent, M., Newnham, R. and Essex, S.: 2002, 'Tourism and sustainable water supply in Mallorca: a geographical analysis', *Applied Geography* 22, 351-374.
- Kimoto, M., Yasutomi, N., Yokoyama, C. and Emori, S.: 2005, 'Projected changes in precipitation characteristics near Japan under the global warming', *Scientific Online Letters on the Atmosphere* 1, 85-88.
- Klein, Y.L., Osleeb, J.P. and Viola, M.R.: 2004, 'Tourism-generated earnings in the coastal zone: A regional analysis', *Journal of Coastal Research* 20, 1080-1088.
- König, U.: 1998, *Tourism in a warmer world: Implications of climate change due to enhanced greenhouse effect for the ski industry in the Australian Alps*, University of Zurich.
- Krupp, C.: 1995, *Klimaänderung und die Folgen: eine exemplarische Fallstudie über die Möglichkeiten und Grenzen einer interdisziplinären Klimafolgenforschung*, Edition Sigma, Berlin, p. 205.
- Lin, T.-P. and Matzarakis, A.: in press, 'Tourism climate and thermal comfort in Sun Moon Lake, Taiwan', *International Journal of Biometeorology*.
- Lise, W. and Tol, R.S.J.: 2002, 'Impact of climate on tourism demand', *Climatic Change* 55, 429-449.
- Lohmann, M. and Kaim, E.: 1999, 'Weather and holiday destination preferences: Image, attitude and experience', *Revue de Tourisme/The Tourist Review* 2, 54-64.
- Luers, A.L.: 2005, 'The surface of vulnerability: An analytical framework for examining environmental change', *Global Environmental Change* 15, 214-223.
- Lundtorp, S.: 2001, 'Measuring Tourism Seasonality', in Baum, T. and Lundtorp, S. (eds.), *Seasonality in Tourism*, Pergamon, Amsterdam, pp. 23-33.
- Maddison, D.: 2001, 'In search of warmer climates? The impact of climate change on flows of British tourists.' *Climatic Change* 49, 193-208.
- Maslow, A.H.: 1943, 'A theory of human motivation', *Psychological Review* 50, 370-396.
- McBoyle, G. and Wall, G.: 1992, 'Great lakes skiing and climate change', in Gill, A. and Hartmann, R. (eds.), *Mountain resort development*, Centre for Tourism Policy and Research, Simon Fraser University, Burnaby, Canada, pp. 70-81.
- Meehl, G.A., Stocker, T.F., Collins, W., Friedlingstein, P., Gaye, A., Gregory, J., Kitoh, A., Knutti, R., Murphy, J., Noda, A., Raper, S., Watterson, I., Weaver, A. and Zhao, Z.-C.: 2007a, 'Global Climate Projections', in Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M.M.B. and LeRoy Miller, H. (eds.), *Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, p.??
- Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J. and Zong-Ci, Z.: 2007b, 'Global climate projections', in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds.), *Climate change 2007: The physical science basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, pp. 747-845.
- Meehl, G.A., Tebaldi, C. and Nychka, D.: 2004, 'Changes in frost days in simulations of twentyfirst century climate', *Climate Dynamics* 23, 495-511.
- Meier, R.: 1998, *Sozioökonomische Aspekte von Klimaänderungen und Naturkatastrophen in der Schweiz. (Projektschlussbericht NFP 31)*, vdf Hochschulverlag, Zürich.
- Mieczkowski, Z.: 1985, 'The tourism climatic index: A method of evaluating world climate for tourism', *The Canadian Geographer* 29, 220-233.
- Moreno, A.: 2007, 'The role of weather in beach recreation: A case study using webcam images', in Matzarakis, A., de Freitas, C.R. and Scott, D. (eds.), *Developments in tourism climatology*.

