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NICHE MARKET STRATEGIES FOR THE ELECTRIFICATION OF ROAD TRANSPORTATION

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Preface and acknowledgments

This research is strongly linked with two projects dealing with electric drivetrain concepts: First, the project called ‘hy.muve’ in which the two Swiss research institutions EMPA and Paul Scherrer Institute (PSI), in collaboration with industrial partners, developed a hydrogen-powered street sweeper that is nearly at the pre-production stage. The vehicle is currently undergoing operational testing on the streets of various cities. Second, the ‘E-scooter Research Project’ coordinated by the University of Bern, which aims to support the development, diffusion and utilization of electric scooters in Switzerland. Hence, this thesis intends to contribute to the specific project goals and enhance the understanding of niche processes that foster the dissemination of eco-innovations. Part I of this cumulative doctoral thesis was published in the *International Journal of Hydrogen Energy*. Thesis Part II and III have been submitted to the journals *Technological Forecasting and Social Change* and *Research Policy*, respectively.

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Abstract

Radical innovations such as fuel cell and battery electric vehicles tend to develop in niches as they initially fail to successfully compete within mainstream selection environments. Niches afford temporary 'protective space' that shield the emerging innovations against the prevailing selection pressures such as established user practices, preferences, and infrastructural requirements. Within this protective space, innovations can gain momentum through niche processes and will eventually be able to compete with established technologies of the incumbent transport system. This dissertation follows a case-study design, with in-depth analysis of different aspects of three major niche processes (shielding, nurturing and empowering). A sound understanding of these processes is an important condition for the development of coherent support strategies for the electrification of road transportation. Hence, the general objective of this thesis is to enhance the (theoretical) insights into the dynamics of niche processes and to identify possibilities to intervene in these processes.

Thesis Part I aims to gain an understanding of the selection environment in which a hydrogen-powered street sweeper has to assert itself and the vehicle's niche market potential. This information is important because the large variety of potential hydrogen and fuel cell applications and the associated uncertainties of selecting a particular application pose a challenge for developers in the field. Therefore, we conducted an online survey comprising a choice experiment in Switzerland and Germany to assess fleet decision-makers' preferences for hydrogen-powered street sweepers compared to (more) conventional diesel and compressed natural gas (CNG)/biogas vehicles. The findings indicate that dominant user practices such as fleet decision-making structures and vehicle operating practices make street sweeper fleets a promising application for the early implementation of hydrogen fuel cell vehicles. Furthermore, the results show that a market niche for hydrogen-powered sweepers exists in both countries. It was also shown which improvements of product characteristics could significantly enhance the overall preference for such vehicles. Hence, these insights can facilitate the formulation of support strategies (e.g. specific *shielding*) for the niche innovation. The choice experiment was a useful approach for the identification of promising market niches and thereby reduces the uncertainties of application selection.

Thesis Part II evaluates the current performance of the innovation system around fuel cell and hydrogen technologies in Switzerland. The build-up of such a technological innovation system (TIS) around these technologies is necessary to make their large-scale diffusion possible. However, the coordination of the build-up process of a well-performing TIS is a challenge. With this study, we propose the combination of an expert-based TIS analysis and a roadmapping exercise to develop a theoretically grounded roadmap for the coordination of innovation system building. The results of the analysis show that well-functioning knowledge networks and a competitive knowledge base have been established in recent years. Nevertheless, only very few entrepreneurs have yet utilized those to explore the market. It is necessary to direct policy initiatives at the identified key areas in which progress is required, i.e. *Entrepreneurial activities*, *Market formation*, and *Resource mobilization*. We discuss how these insights can be used to develop a roadmap through which the build-up process (*nurturing*) of the innovation system can be coordinated and facilitated.

Thesis Part III aims to create deeper insight into the up-scaling process (*empowering*) of niche innovations. Therefore, we perform a comparative niche analysis based on the technological innovation system (TIS) framework. The investigation describes both, the successful and stagnating up-scaling process of two niche innovations (e-bicycles and e-scooters) encompassed by the same TIS. The findings confirm previous theorizing concerning typical stages and processes in the build-up of a TIS. It contributes additional evidence that the TIS framework runs the risk to miss influential processes of niche up-scaling, because it does not pay much attention to the system's environment. We empirically show that beyond the initial protective space, which shielded the niche innovations from selection pressures, the *interplay* between product characteristics, niche characteristics and the selection environment is

critical for the product-specific diffusion pathway of an emerging technology. At this stage, *product-specific maneuvering* becomes critical in terms of fitting and supporting empowerment of niche innovations. The proposed multi-criteria appraisal can be used to support practitioners' strategy choice.

Taken together, the findings of this research highlight the importance of prospective planning and coordination in niche processes. In this respect, the proposed instruments may be helpful and can be used to develop targeted interventions aimed at making the niche processes (shielding, nurturing, empowering) more effective.

Zusammenfassung

Radikale Innovationen wie Brennstoffzellenfahrzeuge und batteriebetriebene Elektrofahrzeuge tendieren dazu, sich in Nischen zu entwickeln, weil sie in der Regel innerhalb eines etablierten Selektionsumfeldes anfänglich nicht im Wettbewerb bestehen können. Nischen bieten einen temporären ‚geschützten Raum', der die neu entstehenden Innovationen gegen vorherrschende Selektionsdrücke wie zum Beispiel etablierte Nutzerverhalten, Präferenzen und infrastrukturelle Erfordernisse schützt. Innerhalb dieses geschützten Raumes können Innovationen durch Nischenprozesse an Dynamik gewinnen und werden letztendlich allenfalls in der Lage sein, mit etablierten Technologien des vorherrschenden Transportsystems zu konkurrieren. Diese Dissertation analysiert verschiedene Aspekte von drei wesentlichen Nischenprozessen: *shielding*, *nurturing*, *empowering* (Abschirmung, Pflegen, Befähigung). Ein tiefes Verständnis dieser Prozesse ist eine wichtige Bedingung für die Entwicklung kohärenter Förderstrategien für die Elektrifizierung des Strassentransportes. Das übergeordnete Ziel der Dissertation ist es, das (theoretische) Verständnis von Nischenprozessen zu verbessern sowie Interventionsmöglichkeiten in diesen Prozessen zu identifizieren.

Teil I der Dissertation beabsichtigt, ein Verständnis des Selektionsumfeldes, in dem sich ein wasserstoffbetriebenes Strassenkehrfahrzeug behaupten muss, zu erlangen. Zudem soll das Nischenmarkt-Potential dieses Fahrzeuges untersucht werden. Diese Informationen sind wichtig, weil die grosse Vielfalt an möglichen Wasserstoff- und Brennstoffzellen-Anwendungen und die damit verbundenen Unsicherheiten bezüglich der Wahl einer bestimmten Anwendung eine Herausforderung für die Entwickler darstellen. Deshalb führten wir in Deutschland und der Schweiz eine Online-Umfrage einschliesslich eines Choice Experiments durch, um die Präferenzen von Flottenbetreibern für wasserstoffbetriebene Kehrfahrzeuge zu erheben. Dies unter Einbezug von konventionelleren Diesel- und Erdgas/Biogas-Fahrzeugen. Die Resultate zeigen auf, dass vorherrschende Nutzerverhalten, wie die Entscheidungsstrukturen innerhalb der Flotten und die Fahrzeug-Betriebspraktiken, Strassenkehrmaschinen zu einer vielversprechenden Anwendung für die frühe Einführung von wasserstoffbetriebenen Fahrzeugen machen. Des Weiteren deuten die Resultate darauf hin, dass in beiden Ländern ein Nischenmarkt für wasserstoffbetriebene Kehrfahrzeuge existiert. Es wird zudem gezeigt, welche Verbesserungen von Produkteeigenschaften die Präferenz für solche Fahrzeuge signifikant erhöhen können. Diese Erkenntnisse können die Ausgestaltung von Fördermassnahmen (z.B. spezifische Abschirmung) für Nischeninnovationen erleichtern. Das Choice Experiment bewährte sich als nützliches Instrument für die Identifikation von vielversprechenden Marktnischen und reduziert auf diese Weise die Unsicherheiten im Zusammenhang mit der Wahl von geeigneten Anwendungen.

Teil II der Dissertation evaluiert die gegenwärtige Leistungsfähigkeit des Innovationssystems rund um Brennstoffzellen- und Wasserstoff-Technologien in der Schweiz. Der Aufbau eines solchen technologischen Innovationssystems (TIS) ist notwendig, um die Diffusion dieser Technologien im grossen Stil zu ermöglichen. Die Koordination des Aufbauprozesses eines gut funktionierenden technologischen Innovationssystems ist jedoch eine Herausforderung. Mit dieser Studie wollen wir eine expertenbasierte TIS-Analyse mit einem Roadmap-Prozess kombinieren, um auf diese Weise eine theoretisch fundierte Roadmap für die Koordination des Systemaufbaus zu entwickeln. Die Resultate der Analyse zeigen, dass in den letzten Jahren eine wettbewerbsfähige Wissensbasis und gut funktionierende Wissensnetzwerke aufgebaut werden konnten. Dennoch haben bisher nur sehr wenige Unternehmer diese Möglichkeiten genutzt, um den Markt auszuloten. Es ist daher notwendig, Massnahmen auf jene Schlüsselbereiche zu konzentrieren, bei denen ein Fortschritt dringend nötig ist. Gemäss unserer Analyse sind dies die Bereiche unternehmerische Aktivitäten, Marktformierung sowie Ressourcen-Mobilisierung. Wir erläutern, wie diese Erkenntnisse genutzt werden können, um eine Roadmap zu entwickeln, mit Hilfe welcher der Aufbauprozess des Innovationssystems koordiniert und erleichtert werden kann.

Teil III der Dissertation soll zu einem besseren Verständnis des Up-scaling-Prozesses von Nischeninnovationen beitragen. Deshalb führen wir eine vergleichende Nischenanalyse basierend auf dem TIS-Ansatz durch. Die Untersuchung beschreibt sowohl den erfolgreichen als auch stagnierenden Up-scaling-Prozess zweier Nischeninnovationen (Elektro-Fahrräder und Elektro-Roller), die vom selben TIS umfasst werden. Die Resultate bestätigen die bisherige Theoriebildung bezüglich typischer Phasen und Prozesse im Aufbau eines TIS. Zudem bieten die Resultate zusätzliche Evidenz, dass der TIS-Ansatz Gefahr läuft, einflussreiche Aspekte des Up-scaling-Prozesses auszublenden, weil dieser die Systemumgebung kaum berücksichtigt. Wir zeigen empirisch, dass jenseits des geschützten Raumes, welcher die zwei Nischeninnovationen anfänglichen vor Selektionsdruck abgeschirmt hat, das Wechselspiel zwischen Produkteigenschaften, Nischeneigenschaften und Selektionsumfeld entscheidend ist für den applikations-spezifischen Pfad einer neu entstehenden Technologie. In dieser Phase wird produkt-spezifisches Manövrieren hinsichtlich Anpassung und Befähigung der Nischeninnovationen ein zentraler Aspekt. Die vorgeschlagene multikriterielle Bewertung kann verwendet werden, um die Strategiewahl von Praktikern zu unterstützen.

Insgesamt zeigen die Erkenntnisse dieser Forschung die Wichtigkeit von Koordination und prospektiver Planung in Nischenprozessen auf. In diesem Zusammenhang dürften die vorgeschlagenen Instrumente von Nutzen sein und können verwendet werden, um gezielte Interventionen zu entwickeln, welche die Nischenprozesse (*shielding*, *nurturing*, *empowering*) effektiver machen.

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1 General introduction

1.1 Motivation and objectives

In September 2009, the leaders of the European Union and the G8[1] announced the target of reducing CO_2 emissions by 80% by 2050 to limit the global temperature rise to the critical level of 2°C. However, an 80% overall decarbonization by 2050 may require 95% decarbonization in the road transport sector [1]. This is a huge challenge that may not be achievable trough improvements in the internal combustion engine alone. Hence, electric vehicles, such as battery electric vehicles and fuel cell electric vehicles, are widely considered to play an important role in future sustainable transport systems.

Nevertheless, the task of supporting the electrification of road transportation is not trivial, as the emerging technologies must not only compete with components of the existing internal combustion engine, but with the overall system in which it is embedded. This situation is labeled by [2] as *carbon lock-in*. Unruh explains how the transport system has evolved into an interlinked system of actors, institutions and technologies over the past decades. This incumbent transport system continuously provides self-reinforcing positive feedback and lock-in in the form of network externalities, scale economies, re-investment, established standards, cumulative learning, and habits for the further development of fossil based technologies [2].

In order for the emerging transport technologies to prosper, the various lock-in conditions of the incumbent system have to be overcome. Hence, electric vehicles need to develop and gain momentum to be able to survive and succeed within the existing transport system. In this context, niches play an important role because radical innovations tend to develop in niches that shield those innovations from mainstream selection pressures such as established user practices, preferences, administrative regulations, technical standards, and infrastructural requirements [3]. Consequently, niches have been conceptualized as ‘protected spaces’.

Smith and Raven [4] argue that protective space dynamics exhibit different functional properties. They differentiate three types of niche processes: shielding, nurturing, and empowering. *Shielding* refers to processes that that keep away selection pressures from mainstream selection environments. *Nurturing* refers to processes that support the development of an innovation within shielded spaces. *Empowering*, finally, involves processes that make niche innovations competitive within (relatively) unaltered selection environments or processes that restructure mainstream selection environments in a manner favorable to the niche. It is argued that trough these processes niche innovations gain momentum and will eventually be able to compete with established technologies. However, such processes are complex, uncertain and involve multiple actor groups. Smith and Raven point out that *“the politics of trying to construct shielding, nurturing and empowering through multi-actor relationships indicates the task will be far from an orderly, singularly rational management task.”* [4] p. 1034 Hence, a better understanding of niche processes is an important condition for the elaboration of coherent support strategies to facilitate the diffusion of emerging transport technologies.

There are two primary aims of this thesis: First, to enhance the (theoretical) insights into the dynamics of niche processes and second, to identify possibilities to intervene in these processes.

[1] The Group of Eight industrial powers: Canada, France, Germany, Italy, Japan, Russia, the UK and the United States

1.2 Structure of the thesis

This dissertation follows a case-study design, with in-depth analysis of different aspects of the three niche processes *shielding*, *nurturing*, and *empowering*. Each investigation was conducted as a separate research project. Hence, the overall structure of the thesis takes the form of three independent chapters.

Thesis Part I aims to gain an understanding of the selection environment in which a hydrogen-powered street sweeper has to assert itself and the vehicle's niche market potential. Hence, we perform an online survey comprising a choice experiment in Switzerland and Germany to provide insights into the competitive environment, the importance of different product characteristics, user practices and preferences, and infrastructural requirements. This information about the market potential and the selection environment is important to decide whether there is a need for the mobilization or creation of protective space (*shielding*) and how it should be shaped.

Thesis Part II evaluates the current performance of the innovation system around fuel cell and hydrogen technologies in Switzerland. A sound understanding of the specific strengths and weaknesses of the system is an important condition for the development of coherent support strategies to enhance the build-up of a well-performing innovation system. The assessment is based on the technological innovation system (TIS) approach, which provides a detailed framework for understanding niche building (*nurturing*). The analysis provides the basis for the development of a transition roadmap through which the further build-up process of the innovation system can be coordinated and facilitated. The approach to empirical research adopted for this study is one of a qualitative, semi-structured interview methodology.

Thesis Part III performs a comparative niche analysis based on the technological innovation system (TIS) framework. The investigation describes the historical development of two niche innovations encompassed by the same technological innovation system: the successful diffusion of e-bikes and the stagnating e-scooter development in Switzerland. The aim is to identify typical stages and processes in the build-up of a TIS and to analyze how different boundary conditions influence the choice or direction of further strategic maneuvering at the stage when niche innovations move beyond the initial protective space. Thus, this study sets out to create deeper insight into the up-scaling process (*empowering*) of niche innovations. A quantitative method for the analysis of events is used in this investigation.

The *General Conclusion* gives a brief summary of the most important insights and includes a discussion of the significance and implications of the findings. Finally, areas for further research are identified.

2 Thesis Part I: Assessing customer preferences for hydrogen-powered street sweepers: A choice experiment

2.1 Abstract

The large variety of potential hydrogen and fuel cell applications and the associated uncertainties of selecting a particular application pose a challenge for developers in the field: identifying and evaluating promising market niches. Therefore, we conducted an online survey comprising a choice experiment in Switzerland and Germany to assess fleet decision-makers' preferences for hydrogen-powered street sweepers compared to (more) conventional diesel and compressed natural gas (CNG)/biogas vehicles. The findings indicate that the fleet decision-making structures and vehicle operating practices make street sweeper fleets a promising application for the early implementation of hydrogen fuel cell vehicles. Furthermore, the results show that a market niche for hydrogen-powered sweepers exists in both countries. The choice experiment was a useful approach for the identification of promising market niches and thereby reduces the uncertainties of application selection.

2.2 Introduction

In autumn 2009, the leaders of the European Union and the G8[2] announced the objective of reducing CO_2 emissions by 80% by 2050 to keep global warming below the critical level of 2°C. However, an 80% overall decarbonization by 2050 may require 95% decarbonization in the road transport sector [1]. With the number of vehicles worldwide expected to rise significantly by 2050, this target may not be feasible through improvements in the internal combustion engine alone. Hence, among other alternatives, fuel cell electric vehicles (FCEVs) are widely considered to have an important role in future sustainable transport systems, as they have the potential to significantly reduce local and CO_2 emissions if the hydrogen is produced from renewable energy sources [5]. Nevertheless, selecting a promising, properly timed market development path for these vehicles is not a trivial task and poses many challenges for decisions-makers in the field.

In innovation studies, the concept of a 'niche' has become a central topic in understanding the processes of technological change (e.g., [6] [3] [7]). This is reflected in discussions concerning hydrogen and fuel cell technologies, where niches are seen as being important for creating demand for these technologies. It is assumed that the technology will initially be applied in various niches and eventually migrate into mass markets [6]. There is a broad range of potential hydrogen and fuel cell applications such as material handling vehicles, garbage trucks and scooters. This research will examine another possible application: street sweepers. This application was selected because it has attracted some interest and has provided a platform for social learning on FCEVs in Switzerland.

Recently, two research institutions in Switzerland concerned with future powertrain technologies have, in collaboration with industrial partners, developed a prototype fuel cell street sweeper that is nearly at the pre-production stage. The Swiss company 'Bucher Municipal', the European market leader in the manufacture of municipal vehicles, is the key industrial partner in the project. The company's aim is to acquire information on the implementation of more eco-friendly drive-train technologies to maintain and develop its leading market position. The vehicle is currently undergoing operational testing on the streets of various cities in the country. The first test phase revealed using the vehicle in everyday conditions allows the operator to save a considerable amount of energy, as the vehicle consumes less than half

[2] The Group of Eight industrial powers: Canada, France, Germany, Italy, Japan, Russia, the UK and the United States

the fuel of a diesel powered equivalent.[3] The vehicle also performs approximately 40% better with respect to CO_2 emissions than its contemporaries, even when the hydrogen is produced by the steam reforming of natural gas using fossil fuels [8]. If the hydrogen were produced using energy from renewable sources the CO_2 reduction would be even greater. Another advantage is that the project's mobile hydrogen fueling station can also be used for other hydrogen vehicles, as is already the case. Thus, the project could act as a catalyst for other mobile fuel cell applications. Compact street sweepers represent a relatively small market, and purchasing decisions are made infrequently (a sweeper's average operating life is approximately 10 years); nonetheless, at least, 90 to 130 new vehicles are registered annually in a small country such as Switzerland. As a possible next step, the project partners see the potential in supplying 'strategic markets' (i.e., demonstration projects in Europe and North America) that foster the deployment of additional types of hydrogen- powered vehicles.

However, the large variety of potential hydrogen and fuel cell applications also creates challenges. Hellman and van den Hoed [9] note that *"the application diversity of FC [fuel cell] technology and the subsequent uncertainties of application selection imply a challenging search and evaluation of potential and profitable niche markets."* There is a risk of choosing the wrong application at the wrong time, and a lack of market acceptance for an application can make the resources and developments that have been acquired worthless [9]. In the context of the sweeper project, important initial steps in the formation of a technological innovation system around hydrogen and fuel cell technologies that have been emphasized in the recent innovation literature [10] [11] have been made: the entry of firms and other organizations along the supply chain, the formation of learning networks (e.g., industry-academia and user-supplier linkages), the alignment of institutions (e.g., safety standards) and the accumulation of knowledge and infrastructure (e.g., fuelling stations). To assess whether further steps and investments are reasonable, in this study we analyze the prospects for the existence of a potential market niche. This is related to a sound understanding of the current state of customers' preferences. Building an understanding of the degree to which sweeper customers value the new qualities of a fuel cell vehicle would help inform decision-makers about the direction of the search process and the importance of specific product characteristics. This is important because suppliers' and researchers' awareness of appropriate solutions that are tailored to customer needs is crucial for initial market formation [12]. Consequently, this paper will focus on fleet customers' preferences. The first customers that bought alternative fuel vehicles were generally fleets, which underlines their role as early adopters. Nesbitt and Sperling [13] argue that vehicle operating practices and purchase decisions make fleets a favorite target for policy-makers. This argument highlights the importance of the sweeper's particular driving profile that includes modest driving dynamics, predominantly low part-load operation and fleet operation from a fixed refueling point. Hence, the application appears particularly well suited for an early market niche introduction of fuel cells.

The aim of this paper is to improve understandings of the market niches for hydrogen and fuel cell applications by demonstrating a quantitative analysis approach to identify promising market niches, explaining why a specific market niche exists and highlighting the role of public fleets as early adopters, as well as the importance of product characteristics for market development.

The paper is organized as follows: the relevant aspects of previous research are summarized in Section 2, followed by a description of the methodological approach used in this study in Section 3. Section 4 presents the results. In Section 5, we discuss the findings and propose avenues for further research. Finally, the key conclusions of the study are presented in Section 6.

[3] In figures: instead of 5 to 5.5 liters of diesel per hour (equivalent to an energy consumption of 180-200 MJ per hour) the hydrogen powered vehicle needs only 0.3 to 0.6 kg of fuel per hour (that is, 40-80 MJ per hour).

2.3 Theoretical and empirical background

An overview of the literature indicates that there are important differences between various conceptions of niche development. The state of the empirical evidence that this research builds on is also developed in the following section. It elaborates on gaps in the research and primary research questions behind this study.

2.3.1 Conceptions of the niche

In innovation theory, niches have been given a prominent role as incubators of radical innovation. The literature presents two dominant and distinct conceptions of niches – the 'technological' niche and the 'market' niche. Markard and Truffer [14] define the two types of niches according to the evolution of their particular selection environments. Technological niches form 'protected spaces' that have been deliberately created by actors and are supported by specific institutions [15]. Schot and Geels [15] describe these protected spaces as *"proto-markets created by a coalition of actors to test and develop new technologies with the aim to develop larger market niches."* Hence, technological niches are created as experiments and pilot and demonstration projects [7]. By contrast, in the case of market niches Markard and Truffer highlight that *"particular selection criteria have emerged, e.g., due to particular application contexts or consumer preferences that significantly deviate from 'usual' contexts or practices."* [14] In this research, we also make distinctions between the two types of niches, but our prospective analysis will solely focus on market niches, which Levinthal [16] characterizes as *"populations of (potential) consumers [that] are distinguished by the functionality they desire and their willingness to pay for these various attributes."* He argues that radical technological change may occur as a result of distinct selection criteria operating in a niche. Therefore, one question that must be asked is whether a market segment exists within the street sweeper market that exhibits a somewhat different set of selection criteria that would support the new technology. More specifically, is there a population of consumers that is willing to pay a higher price for the vehicle because of particular benefits they would gain from the new qualities or attributes of fuel cell technology?

Evolutionary economists and management scholars have emphasized the importance of market niches for radical innovations, such as hydrogen and fuel cell technologies [15] [17]. They argue that a radical innovation improves and stabilizes in multiple market niches until it is able to enter mainstream markets [18]. The niche's internal processes of product development and improvement through improved technology, costs and performance are important for creating demand. Hence, this raises the question of how a new fuel cell product can and should be improved to capture as much demand as possible.
Several authors (e.g., [19] [17] [20]) describe additional processes that occur once a technology begins to be produced and deployed within market niches. In addition to technological and cost related developments, it is important to mention that applying fuel cells (for example) in different market niches may also create and enhance new social networks that support fuel cell technology and the development of institutions such as safety standards [18]. Due to these internal processes, market niches can act as 'nursing' or 'bridging' segments on the way to mainstream markets [17].

2.3.2 The state of the empirical evidence

In recent years, there has been an increasing, yet diverse, amount of literature on the public perceptions and acceptance of hydrogen, including comprehensive reviews (e.g., [21] [22] [23]). Yetano Roche et al. [22] reviewed methodological approaches and findings in the literature with a focus on the acceptance of and preferences for alternative fuel vehicles (AFVs) in general and hydrogen and fuel cell vehicles (HFCVs) in particular.

The main results of their review can be summarized as follows: The studies on HFCVs revealed a low level of awareness about the technology and positive, albeit reserved, attitudes towards it. A few studies included questions regarding respondents' willingness to pay that were predominantly positive but not generally influenced by the respondent's level of environmental awareness. One of the key findings from the research on preferences towards HFCVs and AFVs appears to be that in comparison with traditional attributes, environmental benefits are of relatively minor importance in vehicle purchasing decisions. Monetary attributes (vehicle and operation costs) are of paramount importance in vehicle purchasing decisions, followed by performance and convenience attributes (such as range and fuel availability) [22].