- Commission Climate, Tourism and Recreation. , International Society of Biometeorology, Freiburg.
- Moreno, A., Amelung, B. and Santamarta, L.: in press, 'Linking beach recreation to weather conditions. A case study in Zandvoort, Netherlands.' *Tourism Marine Environments*.
- Morgan, R., Gatell, E., Junyent, R., Micallef, A., Özhan, E. and Williams, A.T.: 2000, 'An improved user-based beach climate index', *Journal of Coastal Conservation* 6, 41-50.
- Müller, H. and Weber, F.: 2007, 'Klimaänderung und Tourismus: Szenarienanalyse für das Berner Oberland 2030', *Forschungsinstitut für Freizeit und Tourismus, Bern*, p. 88.
- Murphy, P.E. and Bayley, R.: 1989, 'Tourism and disaster planning', *Geographical Review* 79, 36-46.
- Murray, F.W.: 1967, 'On the computation of saturation vapor pressure', *Journal of Applied Meteorology* 6, 203-204.
- Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., Lebre La Rovere, E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N. and Dadi, Z.: 2000, 'Special Report on Emission Scenarios, Working Group III of the Intergovernmental Panel on Climate Change (IPCC)', Cambridge University Press, Cambridge, p. 595.
- Nepal, S.K.: 2008, 'Tourism-induced rural energy consumption in the Annapurna region of Nepal', *Tourism Management* 29, 89-100.
- Nicholls, R.J., Hoozemans, F.M.J. and Marchand, M.: 1999, 'Increasing flood risk and wetland losses due to global sea-level rise: Regional and global analyses', *Global Environmental Change* 9, S69-S87.
- Nicholls, R.J. and Tol, R.S.J.: 2006, 'Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the twenty-first century', *Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences* 364, 1073-1095.
- O'Brien, K., Eriksen, S., Schjolden, A. and Nygaard, L.: 2004, 'What's in a word? Conflicting interpretations of vulnerability in climate change research', *Center for International Climate and Environmental Research, Oslo*.
- OECD: 1996, 'Proposed guidelines for collecting and interpreting technological innovation data - Oslo manual', (OECD/EC/Eurostat, Paris, p. 92.
- OECD: 2002, 'Aggregated environmental indices: Review of aggregation methodologies in use', ENV/EPOC/SE(2001)/2, OECD, Paris, p. 43.
- OECD: 2003, 'Composite indicators of country performance: A critical assessment', STI Working Paper 2003/16, OECD, Paris, p. 34.
- OECD: 2007, *Climate change in the European Alps: Adapting winter tourism and natural hazards management*, OECD Publishing, Paris, p. 127.
- Office of National Statistics: 2008, 'Environmental accounts: 2001 76 industry data', Office of National Statistics.
- Olsthoorn, X.: 2001, 'Carbon dioxide emissions from international aviation: 1950-2050', *Journal of Air Transport Management* 7, 87-93.
- Osczevski, R. and Bluestein, M.: 2005, 'The new wind chill equivalent temperature chart', *Bulletin of the American Meteorological Society* 86, 1453-1458.
- Patt, A., Klein, R.J.T. and de la Vega-Leinert, A.: 2005, 'Taking the uncertainty in climate-change vulnerability assessment seriously', *Comptes Rendus Geosciences* 337, 411-424.
- Pedersen, O.G. and de Haan, M.: 2006, 'The system of environmental and economic accounts-2003 and the economic relevance of physical flow accounting', *Journal of Industrial Ecology* 10, 19-42.
- Peeters, P. and Schouten, F.: 2006, 'Reducing the Ecological Footprint of inbound tourism and transport to Amsterdam', *Journal of Sustainable Tourism* 14, 157-171.
- Peeters, P., Szimba, E. and Duijnisveld, M.: 2007, 'Major environmental impacts of European tourist transport', *Journal of Transport Geography* 15, 83-93.

- Peeters, P., van Egmon, T. and Visser, N.: 2004, 'European tourism, transport and environment: Second draft deliverable 1 for the DG-ENTR MusTT project', NHTV Centre for Sustainable Tourism and Transport, Breda, NL.
- Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J. and McFarland, M.: 1999, *Aviation and the Global Atmosphere. A Special Report of IPCC Working Groups I and III*, Cambridge University Press, Cambridge and New York, p. 365.
- Perch-Nielsen, S.L.: submitted, 'The vulnerability of beach tourism to climate change - An index approach', *Climatic Change*.
- Perry, A.H.: 2000, 'Impacts of climate change on tourism in the Mediterranean: Adaptive responses', FEEM Working Paper No. 35.20, Fondazione Eni Enrico Mattei.
- Preston-Whyte, R.A. and Watson, H.K.: 2005, 'Nature tourism and climatic change in southern Africa', in Hall, C.M. and Higham, J. (eds.), *Tourism, recreation and climate change*, Channel View Publications, Clevedon, pp. 130-142.
- Räsänen, J.: 2007, 'How reliable are climate models?' *Tellus* 59A, 2-29.
- Raupach, M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.G., Klepper, G. and Field, C.B.: 2007, 'Global and regional drivers of accelerating CO₂ emissions', *Proceedings of the National Academy of Sciences* 104, 10288-10293.
- Richardson, R.B. and Loomis, J.B.: 2004, 'Adaptive recreation planning and climate change: A contingent visitation approach', *Ecological Economics* 50, 83-99.
- Rotmans, J., Hulme, M. and Downing, T.E.: 1994, 'Climate change implications for Europe: An application of the ESCAPE Model', *Global Environmental Change* 4, 97-124.
- Sausen, R., Isaksen, I., Grewe, V., Hauglustaine, D., Lee, D.S., Myhre, G., Kohler, M.O., Pitari, G., Schumann, U., Stordal, F. and Zerefos, C.: 2005, 'Aviation radiative forcing in 2000: An update on IPCC (1999)', *Meteorologische Zeitschrift* 14, 555-561.
- Schachtschneider, K.: 2002, 'Building new WDM regulations for the Namibian tourism sector on factors influencing current water-management practices at the enterprise level', *Physics and Chemistry of the Earth, Parts A/B/C* 27, 859-864.
- Schmied, M., Buchert, M., Hochfeld, C. and Schmitt, B.: 2001, 'Umwelt und Tourismus: Grundlagen für einen Bericht der Bundesregierung', *Öko-Institut*, Berlin, p. 162.
- Schröter, D., Polsky, C. and Patt, A.G.: 2005, 'Assessing vulnerabilities to the effects of global change: An eight step approach', *Mitigation and Adaptation Strategies for Global Change* 10, 573-595.
- Schweiz Tourismus: 2007, 'Jahresbericht 2006.' Schweiz Tourismus, Zürich, p. 39.
- Scott, D., Gössling, S. and de Freitas, C.R.: accepted, 'Climate Preferences for Tourism: Evidence from Canada, New Zealand and Sweden', *Climate Research*.
- Scott, D., Gössling, S. and de Freitas, C.R.: in press, 'Climate Preferences for Tourism: Evidence from Canada, New Zealand and Sweden', *Climate Research*.
- Scott, D., Jones, B. and Konopek, J.: 2007a, 'Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park', *Tourism Management* 28, 570-579.
- Scott, D. and McBoyle, G.: 2007, 'Climate change adaptation in the ski industry', *Mitigation and Adaptation Strategies for Global Change* 12, 1411-1431.
- Scott, D., McBoyle, G. and Mills, B.: 2003, 'Climate change and the skiing industry in southern Ontario (Canada): Exploring the importance of snowmaking as a technical adaptation', *Climate Research* 23, 171-181.
- Scott, D., McBoyle, G. and Minogue, A.: 2007b, 'Climate change and Quebec's ski industry', *Global Environmental Change-Human and Policy Dimensions* 17, 181-190.
- Scott, D., McBoyle, G. and Schwartzentruber, M.: 2004, 'Climate change and the distribution of climatic resources for tourism in North America', *Climate Research* 27, 105-117.
- Scott, D., Wall, G. and McBoyle, G.: 2005, 'The evolution of the climate change issue in the tourism sector', in Hall, C.M. and Higham, J. (eds.), *Tourism, recreation and climate change*, Channel View Publications, Clevedon, pp. 44-60.