Yetano et al. [22] also found a gap in the scope of the HFCVs studies conducted to date, as they appear to concentrate on preferences for a single technology in isolation. However, customers will most likely have a range of competitive and environmentally friendly transportation solutions to choose from once HFCVs are prepared for market introduction. Therefore, Yetano et al. [22] suggest that future research should analyze hydrogen technologies in the context of competing technologies. In addition, they recommend the use of non-market economic valuation approaches for investigating the potential demand for HFCVs because robust quantitative findings are still relatively scarce. Information on the trade-offs that customers would be willing to make between different attributes, such as price, performance and environmental quality, is a related area that warrants future research, as consumers may be concerned about different attributes by the time that HFCVs become a viable option in their vehicle purchasing decisions [24] [25].

Fleets are a promising target for the early testing and implementation of new drivetrain technologies. Nesbitt and Sperling [26] argue that numerous fleet vehicles are commonly fueled at a single location and can therefore be switched to alternative fuels before a public refueling infrastructure is in place. To obtain a better understanding of fleet purchasing behavior, Nesbitt and Sperling developed a classification scheme that classifies fleet management by decision-making structure (autocratic, bureaucratic, hierarchic and democratic) [26]. For example, bureaucratic decision-making is highly formalized and decentralized and is common in (local) government agencies. Decisions are often the result of objective formal evaluations such as technical and financial assessments and cost-benefit analyses that are conducted systematically through pre-established routines (e.g., bid invitation). Overall, however, there has been little research on commercial fleets and the corresponding purchasing processes. Nesbitt and Sperling conclude that vehicle fleets are an underexplored and hence poorly understood subject [26]. In addition, the research to date has primarily focused on the USA [27]. Thus, there is still a need for commercial fleet vehicle studies that can support the implementation of green technology by improving understandings of fleet purchase and operation patterns and thereby the formulation of more effective implementation strategies for alternative fuel vehicles.

By applying a choice experiment and investigating fleet managers' purchasing decisions in a realistic setting, we address the research gaps identified above. This paper has two objectives. First, we further ground and assess the selection of the specific application (i.e., our case study), and second we perform a multidimensional analysis of a potential market niche. The following four questions form the focal point of the research:

1) How should the selection of the case study be justified and assessed?

2) Does a promising market niche for hydrogen-powered street sweepers exist?

3) If so, what are possible explanations for the existence of such a market niche?

4) Which improvements could be made to hydrogen-powered street sweepers to capture more relative demand?

Research Question 2 emphasizes the quantitative aspects of a potential market niche. Question 3 focuses on the relevance of vehicle attributes, whereas Question 4 centers on sensitivity analysis.

2.4 Methodological considerations

The methodological considerations provide the main arguments for why choice experiments and conjoint analysis are the appropriate methods for addressing the research questions outlined in the previous section. In this section, we also describe the experimental design that the concrete individual choice situations are based on. Finally the section also provides details on the sample and survey structure.

2.4.1 Choice experiments and conjoint analysis

As hydrogen driven street sweepers are not yet commercially available, it is not possible to measure revealed preferences from past purchasing behavior. Therefore, a research technique is needed to elicit stated preferences. One of the main types of stated preference methods are choice experiments [22]. They belong to the family of conjoint analysis methods and have been widely used in market and transportation research. In the last decade, this approach has also become popular in environmental and resource economics because it allows realistic trade-off situations to be modeled while reducing some of the risk of social desirability bias [28].

Choice experiments are based on microeconomic consumer/household theory that assumes consumers to be rational decision-makers. Consumers make purchasing decisions that maximize their utility subject to preferences, knowledge about alternatives and budget constraints. Lancaster [29] has advanced this theory by arguing that the characteristics or attributes of a product are what generate benefits not than the product itself. The overall utility of a product is thus the summation of the utilities assigned to its separate attributes. This is reflected in choice experiments, where products are assumed to consist of several attributes with a variety of levels. During a survey, respondents are presented with hypothetical but realistic choice situations and are asked to choose the most preferred product alternative. The preferences of participants can be derived through this process. A more detailed description of this methodology is beyond the scope of the current paper but can be found in [30]. Several models are available to analyze choice experiments. Hierarchical Bayesian analysis was used in this research [31]. It is regarded as a state-of-the-art method for estimating utilities from choice experiments. Compared to traditional aggregate models (e.g., multinominal logit analysis) the hierarchical Bayesian approach significantly improves the analysis of preferences, particularly in the situations with limited data for modeling based on individual level decision making.

2.4.2 Experimental design

Designing a choice experiment typically involves the following steps: the identification of product attributes, the specification of attribute levels, generating the experimental design, interviewing the respondents, estimating the choice models and analyzing the data [30]. Accordingly, we identified attributes that had high levels of influence over consumer purchasing decisions in previous alternative fuel vehicle (AFV) studies ([32] [25] [33] [34] [27] [35] [36] [37] [38] [39]). Expert interviews (with fleet managers, street sweeper producers, and researchers) and a pre-survey were used to determine the final set of attributes. These attributes include: (1) fuel type, (2) purchase price, (3) running costs, (4) shortest refueling distance (i.e., the time it takes to drive the sweeper to the next refueling station), (5) polluting emissions, and (6) noise emissions. Because fuel cell and CNG/biogas technologies offer new qualities, the non-traditional performance indicators polluting emissions and quiet performance were explicitly included in the set of attributes as suggested by Mau et al. [25]. In addition to these six attributes, respondents were told to assume that the street sweepers are identical in all other aspects (e.g., performance, cruising range, reliability). Expert opinion was also sought to ensure that the selected attribute levels are as meaningful as possible. A full list of the attributes and related levels is shown in Table 2-1.

Table 2-1: Attributes and their levels.

ATTRIBUTES	ATTRIBUTE LEVELS	
	Conventional Vehicle	**Alternative Fuel Vehicle**
Fuel Type	Diesel	CNG/Biogas Hydrogen
Purchase Price (in EUR)	130,000	130,000 143,000 (+10%) 169,000 (+30%) 195,000 (+50%) 221,000 (+70%)
Running Costs (in EUR) Includes maintenance-, repair- and fuel costs.	20,000	18,000 (-10%) 20,000 24,000 (+20%) 28,000 (+40%) 32,000 (+60%)
Refueling Distance (one-way in minutes)	5 minutes	5 minutes 10 minutes 15 minutes 20 minutes
Polluting Emissions as % of Present Vehicle (weighting: 50% pollutants and 50% greenhouse gas emissions)	100%	0% 25% 50% 75%
Noise Emissions	High	Low Middle

In our choice experiment, respondents were provided with descriptions of three sweeper types: (1) conventional diesel vehicles (defined as the status quo), (2) vehicles that run on CNG/biogas, and (3) hydrogen driven vehicles. According to expert opinion, these three vehicle types represent the full spectrum of technologies that are currently available or are likely to be available in the foreseeable future. CNG and biogas are based on the same technology, but for users the difference in these fuels lies in different levels of polluting emissions. Broadly speaking, the same applies to the option of a (not yet existing) CNG-hybrid sweeper. Therefore, the decision was made to place these types of drivetrains and fuels in a single vehicle category. Concerning additional possible sweeper types, interviews with experts in the field revealed that a pure electric vehicle is not practically feasible or economically viable for the foreseeable future. An 80-90 kWh battery would be necessary to allow a driving range of 7-8 hours, implying a vehicle that is too heavy, large and expensive. Furthermore, the experts believe that the development of a diesel-hybrid sweeper makes little sense because of tougher future emissions regulations. A significant reduction in nitric oxide emissions in low part-load operation will be particularly difficult to achieve. Thus, both pure electric and diesel-hybrid vehicles are not included in this research, and, consequently, it was not necessary to gather attribute information about charging time.

The use of alternatives makes it possible to analyze hydrogen in the context of other competing technologies. In each choice situation, interviewees were first asked to choose among three alternative fuel sweepers (hydrogen and CNG/biogas) and then next asked if they would buy the alternative they selected in the first stage were a diesel vehicle also available. The advantage of forcing respondents to choose between alternative fuel vehicles first is that we still obtain highly valuable preference information about the alternatives even if the status quo is chosen as the preferred vehicle. The model can therefore capture and use more information about the relative values of the attributes and the corresponding levels. This approach is called Dual Response 'None' and has not been found to significantly alter the underlying model estimates. For further details, refer to [40]. For the conventional diesel vehicle, we set all of the attribute levels at fixed values. The experiment was a forced-choice task, i.e., the respondent could not decline all alternatives. The unrealistic combination of CNG/biogas fuel with 0% polluting emissions did not appear in the questionnaire. To avoid fatigue and nuisance effects, each respondent only received a set of ten choice scenarios, instead of the total number of possible combinations. Therefore, the choice tasks were calculated randomly using 'Sawtooth' software (and respecting the orthogonality, minimal overlap and level balance criteria) [41]. The respondents' decisions were based on the attribute description provided. Hence, the values elicited by a stated preference approach are generally contingent on the information provided. There is a large body of research discussing the effects of information availability on the formation of preferences [42]. It is not possible to rule out the possibility that respondents react to hypothetical markets in ways that are different from those in a real market.

2.4.3 The respondent sample

We conducted identical online surveys comprising a choice experiment in Switzerland (German-speaking part only) and Germany (see Appendix I-A). The questionnaire was administered to street sweeper fleet managers (the person in charge of daily fleet activities), it should be noted that the vast majority of them work for a public institution. Typically, fleet managers are involved in the decision process for sweeper purchases or trigger strategic decisions. Their technical know-how, practical experience and knowledge about the latest technological solutions give them considerable leverage in the decision process. The interviews in Switzerland were conducted in April 2010, those in Germany from September through October 2010. The Swiss study collected 174 completed surveys, and the German study collected 100 surveys. The response rate for the Swiss sample was the highest at 22%.

The survey was structured as follows: part one consisted of questions regarding fleet characteristics and vehicle operating practices, while the second part was the choice experiment. To obtain a better understanding of the fleet's purchase decision-making structure, we included the relevant questions (based on Nesbitt's and Sperling's classification scheme [26]).

2.5 Results

Only those results of the questionnaire and the choice experiment that inform the four research questions are presented. With regard to data quality, the “percent certainty” (Pct. Cert.) can be used as a goodness-of-fit measure in order to asses convergence of hierarchical Bayes estimates. It indicates how much better the solution is than chance (a value of zero), as compared to a “perfect” solution (a value of one) [31]. Pct. Cert. was 0.702 for the “Swiss” model and 0.686 for the “German” model. A recent analysis of 25 choice experiment studies by ‘Sawtooth Software’ revealed that the average Pct. Cert. was 0.71 [43]. Hence, our values indicate good fit of the two models.

2.5.1 Descriptive results

Unlike the general public, fleet managers are kept apprised of trends and developments in the vehicle industry through different sources such as manufacturers, colleagues, industry journals, trade fairs, etc. We therefore hypothesized that they would also be well informed about alternative fuel vehicles in general. Nevertheless, our findings indicate that the majority of fleet managers (71% in Switzerland and 80% in Germany) are uninformed about hydrogen vehicles (see question 1 in Table 2-2 for further details).

Table 2-2: Questions about the awareness of hydrogen vehicles and refueling practices.

Nr.	Questions	Switzerland		Germany	
		Yes	No	Yes	No
1	Do you know any examples of vehicles (of any type) that are operated on hydrogen?	29%	71%	20%	80%
2	Do you have an on-site fueling station where the sweepers are refueled?	41%	59%	47%	53%
3	Do you refuel your sweeper(s) at only one location? (in 90% of cases)	91%	9%	90%	10%

Back-to-base operation and on-site refueling capability were important factors for choosing a sweeper in this demonstration project. However, this does not necessarily mean that one fuelling point is sufficient, as operators might refuel their vehicles at several different locations. To learn more about a fleet’s refueling practices, we asked the respondents two questions (see questions 2 and 3 in Table 2-2). Over 40 % of those surveyed (41% in Switzerland and 47% in Germany) reported that they have on-site refueling capability. In response to the second question, most of those surveyed, 91% of the Swiss and 90% of the German fleet managers, indicated that the vehicles are regularly fueled at a single location.
The analysis of the fleets’ stated purchasing decision processes revealed a predominance of bureaucratic decision-making structures. Autocratic and hierarchic decision-making structures were the least common. The small number of private fleets in our surveys means that this outcome is not surprising. Bureaucratic decision-making implies that there is no single decision-maker but rather several individuals who influence the decision. Approximately 80% of the respondents indicated that more than two people would be involved in a decision process regarding initial alternative fuel vehicle purchases. Furthermore, in the majority of cases, the final choices would then need approval from political authorities (e.g., a local government or city council).