- Siple, P.A. and Passel, C.F.: 1945, 'Measurements of dry atmospheric cooling in subfreezing temperatures', *Proceedings of the American Philosophical Society* 89, 177-199.
- Small, C. and Nicholls, R.J.: 2003, 'A global analysis of human settlement in coastal zones', *Journal of Coastal Research* 19, 584-599.
- Smith, K.: 2001, *Environmental hazards: Assessing risk and reducing disaster*, Routledge, London and New York.
- Statistik Austria: 2008, 'Tabellen Integrierte NAMEA 1999 - 2003', Statistik Austria.
- Statistik Austria and WIFO: 2003, 'Tourismus-Satellitenkonto für Österreich 2003', data provided 2008 by Statistik Austria and Österreichisches Institut für Wirtschaftsforschung, Vienna.
- Statistiska centralbyrån: 2008a, 'National accounts: Förädlingsvärdets delkomponenter (ENS95) efter näringsgren SNI 2002 och transaktionspost, löpande priser. 1993-2005', Statistiska centralbyrån.
- Statistiska centralbyrån: 2008b, 'System of environmental and economic accounts: Air emissions by industry SNI92 (NACE) and subject. Year 1993-2004', Statistiska centralbyrån.
- Statistiska centralbyrån: 2008c, 'Turistsatellitkontot : Tabell 2: Beräkning av förädlingsvärde och andel av BNP 1995-2006', Statistiska centralbyrån.
- Steadman, R.G.: 1984, 'A universal scale of apparent temperature', *Journal of Climate and Applied Meteorology* 23, 1674-1687.
- Stettler, J.: 1997, 'Sport und Verkehr. Sportmotiviertes Verkehrsverhalten der Schweizer Bevölkerung. Umweltbelastung und Lösungsmöglichkeiten.' *Berner Studien zu Freizeit und Tourismus* Nr. 36, Forschungsinsitut für Freizeit und Tourismus (FIF) der Universität Bern, Bern.
- STV: 2007, 'Schweizer Tourismus in Zahlen', Schweizer Tourismus-Verband, Bern, p. 48.
- Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson, A., Phillips, O.L. and Williams, S.E.: 2004, 'Extinction risk from climate change', *Nature* 427, 145-148.
- Tol, R.S.J.: 2007, 'The impact of a carbon tax on international tourism', *Transportation Research Part D-Transport and Environment* 12, 129-142.
- Tol, R.S.J. and Yohe, G.W.: 2007, 'The weakest link hypothesis for adaptive capacity: An empirical test', *Global Environmental Change* 17, 218-227.
- Trung, D.N. and Kumar, S.: 2005, 'Resource use and waste management in Vietnam hotel industry', *Journal of Cleaner Production* 13, 109-116.
- Turner II, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Kasperson, J.X., Luers, A.L., Martello, M.L., Polsky, C., Pulsipher, A. and Schiller, A.: 2003, 'A framework for vulnerability analysis in sustainability science', *Proceedings of the National Academy of Sciences* 100, 8074-8079.
- UN-WTO: 2006a, 'Arrivals by purpose of visit', WTOelibrary.
- UN-WTO: 2006b, 'The impact of rising oil prices on international tourism', *Special Report Number 26*, World Tourism Organization, Market Intelligence and Promotion, Madrid, p. 36.
- UN-WTO: 2006c, 'Tourism Database', WTOelibrary.
- Unbehaun, W., Haider, W. and Pröbstl, U.: 2007, 'Trends in winter sport tourism - challenges for the future development in the European Alps', in *Leisure Futures Conference*, St. Gallen, Switzerland.
- UNDP: 2005, *Human Development Report 2005: International cooperation at a crossroads: aid, trade and security in an unequal world*, New York.
- UNDP: 2007, *Human Development Report 2007/2008. Fighting climate change: Human solidarity in a divided world*, New York, p. 399.
- UNEP: 2002, 'Assessing human vulnerability to environmental change: concepts, issues, methods and case studies'.