2.5.2 Conjoint analysis results

The choice experiment provides various outputs that may be analyzed to help to address research questions two through four. Accordingly, three different types of analytical results will be presented in the following sections: findings from market simulations, relative attribute importance and sensitivity analyses.

Market Simulation: Good strategic information regarding the introduction of new technologies is produced by carefully defined market simulations. In this section, we conduct two hypothetical market simulations to answer our second research question: “Does a promising market niche for hydrogen-powered street sweepers exist?” A software-based market simulator enabled us to project the percentage of respondents that would choose each product within a simulated market scenario, or preference shares.

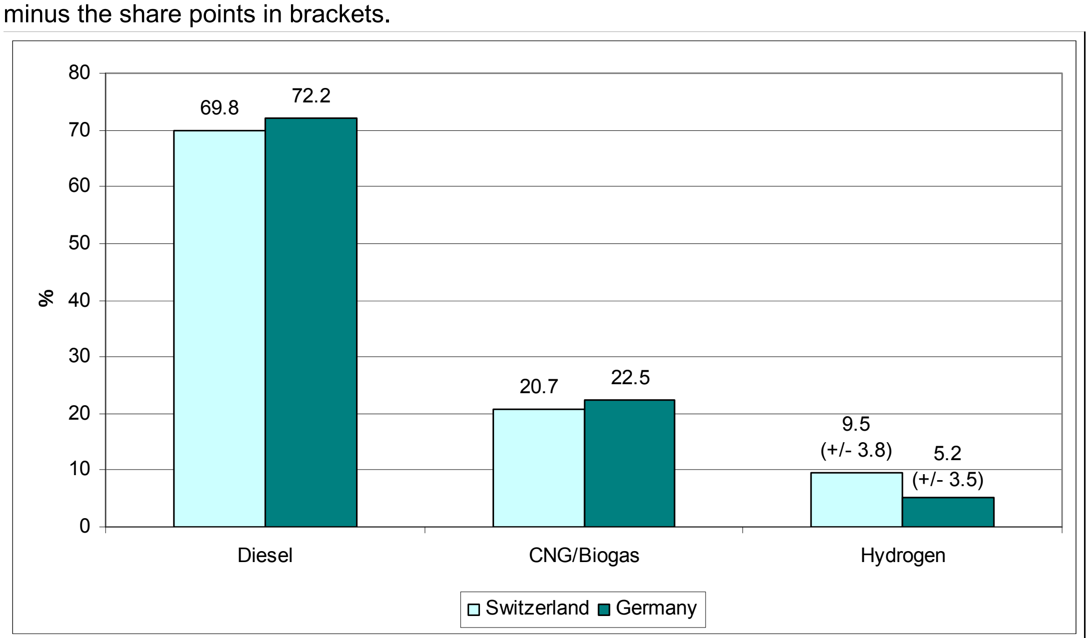
A conceivable initial scenario is the introduction of a small batch series of hydrogen driven street sweepers to a market that currently consists of only diesel and CNG/biogas vehicles. Expert opinion was again consulted to assign each vehicle realistic attribute values in this scenario. Table 2-3 provides the values that were used.

Table 2-3: Attributes and their levels in the 'hydrogen small batch series' scenario.

	Purchase Price	Running Costs	Refueling Distance	Polluting Emissions	Noise Emissions
Diesel	EUR 130,000	EUR 20,000	5 Minutes	100%	High
CNG/Biogas	EUR 169,000	EUR 20,000	15 Minutes	75%	Medium
Hydrogen small batch	EUR 221,000	EUR 32,000	15 Minutes	25%	Low

The preference shares for each technology in this scenario are presented in Figure 2-1.

Figure 2-1: Preference shares in the 'hydrogen small batch series' scenario.
The 95% confidence interval of the results in the hydrogen case is the preference share plus or minus the share points in brackets.



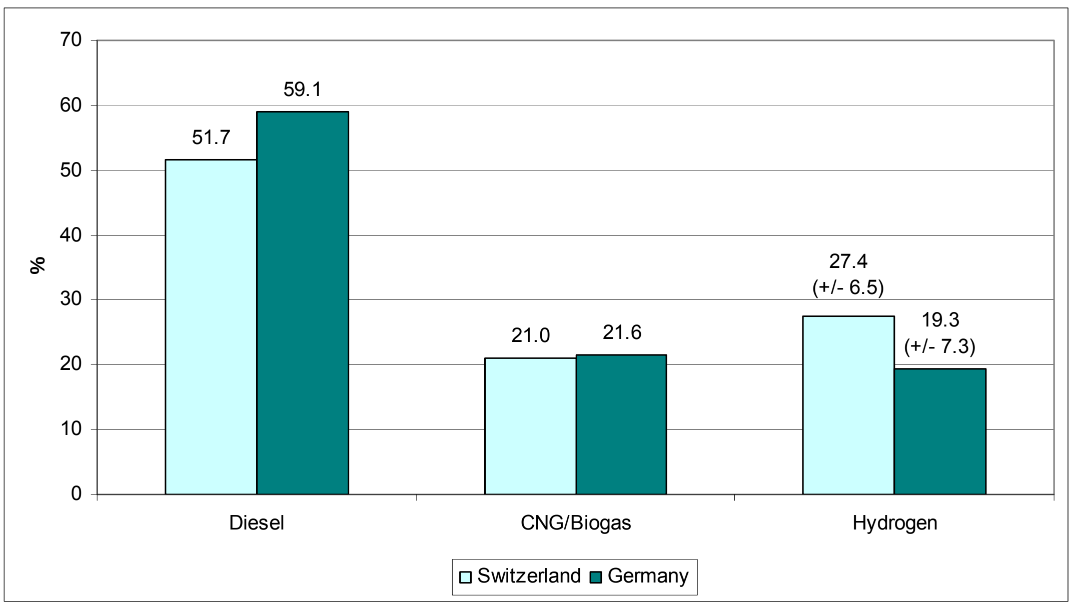
From the graph above, we can see that in this simulation the choice patterns in Switzerland and Germany are similar. With a roughly 70% preference share, the diesel vehicle is by far the most preferred product followed by the CNG/biogas vehicle with about a fifth of the respondents preferring this alternative. In Switzerland, 9.5% of respondents preferred the hydrogen driven sweeper, and 5.2% of German respondents had the same preferences. Here, some variation in preferences is observable. This difference in the hydrogen case is significant. For calculation details see [41].

The second simulation examines the impact of the introduction of a large batch series of hydrogen driven vehicles. In this scenario, the monetary attributes of the hydrogen driven sweeper become more favorable due to assumed economies of scale. Nevertheless, compared to the diesel vehicle, the purchase price is 50% higher and the operating costs are 20% higher. Furthermore, we assume the use of renewably generated hydrogen that generates no polluting emissions. The values of the diesel and CNG/biogas vehicles are completely unchanged. The corresponding attribute levels are provided in Table 2-4, and the resulting preference shares of each technology are in Figure 2-2.

Table 2-4: Attributes and their levels in the 'hydrogen large batch series' scenario.

	Purchase Price	Running Costs	Refueling Distance	Polluting Emissions	Noise Emissions
Diesel	EUR 130,000	EUR 20,000	5 Minutes	100%	High
CNG/Biogas	EUR 169,000	EUR 20,000	15 Minutes	75%	Medium
Hydrogen large batch	EUR 195,000	EUR 24,000	15 Minutes	0%	Low

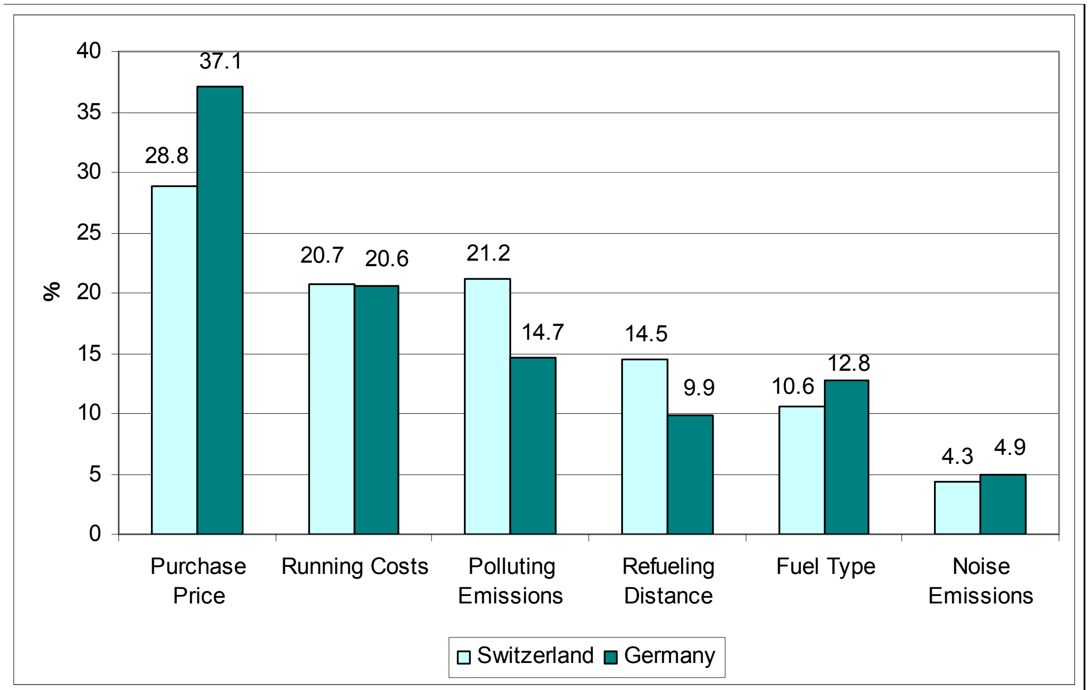
Figure 2-2: Preference shares in the 'hydrogen large batch series' scenario.
The 95% confidence interval of the results in the hydrogen case is the preference share plus or minus the share points in brackets.



The new simulated shares in Figure 2-2 show that the diesel vehicle is still the most preferred product in the hypothetical market. Apart from that, the pattern has changed. In Switzerland the hydrogen driven street sweeper is now preferred to the CNG/biogas vehicle, while in Germany the preferences for the two alternative vehicles are comparable. The difference in the hydrogen case is significant again. Interestingly, compared to the small batch series simulation, the preference share for the CNG/biogas vehicle remained broadly stable. This indicates that the hydrogen vehicle can expand its share, generally at the expense of the diesel vehicle.

Relative Attribute Importance: In the next step, we characterized the relative importance of each attribute. These relative importance figures describe the degree of influence each attribute has on the purchasing decision. The results obtained from this type of analysis [41] are presented in Figure 2-3.

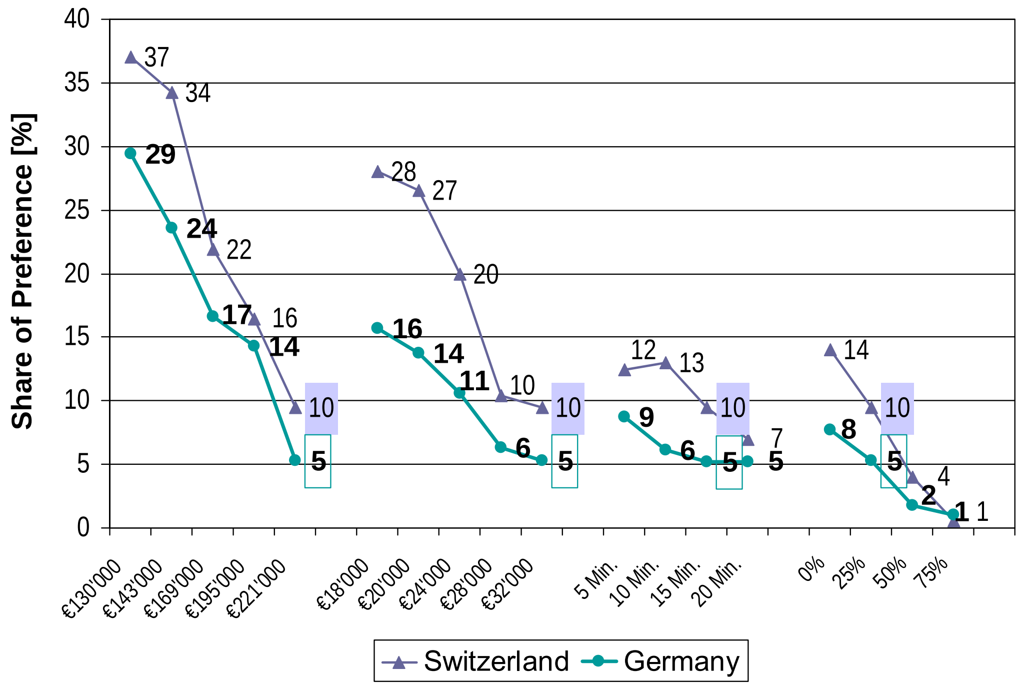
Figure 2-3: Relative importance of the attributes derived from hierarchical Bayes utility estimation.



The data indicate that the purchase price is the most important attribute with a relative importance of 28.8% in Switzerland and 37.1% in Germany. Interestingly, the importance of operating costs is almost identical for respondents in both countries (Switzerland: 20.7%; Germany: 20.6%). Taking the two monetary attributes together, it is clear that they have profound influence on the purchasing decision. The most striking result to emerge from the data is that polluting emissions occupy the 2nd and 3rd positions in the rankings of Switzerland and Germany, respectively. In Switzerland, the 'polluting emissions' attribute has over six percentage points more influence on the consumption decision than in Germany. The availability of fuel (refueling distance) and fuel type come next in the attribute ranking and therefore exert less influence on the decision than polluting emissions. Furthermore, noise emissions play a rather marginal role in the product choice in both countries. Note that an attribute's importance is always relative to the other attributes in the study. Additional vehicle characteristics such as performance and reliability were not included in the analysis. Therefore, no information can be provided regarding these attributes. However, any deficiency may be classified as a critical technology failure that needs to be addressed.

Sensitivity Analysis: Finally, the hydrogen small batch series scenario was used to conduct a sensitivity analysis. This approach can indicate the degree to which we can improve (or worsen) the hydrogen driven sweeper's overall preference by changing its attribute levels individually, while holding all other attributes constant at baseline levels (i.e., the hydrogen small batch series). In this way, the impact of each attribute level is estimated within the specific context of the competitive landscape of the (future) street sweeper market [41]. Figure 2-4 shows estimated preference shares using this type of sensitivity analysis.

Figure 2-4: Sensitivity analysis results for purchase price[4], running costs[5], refueling distance and polluting emissions, respectively.
Starting point of the analysis is the 'hydrogen small batch series' scenario (see Figure 2-1).



In our baseline scenario, the hydrogen driven sweeper captured approximately 10% of the relative preference share in Switzerland and approximately 5% in Germany. These shares represent the starting points of the sensitivity analysis. From the graph above, we can see that decreasing the purchase price by 10% (from EUR 221,000 to EUR 195,000) results in a 16% greater relative preference in Switzerland and a 14% greater relative preference in Germany. This corresponds to increases of 6% and 9%, respectively. In contrast, a 10% reduction in running costs translates to a modest, approximately 1%, relative preference increase in both countries. However, a further 10% decrease in running costs generates a significant increase in its preference share (+10%) in Switzerland.

Reducing the refueling distance from 15 to 10 minutes, as might be possible through a denser service station network, would increase the hydrogen vehicle's share by a mere 1% in Germany and 3% in Switzerland.

By including preference levels for the negative attributes, we observe a loss in relative preference. One of these attributes is polluting emissions. Increasing the vehicle's polluting emissions from 25% to 50% results in a lower relative preference of 6% in the Swiss case.

The results of the sensitivity analysis may also be used to assess elasticities. A log-log regression reflects the following elasticities [41]:

Table 2-5: Computed average elasticities (log-log regression).

	Purchase Price	Running Costs	Refueling Distance	Polluting Emissions
Switzerland	-2.53	-2.11	-0.39	-0.31
Germany	-2.86	-2.01	-0.40	-0.24

[4] The corresponding purchase prices in Swiss Francs are: 160,000; 176,000; 208,000; 240,000; 272,000.

[5] The corresponding running costs in Swiss Francs are: 27,000; 30,000; 36,000; 42,000; 48,000.

2.6 Discussion

Our findings help to substantiate a promising market development strategy for HFCVs. This strategy will be discussed with respect to the four research questions.

The first research question was the following: “How should the selection of the case study be justified and assessed?”

The findings suggest that the fleet refueling practices in both countries are favorable for the early implementation of a hydrogen infrastructure. Similarly, the predominance of bureaucratic decision-making structures is promising in so far as Nesbitt and Sperling [26] argue that bureaucratic decision-making fleets (government agencies) have been and will likely continue to be early adopters of alternative fuel vehicles. In general, it seems that the operating parameters and decision-making structures are conducive for the early implementation of HFCVs. However, the fleet managers’ low technological awareness indicates that the public and professionals need to be provided with further information about hydrogen technologies. This is also the case for high-level decision-makers such as local governments or city council members who are involved in purchasing decisions. Informing these individuals is all the more important, as fleet managers are generally better informed about technical possibilities than high-level decision-makers who are responsible for a wide range of issues. In addition, the results show that the choice experiment, as a prospective analysis instrument, makes it possible to provide direction in the search process. As the recent innovation literature highlights, this is of particular relevance in a very early phase of the evolution of an innovation system and therefore for the Swiss application case [10]. To conclude: works similar to this research make important contributions to the management of expectations.

The second question focused on the quantitative aspects of a potential niche: “Does a promising market niche for hydrogen-powered street sweepers exist?”

With a preference shares of 27% in Switzerland and 19% in Germany (large batch series), the market simulation results indicate that a market niche for hydrogen driven sweepers exists in these countries. Hydrogen and CNG/biogas vehicles have the potential to be alternatives to the conventional diesel technology in the municipal vehicle segment, despite the significantly higher purchase price. However, the share of preference predictions presented here should not be interpreted as market shares but as indicators of relative preferences. This is because many real-world factors such as the length of time in the market, distribution, advertising, etc. may not be accounted for in a choice experiment. Nevertheless, the method is useful for policy analysis and identifies a promising market niche. Furthermore, the economic conditions must be considered. Many municipalities in Germany face financial difficulties that lead to additional uncertainties in business development decisions. Due to the promising market simulation results and other factors, such as the relatively low local debt in Swiss municipalities or the strong position of Swiss companies in the street sweeper vehicle segment, it can be argued that Switzerland could serve as a lead market for hydrogen driven street sweepers (see lead market literature, e.g., [44]).

The relevance of vehicle attributes was the focus of the third question: “What are possible explanations for the existence of a market niche?”

Hellman and van den Hoed [9] indicate that hydrogen and fuel cell technology offers new qualities and non-traditional performance indicators, most notably quiet performance and zero emissions. These new values may provide market opportunities for market niche applications. However, our findings revealed that noise emissions play a rather marginal role in product choice. Nevertheless, these data must be interpreted with caution because an objective benefit such as noise reduction will often not register as such if the data are merely

communicated [45]. It is likely that communicating this novel value of hydrogen driven vehicles through demonstrations such as the project in Switzerland will elicit positive reactions from pedestrians, and the vehicle drivers will influence fleet decision-makers' evaluations.
The picture is different regarding polluting emissions. As mentioned in the literature review, environmental benefits are consistently found to be of relatively little importance in vehicle purchasing decisions. However, the findings of the current study do not support the previous research. Our results show that polluting emissions are more important in purchasing behavior than has been found in recent HFCV and AFV studies. A possible explanation for this may be that the respondents in our survey were mainly public sector fleet managers. They are responsible for the cleanliness of the public space, which is a public good. Therefore, it appears likely that these managers place a higher priority on public benefits such as pollution reduction than private actors. This might also be politically motivated, as it is difficult to justify why a public good should be managed with a 'dirty' technology if cleaner solutions are available. This is in keeping with earlier interview studies, which showed that public scrutiny is one reason that government agencies are more inclined to purchase AFVs [13]. From this perspective, the findings are also consistent with those of Golob et al., [38] who found that along with schools, public fleets (local and county governments) are the only fleet sector where reduced tailpipe emissions levels are a significant predictor of vehicle choice. It can therefore be assumed that the early adopters forming the above identified market niches have a higher willingness to pay for the hydrogen technology because of particular (environmental) benefits they gain from it that are not addressed by mainstream technologies. The novel and non-traditional attributes seem to provide sufficient added value to compensate for the relatively high cost and reduced fuel availability.

Finally, the forth question focused on sensitivity aspects: "Which improvements could be made to hydrogen-powered street sweepers to capture more relative demand?"

Based on the sensitivity analysis results in Figure 2-4, potential improvements to the product are apparent. It is not surprising that the monetary attributes have a strong influence on the purchasing decision. Both reductions in purchase price and running costs can significantly improve the overall preference for hydrogen vehicles. In contrast to the substantial impact of prices on relative demand, changes in refueling distance only have a small effect. Interestingly, the results regarding polluting emissions reveal the importance of the source of the hydrogen. To capture a relevant preference share, the hydrogen must be generated renewably, for example by using solar or wind power. Otherwise, there will be a sharp decrease in relative demand. This type of sensitivity analysis enables decision-makers to assess the relative preferences for product attributes and assists these individuals with business development decisions. Of course, prior to beginning any potential manufacturing run, it would be reasonable to conduct more sophisticated hypothetical analyses that shift more than one attribute at a time.

2.6.1 Recommendations

The development of a public hydrogen infrastructure has often been identified as a key barrier to implementing hydrogen as a future transportation fuel; this is also referred to as the 'chicken-and-egg' problem. The findings of this study show that a market niche strategy for the early implementation of HFCVs and the construction of hydrogen refilling stations has some promise. Hence, we recommend identifying (for example with a choice experiment) further early adopter market niches in which the new and non-traditional attributes provide sufficient added value and where the vehicles are operated from a fixed refueling point. The internal niche processes that lead to improved performance through multiple learning effects and economies of scale may become crucial for the reduction of barriers to implementation and for other fuel cell applications. One promising market niche, similar to the one identified in this research project, could act as a catalyst for other niche transport applications such as material handling equipment, special vehicles and buses. It can be assumed that at a later date these market niches could facilitate access to mass markets. However by the time a fuel cell application enters a market niche, either favorable social rules and institutions regarding the new technology already exist or these rules have to be adjusted as suggested by the strategic niche management approach [3]. Although our results indicate that favorable fleet decision structures exist in the analyzed case studies, environmental innovation studies highlight the need for further (policy driven) rule adjustments (e.g., [46]). Specifically, it is conceivable that without the 'protected space' of a technological niche in Switzerland, the risk for firms to invest might be too high and development would never be possible. Therefore, we believe that further steps in generating protective spaces still will be necessary to nurture the promising niche developments.

Some of the issues that emerge from our findings relate to additional measures that may be necessary. That fleet managers are largely uninformed about hydrogen vehicles suggests that measures that educate and inform should be implemented. Field trials support the accumulation of experience and are an important source for information campaigns based on real world testing. Intermediary organizations may play an important role in coordinating the diffusion of knowledge. The predominance of bureaucratic decision-making structures in our survey highlights the importance of a purchasing practice that is common to many bureaucratic fleets: the solicitation of bids. Policy/decision-makers can support efforts to ensure that procurement specifications promote environmentally relevant product attributes.

The sensitivity analysis results indicate that a reduction in the purchase price, as a first step, has the strongest impact on relative demand. Taking steps in this direction could, for example, consist of regional and local public procurement programs and competitions, which are often very effective tools in the promotion of clean technologies and their market introduction by fostering learning by doing and economies of scale [47] [48]. In this regard, the concept of a 'hydrogen community' as an end user seems to be very interesting [49]. Such communities could be regions, cities, etc. and may evolve out of demonstration projects [50]. They present good end users because they think in longer terms, and their fleets are perceived as being in the public eye, as the current study has confirmed. In addition, the establishment of a hydrogen fuelling infrastructure is more easily achieved by such public bodies that are per se providing public goods. For example, it is conceivable that communities or municipalities could collaborate to operate a hydrogen service station. A certain oversizing of the infrastructure would allow other end users to start using hydrogen as well. Therefore, we recommend that an infrastructure that exploits synergies through the combination of different applications should be funded preferentially. Finally, again, this hydrogen should be generated renewably (e.g., from municipal waste) to gain wide acceptance.

2.6.2 Limitations and suggestions for future research

Finally, an important limitation needs to be considered: the current study has only examined fleet managers' decisions at the operational level. As previously mentioned, fleet managers usually play an important role in the decision process for a variety of reasons. However, Nesbitt and Sperling [13] note that initial alternative fuel vehicle purchasing decisions are frequently made at a higher level within the organization. Respondents in our survey confirmed that high-level decision-makers would generally be involved in such a decision process. Therefore, it can be assumed that well-selected expert interviews with high-level decision-makers would lead to a more precise picture about the preferences of additional decisive actors that are involved in the decision process. The interplay of the strategic and operational levels seems to be of particular relevance; specifically, the willingness of high-level decision-makers to test and implement new technologies and the fleet manager's knowledge about technological options and their abilities to trigger and influence strategic decisions. In particular, the favorable characteristics of a hydrogen-powered sweeper, such as its ability to reduce polluting emissions or enhance an organization's 'environmental image', are arguably highly valued by political authorities tasked with managing a public good.