- UNESCO: 2006, 'Total gross enrolment ratio: All levels combined (except preprimary)', UNESCO Institute for Statistics online database.
- United Nations: 1992, 'United Nations Framework Convention on Climate Change'.
- United Nations: 1993, 'System of National Accounts', United Nations Publication Series F, N° 2, Rev.4, United Nations, Eurostat, International Monetary Fund, Organisation for Economic Co-operation and Development and World Bank, New York, p. 711.
- Uppala, S.M., Kallberg, P.W., Simmons, A.J., Andrae, U., Bechtold, V.D., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., Van De Berg, L., Bidlot, J., Bormann, N., Cairns, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Holm, E., Hoskins, B.J., Isaksen, I., Janssen, P., Jenne, R., McNally, A.P., Mahfouf, J.F., Morcrette, J.J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P. and Woollen, J.: 2005, 'The ERA-40 re-analysis', *Quarterly Journal of the Royal Meteorological Society* 131, 2961-3012.
- Uyarra, M.C., Côté, I.M., Gill, J.A., Tinch, R.R.T., Viner, D. and Watkinson, A.R.: 2005, 'Island-specific preferences of tourists for environmental features: Implications of climate change for tourism-dependent states', *Environmental Conservation* 32, 11-19.
- Vavrus, S., Walsh, J.E., Chapman, W.L. and Portis, D.: 2006, 'The behavior of extreme cold air outbreaks under greenhouse warming', *International Journal of Climatology* 26, 1133-1147.
- Vidale, P.L., Lüthi, D., Frei, C., Seneviratne, S.I. and Schär, C.: 2003, 'Predictability and uncertainty in a regional climate model', *Journal of Geophysical Research-Atmospheres* 108.
- Vlaams Instituut voor de Zee: 2005, 'Maritime Boundaries Geodatabase'.
- Volo, S.: 2005, 'A consumer-based measurement of tourism innovation', *Journal of Quality Assurance in Hospitality & Tourism* 6, 73-87.
- Whetton, P.H., Haylock, M.R. and Galloway, R.: 1996, 'Climate change and snow-cover duration in the Australian alps', *Climatic Change* 32, 447-479.
- Wit, R.C.N., Dings, J.M.W., Mendes de Leon, P., Thwaites, L., Peeters, P., Greenwood, D. and Doganis, R.: 2002, 'Economic incentives to mitigate greenhouse gas emissions from air transport in Europe', CE, Delft, p. 206.
- Wolfsegger, C.: 2005, Perception and adaptation to climate change in low altitude ski resorts in Austria, Master's Thesis, Lund University, Lund, p. 48.
- WTTC: 2004a, 'Country league tables, travel & tourism: Sowing the seeds of growth. The 2005 travel & tourism economic research.' World Travel & Tourism Council, London, p. 84.
- WTTC: 2004b, 'World travel & tourism: Sowing the seeds of growth.' World Travel & Tourism Council, London, p. 34.
- WTTC: 2007, 'World travel & tourism: Navigating the path ahead', World Travel & Tourism Council, London, p. 36.
- Xie, P.P. and Arkin, P.A.: 1997, 'Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs', *Bulletin of the American Meteorological Society* 78, 2539-2558.
- Yacoumis, J.: 1980, 'Tackling seasonality : The case of Sri Lanka', *International Journal of Tourism Management* 1, 84-98.
- Yorukoglu, M. and Celik, A.N.: 2006, 'A critical review on the estimation of daily global solar radiation from sunshine duration', *Energy Conversion and Management* 47, 2441-2450.

Curriculum Vitae

Sabine Louise Perch-Nielsen

Date of birth March 24, 1979
Nationalities Swiss and Danish
E-Mail s.perch-nielsen@alumni.ethz.ch

Education

- 2005 - 2008 **PhD studies at ETH Zurich, Switzerland**
Studies at the Climate & Energy Group of Environmental Physics at ETH Zürich on the Interactions between Tourism and Climate Change.
- 1998 - 2004 **Studies of Environmental Sciences at ETH Zürich, Master's Degree**
Diploma Thesis „Understanding the Effect of Climate Change on Human Migration”.
Semester Paper “Driving Forces behind the Emergence of the “Climate Centime” as an Alternative to a CO₂-Levy in the Swiss Transportation Sector”.
- 2000/2001 **Exchange Semester at the Technical University of Denmark**
Participation in courses of the Masters Programme for Environmental Engineering.
- 1985 - 1998 **Primary and secondary education**
Schools in Austria, England, Costa Rica and Switzerland. High school degrees in both Costa Rica and Switzerland.

Work Experience

- 2002 - **Co-founder and vice-president of the myclimate foundation**
Co-founding of myclimate, a non-profit-organisation in the field of innovative solutions in climate protection (www.myclimate.org).
- 2004/2005 **Tutor at transdisciplinary case study at ETH Zürich**
- 2001/2002 **Intern at the National Cleaner Production Centre in Costa Rica**

Awards

- 2004 “Willi Studer Preis” – annual award of the ETH Zürich for the best degree in a course of studies.
“ETH medal” – annual award of the ETH Zürich for the best diploma thesis in a course of studies.