While Haug and Neef [51] suggest the potential for first mover advantages and the creation of a lead market, both the entrepreneurial risk and the broader innovation system context demand further analysis. In addition to technological and market characteristics, contextual factors such as institutions (norms, laws, etc.) also influence the commercialization of hydrogen and fuel cell technology. Several theoretical branches of innovation system studies are available to analyze these frameworks. An example is the *Technological Innovation System (TIS)* approach (e.g., [10] [11]). It focuses on analyzing barriers to and drivers of the development and diffusion of new technologies. Further research should be conducted in this area.

2.7 Conclusions: building an understanding of market niche potential at an early stage

This paper attempts to contribute to an improved understanding of the market niches for hydrogen and fuel cell applications. The investigation was based on theoretical implications of the two dominant niche conceptions (the market niche and the technological niche) and has addressed issues such as willingness to pay and the existence of appropriate decision rules and user practices. Several analytical perspectives were applied to obtain a comprehensive assessment of the characteristics of a potential market niche. The following primary conclusions can be drawn from the present study:

The descriptive results of this investigation show that fleet decision-making structures and refueling practices make sweeper fleets a promising technological platform for the early implementation of hydrogen fuel cell vehicles (HFCVs). However, even professionals such as fleet managers have a low level of awareness regarding hydrogen vehicles. The clearest finding of this study is that a promising market niche for hydrogen driven street sweepers exists in both Switzerland and Germany. The choice experiment was a fruitful approach for the identification of such market niches. The description and inclusion of new attributes and their effects on purchasing decisions is an approach that offers advantages for prospective market studies of HFCVs. The third major finding refers to the importance of environmental attributes in the purchasing decision. The managers of the (generally) public fleets in this survey place a greater emphasis on polluting emissions than the (private) respondents in comparable previous studies. These early adopter fleets have preferences that differ from those of mainstream users and comprise the market niches identified in this study. Lastly, the sensitivity analysis results have shown that reductions in the purchase price (and to a lesser extent in running costs) can significantly improve the overall preference for hydrogen-powered sweepers. In addition, it is critical that the hydrogen be generated renewably to exploit the identified market niches.

Ultimately, the results in this study support the idea that the pathway to a hydrogen-supported economy involves market niches and technological niches in the creation of demand for hydrogen and fuel cell technology. This will increase production volume, creating supply chains and an infrastructure. A strategy that identifies early adopters that have a high willingness to pay for this new technology and comprise those market niches seem to be important for the early implementation of transportation applications and an appropriate refueling infrastructure.

NOTICE: this is the author's version of a work that was published in the *International Journal of Hydrogen Energy*.

Walter, S., S. Ulli-Beer, and A. Wokaun, *Assessing customer preferences for hydrogen-powered street sweepers: A choice experiment.* International Journal of Hydrogen Energy, 2012. **37**(16): p. 12003-12014.

3 Thesis Part II: A theoretically grounded transition roadmap: The Swiss innovation system around fuel cell and hydrogen transport technologies

3.1 Abstract

Fuel cell and hydrogen technologies are holding a promise for supporting a cleaner transport system. The build-up of a technological innovation system (TIS) around these technologies is necessary to make their large-scale diffusion possible. However, the coordination of the build-up process of a well-performing TIS is a challenge. With this study, we propose the combination of the TIS analysis and a roadmapping exercise to develop a theoretically grounded roadmap for the coordination of innovation system building. We apply the TIS framework to assess the current performance of the Swiss fuel cell and hydrogen innovation system. The results of the analysis show that well-functioning knowledge networks and a competitive knowledge base have been established in recent years. Nevertheless, only very few entrepreneurs have yet utilized those to explore the market. It is necessary to direct policy initiatives at the identified key areas in which progress is required, i.e., *Entrepreneurial activities*, *Market formation*, and *Resource mobilization*. We discuss how these insights can be used to develop a roadmap through which the build-up process of the innovation system can be coordinated and facilitated.

3.2 Introduction

Fuel cell and hydrogen technologies are widely considered to play an important role in future sustainable transport systems (see e.g. [1] [52] [53]). However, up to the present day, technological, economic and societal barriers have held back their large-scale diffusion. The development of a hydrogen based transport system is a long-term process that requires substantial shifts in institutions, actor networks, physical infrastructure, supply chains, user behavior, etc. [54]. Hence, it is regarded as a socio-technical transition [55].
Technology roadmaps are increasingly used by governments to inform and promote such socio-technological transitions [54]. In an emerging innovation system the alignment of actors' rules is usually poor, for example shared expectations are weak. To further develop the system, networks of actors must coordinate their actions. In this respect, technology roadmaps can play a central role in providing a coherent direction of search for the involved actors [54]. However, many of the roadmaps lack a theoretical background model [56]. In this regard, the technological innovation system (TIS) approach, and the broader literature on socio-technical transitions it stems from, can provide a theoretical basis as well as a conceptual framework for the analysis of key areas, in which progress is required.
The basic concept of a (technological) innovation system is that the innovation process is strongly influenced by a network of actors that are involved in the generation, diffusion and utilization of a new technology, and by a particular institutional infrastructure that legitimizes, regulates and standardizes the emerging technology [57] [58]. For hydrogen and fuel cell technologies such a system needs to be build-up in order to make large-scale diffusion possible. In recent years, researchers in the field of transition studies have made further progress in the identification of key activities, so-called system functions, that need to take place in innovation systems to perform well (see, e.g. [11]; [10]). In earlier empirical work, the TIS approach has been used effectively to deliver explanations for the success or failure of the build-up process of innovation systems (see e.g. [59] [60] [61] [62] [63]). Many of these TIS analyses aimed to inform policy making by identifying drivers and barriers to innovation.

To develop successful support strategies for an emerging technology, it is essential to understand the strengths and weaknesses of respective innovation processes. This is what a TIS analysis can provide [11]. Therefore, this study applies the TIS framework to evaluate the performance of the innovation system around fuel cell and hydrogen technologies in

Switzerland. The analysis provides the basis for the development of a roadmap through which the build-up process of the innovation system can be coordinated and facilitated. The audience of such a roadmap is the evolving actor network, innovators and policy makers in particular.

The paper is structured as follows: Section 2 outlines the relevant aspects of previous research and the analytical framework, followed by a description of the methodological approach used in this study in Section 3. Section 4 presents the results of the TIS analysis. In section 5, we discuss the areas in which progress is required and formulate short-term and medium-term support strategies based on the literature and the expert-based assessment. As a policy implication the transition roadmap is presented. Finally, the key conclusions of the study are presented in Section 6.

3.3 Literature review and conceptual framework

3.3.1 TIS framework

A socio-technical transition differs from a technological transition as it includes changes in user practices and institutional (e.g. regulatory and cultural) structures, in addition to the technological aspects [64]. Such transitions involve a broad range of actors and typically take considerable time to unfold (e.g., 50 years or more) [64].

For an emerging radical technology an innovation system has yet to be built up [61]. Recent literature points out that such a new technology will have to pass trough a so-called formative stage before market expansion is possible [65]. The technological innovation system (TIS) framework provides insights in the dynamics of this build-up process [11] [10]. A TIS in the formative stage is characterized by unstable rules. At this early stage of development, the actors involved in the emerging innovation system are less coordinated than those in mature systems. Hence, to develop, networks of actors must coordinate a series of key activities to build-up a well performing TIS. These key activities or system functions are *Entrepreneurial activities*, *Knowledge development*, *Knowledge diffusion*, *Guidance of the search*, *Market formation*, *Resource mobilization*, and *Creation of legitimacy* (see Table 3-1 for definitions). Each function covers a particular aspect of technological innovation. We consider the seven system functions as a suitable set of criteria for the performance assessment of the emerging innovation system around fuel cell and hydrogen technologies in Switzerland. The TIS framework is based on the assumption that policy interventions directed at stimulating a successful build-up process of the emerging innovation system should focus on improving system functions that are considered to be 'weak' [62].

Table 3-1: Functions of technological innovation systems. [11] [66]

Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative (pre-)commercial experiments, seeing and exploiting business opportunities.
Knowledge development	Technology R&D are prerequisites for innovations, creating variety in technological options and breakthrough technologies.
Knowledge diffusion	This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government and market.
Guidance of the search	This function represents the selection process that is necessary to facilitate a convergence in technology development, involving policy targets and expectations about technological options.
Market formation	This function comprehends formation of new (niche) market by creating temporary competitive advantage through favorable tax regimes, consumption quotas, or other public policy activities.
Resource mobilization	Financial and human resources are necessary inputs for all innovative activities, and can be enacted through, e.g. investments by venture capitalists or through governmental support.
Creation of legitimacy	The introduction of new technologies often lead to resistance from established actors, or society. Advocacy coalitions can counteract this inertia and lobby for compliance with legislation/institutions.

3.3.2 Technology roadmapping in public policy

In the last decade, an increasing number of roadmaps were used by governments as a tool in technology policy, particularly within the scope of energy policy and the transition to a low-carbon energy system [67]. Hence, policy-makers are already using roadmaps as an instrument for promoting and governing socio-technical transitions. This comes as no surprise as roadmaps have many strengths: A roadmap describes the current state of a technology, maps the key areas in which progress is required, facilitates the realization of networks and the coordination of coherent actions within an innovation system, simplifies the ongoing management of innovation, to name but a few [54]. However, most (hydrogen) roadmaps are not theoretically grounded [56]. McDowall points out that *"the practice and literature on roadmapping, and the literature on the governance of transitions, have developed largely separately."* [54] p. 532 Therefore, he seeks to position so-called 'transition roadmaps' within the broader theoretical literature on the governance of long-term socio-technical transitions. By reviewing existing hydrogen roadmaps, he identified considerable scope for improvement in roadmapping practice for transitions. That is why he developed a framework through which 'transition roadmaps' can be developed and evaluated. The framework suggests the following criteria that must be addressed if a roadmap were to provide a useful instrument of transition policy [54] (see Table 3-2 for an overview):

3.3.2.1 Credibility

A roadmap must be credible and persuasive. This has a number of practical implications:
First, it demands that the analysis on which the roadmap is constructed is based on reasonable methods. Second, credibility requires that especially in the context of a system innovation a wide range of expertise has to be involved. This implies some form of consultative or participatory process with a broad range of expert stakeholders. Third, roadmap credibility demands the participation of key stakeholders whose actions are critical in the future development of the innovation system. Finally, credibility requires that a roadmap also addresses broader economic, political and social aspects of a transition.

3.3.2.2 Desirability

Roadmap desirability requires that the transition meets social goals and directions established through democratic institutions. It also demands that a roadmap should be transparent concerning its aims, the process used, and who took part (including how participants were selected). In addition, the roadmapping process should be broadly inclusive and participatory.

3.3.2.3 Utility

The third criterion refers to utility: Does the roadmap and the corresponding roadmapping process facilitate the further successful build-up of the innovation system? To be useful, a roadmap should specify a coherent direction of search. In doing so, it provides guidance to the actors of the innovation system. In addition, where a roadmap meets the criteria credibility (see 3.3.2.1) and desirability (see 3.3.2.2) it helps foster legitimacy for the technology in question. Finally, roadmap utility requires that the roadmapping process must be appropriate for the stage of the innovation system [68]. Depending on the degree of maturity of the innovation system, either a 'framing roadmap' or a 'technically-detailed roadmap' may be appropriate. For innovation systems in a formative stage, a 'framing roadmap' seems to be useful, which clarifies the state of the emerging innovation system, highlights the areas of particular concern and sets out a broad framing description of the path forward. Once this broader framework is established, it makes sense to provide more specific direction in the form of technically-detailed targets.

3.3.2.4 Adaptability

Most of the hydrogen roadmaps reviewed by McDowall seem to be one-off exercises rather than instruments for the ongoing management process. *"This is particularly true for the 'framing' roadmaps, which tend to set out a strategic view rather than a detailed structure for monitoring progress."* [54] p. 539 However, the literature on roadmapping points out that roadmaps are more effective if they are developed as an ongoing process [69]. Therefore, McDowall stresses the importance of developing and maintaining roadmaps within an institutional context (e.g. a partnership between the government and innovation system actors) including periodic reviews and updates.

Table 3-2: Criteria for transition roadmap development and evaluation. [54]

Criteria	Key questions
Credibility	Is the roadmap based on sound analysis? Does the roadmap draw on the right breadth of expertise? Has the roadmap secured the participation and commitment of key actors in the innovation system? Does the roadmap adequately address the political, social and economic aspects of the transition?
Desirability	Does the transition meet social goals established through democratic institutions? Does the roadmap give a clear account of the justification for the proposed pathway, with transparency in aims, process and who took part? Is the roadmap process inclusive and participatory?
Utility	Does the roadmap effectively articulate a path forwards that can enable alignment around common goals? Is the roadmapping approach appropriate for the stage of innovation system maturity?
Adaptability	Does the roadmapping process involve periodic reviews, updates and learning? Is the roadmapping process embedded in a broader institutional structure that enables reflexivity and learning?

3.3.3 Hydrogen in transportation

Based on a comprehensive assessment Wietschel and Ball [53] claim that *"hydrogen offers the possibility of responding to all the major energy policy objectives in the transport sector at the same time."* This includes greenhouse gas emissions reduction, energy security and reduction of local air pollution and noise. However, the widespread introduction of hydrogen as a transportation fuel faces three main classes of barriers: the creation of a hydrogen distribution infrastructure, the higher cost of hydrogen vehicles, and the necessity of winning consumer acceptance [70]. To overcome these barriers support measures need to be put in place to create public awareness, stimulate consumer acceptance, and guarantee investment security for entrepreneurs [53]. Hence, the introduction of hydrogen as a vehicle fuel requires a joined-up approach between all relevant stakeholders [53]. In this respect, this study aims to make a contribution.

3.3.4 The structural dimensions of the Swiss innovation system

In Switzerland, research into fuel cell and hydrogen technologies has been ongoing since the 1970s. Research competencies primarily exist in the two federal institutes of technology (ETH in Zurich, EPF in Lausanne), associated research facilities (PSI, EMPA), and universities of applied sciences. In addition, about 30 private firms are active in the areas of development and pilot projects. The research and demonstration activities usually take place in national collaborative networks and are to a large extent integrated into international projects. The Swiss Federal Office of Energy (SFOE) coordinates these activities and provides additional funding. The main elements of the national fuel cell and hydrogen research programs are hydrogen production, hydrogen storage, and proton exchange membrane and solid oxide fuel cells. For further details about the structural dimensions of the Swiss system see [71].

3.3.5 Research questions

The following three questions form the focal point of the research:

1. What is the current state of the system regarding technology?
2. Where do weaknesses in the innovation system exist?
3. What types of support measures are promising?

Based on the case study also more general questions can be addressed:

4. How should the current state of a technological innovation system be assessed?
5. How should the development of transition roadmaps be grounded in theory?

3.4 Material and methods

In order to assess system performance we conducted semi-structured interviews with the main actors involved in the development and use of fuel cell and hydrogen (transport) technologies in Switzerland. Thereby, we used indicative questions, which provide insight in the fulfillment of the system functions (see Table 3-4). These indicative questions are based on the TIS literature and earlier empirical research but were refined for this study (see [62] [66] [72]). The approach proved to be an efficient method for the performance assessment of an emerging innovation system. Therefore, we regard the use of the indicative questions as suitable for this investigation.

In total, 18 interviews have been conducted with representatives from the supply-side, the demand-side, the knowledge structure, the government structure and the intermediary structure of the innovation system (see Table 3-3). These five system components make up any TIS [73]. Hence, a broad range of expertise was involved including voices from consumer perspectives. With an extensive literature review (e.g. annual reports, policy papers and roadmaps) and cross-referencing the key actors in the system, whose actions are critical in the future development of the innovation system, were identified. External justification guaranteed the adequacy of the selection of interviewees.

The experts have been asked to score the fulfillment of each indicative question on a 5 point Likert scale, where 1 = very unsatisfactory, 2 = unsatisfactory, 3 = satisfactory, 4 = good and 5 = outstanding. The interviewees had also to comment on each rating they made. In this way, the experts were able to give their view on what should be done to improve the fulfillment of the corresponding system function. In addition, the interviewees have been asked to appraise the current state of the technology. Four different descriptions of state were provided to choose from (see Appendix II-A for the questionnaire).

Table 3-3: Full list of experts interviewed.

Santis	Marco	CEKAtec AG
Gianmario	Picciotti	MES SA
Hannesen	Uwe	Belenos Clean Power Holding Ltd
Herren	Georges	Carbagas AG
Holdener	Fridolin	WEKA AG
Anthamatten	Beat	Bucher Schörling AG
Seraidou	Nikoletta	PostAuto Schweiz AG
Tschan	Erwin	Industrielle Werke Basel
La Malfa	Michelangelo	elvetino AG
Züttel	Andreas	EMPA & HYDROPOLE
Buechi	Felix	Paul Scherrer Institut
Bach	Christian	EMPA
Höckel	Michael	Berner Fachhochschule Technik und Informatik
Oberholzer	Stefan	Bundesamt für Energie
Keller	Dominik	Amt für Umwelt und Energie Basel-Stadt
Dietrich	Phillip	Paul Scherrer Institut
Spirig	Michael	European Fuel Cell Forum & Fomenta AG
Hart	David	E4tech

3.5 Results

3.5.1 Evaluation of innovation system performance

This section describes the current fulfillment of the seven system functions as assessed by the experts. A full list of the scores and the standard deviations is shown in Table 3-4.

Table 3-4: Indicative questions that reflect the extent to which each function in the innovation system is fulfilled.
Scores (SC), and standard deviations (SD) (see also [11]; [10]; [62]; [72]).

System function	SC	SD
Entrepreneurial activities		
The number of entrepreneurial projects?	1.93	0.46
The variety of applications of all these projects?	2.87	0.92
The number of new actors who decide to run such projects (on an annual basis)?	2.09	1.04
The coverage of the entire value chain by Swiss actors?	2.40	0.74
Knowledge development		
The number of research and development projects?	2.64	0.84
The realization of prototypes?	3.14	0.77
Profound knowledge of (potential) customers, business opportunities and markets?	3.09	0.83
The quality of the knowledge base as compared to international standards?	4.38	0.65
Knowledge diffusion		
The amount of official gatherings (e.g. conferences, workshops) organized?	3.47	1.13
The amount of national and international (Swiss participation) networks?	3.75	0.87
The breadth of these networks concerning involved actors (supply-side, demand-side, knowledge structure, government structure, intermediary structure)?	3.46	0.97
The effect of the knowledge exchange in these networks (w.r.t. technology development)?	3.42	1.16
Guidance of the search		
The effect of visions and expectations on the technology development (e.g. hydrogen based mobility, 2000-Watt-Society)?	2.82	0.98
The number of actors who have grate expectations for the development potential of the technology?	2.64	1.15
The articulation of interests by pilot customers (e.g. financial participation in projects)?	2.88	1.32
The effect of specific targets (e.g. technology roadmaps), legal regulations and standards set by the government or industry?	2.31	0.95
Market formation		
Financial incentives for market formation (e.g. by creating (temporary) competitive advantage through favorable tax regime)?	1.94	0.66
Investments in the creation of protected spaces (e.g. proto-market, flagship project)?	1.89	0.68
Investments in promotional measures (e.g. information events and brochures)?	2.88	0.99
Articulation of demand from customers (e.g. purchase intentions, order books)?	2.18	0.87
Resource mobilization		
Availability of skilled personnel and managers?	2.81	0.98
Availability of financial capital (e.g. venture capital, government funds, EU funds, diversifying firms)?	2.44	0.96
Awareness of funding opportunities?	3.57	1.09
Availability of complementary assets (e.g. network infrastructure, complementary products, consulting services)?	2.24	0.75
Creation of legitimacy		
Public interest in the technology and media coverage of the technology?	3.19	0.98
Resistance to the diffusion of the technology?	3.35	1.06
Perceived pressure (legitimacy), to make investments in the technology?	2.75	0.93
Activity of lobby groups/political networks active in the innovation system?	2.33	0.72

3.5.1.1 Entrepreneurial activities

The experts rated their satisfaction of the current fulfillment of this function with a score of 2.3, which indicates that on average it is rated as unsatisfactory (see Figure 3-1 for an overview of the system functions' overall score).
The interviewees agreed almost unanimously that the number of entrepreneurial projects is very unsatisfactory. It is argued that far more could be done, since there is a broad range of

possible applications, and the realization of further projects would enhance the visibility of the technology. The involvement of fleets and actors from the semi-public sector is proposed. It is also noted that care should be taken that the projects are sufficiently interconnected on an international level.
The variety of applications of all these entrepreneurial projects is rated as just about satisfying. However, the opinions are divided. Some experts argue that there is variety in research but not in the implementation of applications. Hence, they point out that variety still could be improved. It is argued that there is probably too much focus on transport applications and that a hydrogen storage project is missing. More activities in the low-power segment (portable applications) are also proposed. Others, however, are satisfied with the variety, or even argue that there is too much variety and too little focus.
On average, the experts are unsatisfied with the number of new actors, who decide to run such projects. Different opinions were expressed. Some argue that there are very, very few. Others consider the number of new actors as satisfying. However, there is wide agreement among the experts that it is desirable that more actors become active. Especially utility companies (public transport, energy producers) and technology firms are mentioned.
Finally, the coverage of the value chain by Swiss actors is also rated as unsatisfactory. Some interviewees believe that there is a potential for further actors in different fields: electrolysis and engineering components, to name just a few. Actors that implement the technology in applications are needed. It is also argued that there are insufficient activities at the customer end of the value chain. Others are satisfied with the current situation.

3.5.1.2 Knowledge development

The interviewees rated their satisfaction of this function with a score of 3.3, which indicates that on average their opinion is satisfactory. However, a closer look reveals that in the context of knowledge development some weak spots exist.
The experts rated the number of research and development (R&D) projects as unsatisfactory. Some interviewees argue that the number is too small in order to generate and diffuse knowledge on a broad basis. Hence, there are too few knowledge carriers. Moreover, it is argued that R&D efforts should be more interdisciplinary. It was noted that more attention should be paid to integrate institutes that are active in related fields (e.g. compressor technology). Finally, it is argued that in general more applied research is needed. Others regard the current situation as satisfactory or good.
On average, the interviewees are satisfied with the realization of prototypes. However, several experts argue that there is a huge gap between a prototype and a market-ready product, and Switzerland struggles to overcome this gap. It is argued that effective institutions or instruments that would bridge this gap are missing. In addition, some experts point out that it is easier to get funding for basic research than for applied research and product development.
The knowledge about (potential) customers, business opportunities and markets is regarded as satisfying. Experts point to the established collaboration between academia, industry, and end-users. However, there are some voices, which say that coherent analysis or understanding of potential markets is missing.
The experts rated the quality of the knowledge base as compared to international standards with a score of 4.4, which is the highest in this analysis. The interviewees almost unanimously agreed that the fundamental knowledge base is good or even very good and that this has to be maintained. Some interviewees argue that more field experience is needed.

3.5.1.3 Knowledge diffusion

According to the experts, knowledge diffusion is the best-developed function of the innovation system with a score of 3.5.
On average, the experts are satisfied with the amount of official gatherings such as conferences and workshops in Switzerland. The most well known conference is the European Fuel Cell Forum (EFCF) in Lucerne, which is also internationally recognized. However, some experts also believe that there are still too few (specific) conferences and workshops.

The amount of national and international networks is also regarded as satisfying. For example, the participation of Swiss actors in the ‘Fuel Cells and Hydrogen Joint Technology Initiative’ is relatively strong. It is argued that international collaboration is very important for a small country like Switzerland.
Overall, the experts are also satisfied with the breadth of these networks concerning the involved actors. However, some criticize the low involvement of the government. Others would like to see the participation of knowledge carriers from other disciplines. In addition, it is argued that the demand side should become more closely involved in these networks.
Finally, also the effect of the knowledge exchange in these networks is rated as satisfying. But there are also some experts that are not satisfied with the current situation. In terms of national collaboration, some interviewees would like to see more acting in concert, more end-user involvement, and that the knowledge exchange is more institutionalized.

3.5.1.4 Guidance of the search

The interviewees rated their satisfaction of this system function with an overall score of 2.7.
On average, the interviewees are unsatisfied with the effect of visions and expectations on technology development. However, concerning this matter, some experts advise caution. They point out that visions may raise expectations that can‘t be fulfilled, and this may harm the technology. These experts regard the current situation as adequate. Others argue that visions do have a positive effect as they motivate people and provide guidance of search. They believe that such visions are not well known or even non-existing and too technology unspecific.
The experts rated the number of actors who have great expectations concerning the development potential of the technology also as unsatisfactory. The scores on this topic diverge from 1 to 5 causing a relatively high standard deviation of 1.15. Here again, it is argued that over-promising expectations or even a hype should be avoided. Others would like to see more actors with high expectations. They are convinced that there is a potential, especially in the public sector.
The articulation of interest by pilot customers is regarded on average as not satisfactory. However, the relatively high standard deviation of 1.3 specifies that there is no agreement on this score. Some experts argue that there are pilot customers who have some money, and they are prepared to invest once a suitable pilot/demonstration project exists. Others argue that it is more difficult: potential pilot customers are interested but unwilling to invest a lot of money, because they can‘t put the technology into context. As compared to other fields participation is rather small. It is argued that in particular the public sector could play a more active role.
The expert’s opinion is that the effect of specific targets, legal regulations and standards set by the government or industry is unsatisfactory. Several experts argue that specific targets (e.g. roadmaps) don’t really exist and more could be done here. But it is noted that the effect of such targets is strongly correlated with the money that is available. Some of the interviewees note that more clear legislation is still needed to reduce uncertainty. Others regard today’s legal regulations as barriers to the (mass) application of the technology. For example, it is argued that an expansion of the hydrogen infrastructure under prevailing conditions is not thinkable. And yet others would like to see regulations that may support the technology (e.g. ban of diesel generators in buildings). Hence, it is argued by some experts that changes have to be made, whereas others got along with the current regulations. Finally, it was noted that standards are internationally determined and then adopted.

3.5.1.5 Market formation

The current fulfillment of this function is scored 2.2. According to the experts, this is the least-developed function of the innovation system.
There is wide agreement among experts that financial incentives for market formation are very unsatisfactory. Some interviewees point to other countries where much more incentives are provided. Others believe that without any financial incentives a successful market launch is not possible. It is also noted that financial incentives could accelerate the development of

the technology. Nevertheless, some experts point out that products, which could be supported do not exist yet.

Investments in the creation of protected spaces, such as flagship projects and proto-markets, are also regarded as very unsatisfactory. The experts agreed almost unanimously on this point and the score is the lowest in this analysis. The interviewees point out that much needs to be done in this context. It was noted that in respect of flagship projects, Switzerland lags behind other countries. It is recognized that such projects are important for the involvement of (potential) users, and for broadening their experience base with the technology.

On average, the experts rated the investments in promotional measures as not satisfactory. However, the opinions are divided. It is argued by some interviewees that today's promotional measures are adequate. They note that selective promotions indeed make sense, whereas general measures that fuel expectations should be avoided. Other experts argue that more should be done, because the technology still is little known and differences between linguistic regions exist.

The interviewees are unsatisfied with the articulation of demand from customers. Several reasons are mentioned: the high costs of the products, the missing hydrogen distribution network, and low awareness of the technology. It is also noted that some potential customers adopted a wait-and-see attitude. Some of the interviewees point out that the demand side is the most important thing that is lacking. Other experts, however, argue that demand articulation corresponds with the current state of the technology.

3.5.1.6 Resource mobilization

The interviewees rate their satisfaction on the availability of resources with an overall score of 2.5 (the value doesn't include the score concerning the awareness of funding opportunities).

On average, the availability of skilled personnel and managers is regarded as unsatisfactory. However, the opinions are divided. Some experts argue that there is enough trained and educated personnel that can work in the field. Others see a shortage of PhD students, decision-makers, user knowledge, etc. Some experts are worried about the availability of human capital in the future, if the market were growing.

The expert's opinion is that the current availability of financial capital is not satisfactory. Here, too, the situation is judged ambivalent. It is argued by some experts that especially government funding is fairly limited. Some experts point out that more financial resources are needed for applied research. It is argued that the current availability of such resources is not sufficient to realize more than just a prototype. Venture capital is regarded as not available or hard to get. Others, however, are satisfied with the availability of financial capital. It is noted that some projects could be financed easily. Finally, there is wide agreement that EU funds are sufficient.

In contrast to the availability of financial resources, it is argued that the awareness of funding opportunities is satisfying. However, it becomes apparent that researchers and intermediaries are well informed about funding opportunities. But for some actors of the demand and supply side this is less clear.

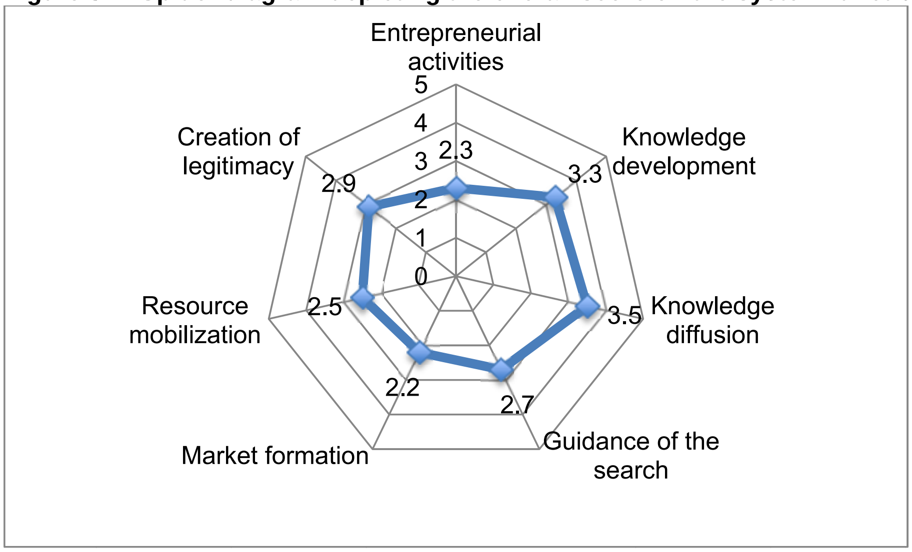
On average, the experts are not satisfied with the availability of complementary assets such as network infrastructure or consulting services. It is noted that the current hydrogen infrastructure is too small. Others argue that that the hydrogen infrastructure is adequate for the current situation. At this stage, infrastructure is still part of the projects. It would be counterproductive to have an existing infrastructure but nobody that is using it. It is argued that infrastructure is not a big restriction at the moment and there are other barriers, which come first.

3.5.1.7 Creation of legitimacy

Finally, the experts rated their satisfaction of the current fulfillment of this function with a score of 2.9, which indicates that the interviewees regard the creation of legitimacy as just about satisfying.

On average, public interest in the technology and media coverage of the technology is regarded as satisfying. However, the scores on this topic diverge from 2 to 5. There is wide agreement among experts that public interest in the technology is large. But concerning media coverage the opinions are divided. Some experts would like to see more media coverage and such of better quality. For example, reports that place the technology in a broader context. Others are satisfied with the coverage.
The resistance to the diffusion of the technology is regarded as moderate. Some experts see an unconscious resistance: Fear of hydrogen. It is argued that uneasy feelings cannot be reduced through information but through direct experience. Resistance related to decentralized energy supply is also mentioned. Other interviewees don't see any resistance or argue that it became smaller (for example, in the context of the power to gas discussion).
The expert's opinion is that the perceived pressure (legitimacy) to make investments in the technology is not satisfactory. It is argued that the technology is little noticed and therefore not taken into consideration. However, some interviewees consider the current legitimacy or pressure as adequate: for example, thanks to the CO_2 legislation in the mobility sector.
On average, the interviewees are unsatisfied with the activities of lobby groups or political networks in the innovation system. However, the opinions are divided. Some are satisfied with the current situation. It was noted that there are mainly individual persons, which perform such activities. There are doubts as to whether the build-up of a broad lobby group to campaign specifically for the technology is the right thing. Other experts see a need for action. They argue that a lobby group or a political network should be established so that, for example, the topic is discussed more comprehensively or politicians could be involved. It is argued that in the field of research, there are lobbying activities for resources, whereas an industry lobby group that could exert pressure at a political level does not exist. It is noted that, at the moment, the actor basis of the industry is still too small to build up such a political network.

Figure 3-1: Spider diagram depicting the overall score on the system functions.



3.5.2 Current state of technology

In Switzerland, fuel cell and hydrogen technology has been the subject of research for several decades. A clear majority of the experts considers the following general description of the current state of technology as most appropriate: *The technology is predominantly reliable, i.e. failure-free operation and adequate durability, and beyond the stage of demonstration but is usually costly.* However, it has to be mentioned that some experts see differences in the state of development of mobile, portable, and stationary technology.

3.6 Formulation of support strategy

3.6.1 Disparities in the level of development

In this section, we perform a target/actual comparison in which we compare the current state of the innovation system with the requirements stated in the literature. Four ideal-typical stages have been identified that characterize the formative stage of a TIS: *Science and Technology Push Stage*, *Entrepreneurial Stage*, *System Building Stage*, and *Market Stage* (see [61, 74, 75]). Thereby, one stage builds upon another. Based on this previous empirical research and the experts' appraisal we propose further steps that need to be taken in order to advance the build-up process of the innovation system. For this analysis we make a distinction between so-called enactors and selectors [76] [75]: Enactors (typically entrepreneurs, technology developers, research institutes) are actors that are directly involved in the development of an emerging technology and fundamentally dependent on its success. Selectors (typically policy makers, technology end-users, large firms) are actors that are engaged at a distance, for example because their interest in the new technology is not fixed, since they have the possibility to choose between multiple technologies.

3.6.2 Current state of the innovation system

According to the literature, the prime barrier of the first stage (the so-called *Science and Technology Push Stage*) to get to the next stage is poor technological performance and severe uncertainties in terms of the emerging technology's future development [74]. As the results of this study show, this barrier has been overcome and a knowledge base has been established. In addition, supply-side structures for mobile, portable and stationary applications have been build-up. Another topic at this stage is variety creation concerning applications [74]. The experts regard this as just about satisfactory. However, it is also argued that there is still need for action.

Based on the results, we argue that the TIS has developed to such an extent that it is currently at an *Entrepreneurial Stage*. This stage evolved because a group of actors (research institutes, technology developers and technology adopters) saw opportunities to develop commercial applications for the emerging fuel cell and hydrogen technology. Their activities resulted in the setting up of pilot and demonstration projects in cooperation with pilot customers. For example, Swiss research institutions have, in collaboration with industrial partners, developed a prototype fuel cell street sweeper that is currently undergoing operational testing on the street of several cities, which are involved in the project [77]. Another example is a hydrogen fuel cell system for mobile sales units (minibars) that a company realized together with universities and the catering company of the Swiss railway. Hence, first linkages between supply-side and demand-side actors have been established. In this respect, another important barrier associated with the *Science and Technology Push Stage* has been overcome: the current activities are not stuck in the realization of feasibility studies and laboratory trials [74], but go beyond and involve pilot and demonstration projects. Furthermore, intermediary and network structures (e.g. in the form of national collaborative networks, the fuel cell and hydrogen research programs of the SFOE, and the knowledge platform 'HYDROPOLE') have been established. According to the TIS-literature, the current state of technology, as judged by the experts, can already be assigned to the next ideal-typical stage of development.

3.6.3 Short-term support strategies

At this point of the innovation system's build-up process the following strategic issues become relevant (besides removing technological bottlenecks).

3.6.3.1 Drawing in selector support

The main driver of the *Entrepreneurial Stage* is the availability of a relatively mature technology and the existence of an actor group willing to support this emerging technology [75]. According to the literature, this group should be expanded to sustain the developments of the *Entrepreneurial Stage*, which is typically done, by further increasing the number of practically and commercially oriented projects [74]. In this respect, the results of this study show that there is a strong need for action. The experts argue that there are too little entrepreneurial projects and new actors joining the innovation system. To develop and set up such entrepreneurial projects resources are needed. Therefore, enactors need to draw in selector support [74] [78]. The lobby for project-specific resources may be directed at the national government. The justification may be that the technology contributes to a more sustainable energy system [74]. Other legitimation strategies could be based on job creation opportunities. In addition, we recommend that the Commission for Technology and Innovation (CTI), which is responsible for market-oriented R&D funding, should take into account the specific circumstances in the energy sector. Today, the CTI wants to see the realization of a product within two years in order to provide funding. The experts argue that it is very challenging to fulfill this requirement, for example because of the long development times that are usually necessary in the energy sector. Another possibility is to mobilize support from local governments and utility companies (e.g. public transport, energy producers). The results show that the experts see potential here. Lobbying activities may also be directed at private firms. However, due to uncertain returns on investments, this is often not effective at this stage without some form of support from government actors [74].

Enactors and selectors should further support a variety of demonstration projects involving multiple technologies and applications (i.e., a portfolio strategy) [74]. If the actors succeed in demonstrating that the fuel cell and hydrogen technology offers a promising solution to a problem, then successful entrepreneurial projects will draw in even more actors. To sustain developments at the *Entrepreneurial Stage*, literature also emphasizes the importance of the shaping of a policy environment that settles practical issues related to basic infrastructure, licensing procedures, safety standards, etc. [74]. The results of this study indicate that there is need for action in this area. An alignment of the policy environment to the emerging fuel cell and hydrogen technology would further reduce uncertainty in the field.

3.6.3.2 Coordination and collaboration

A technological innovation system that is only just emerging usually suffers from a lack of coordination and direction: It is argued that at an early stage of development, this is usually not a problem but as the fields expands it becomes critical to establish networks [74]. As mentioned above, national and international collaborative networks have been established and the SFOE sets out to coordinate national and international activities, as well as cooperation between research and industry. In this respect, important first steps have been taken. However, the performance assessment of the innovation system shows that open issues still exist. Intermediaries such as the SFOE or 'HYDROPOLE' could play a more active role in managing cooperation. For example, they could support the integration of research institutes that are active in related fields, coordinate the identification of missing actors in the value chain, and organize their participation in the innovation system. In general, they could support the process of drawing in selector support more actively. In this context, the public private partnership 'Hydrogen Sweden' is an interesting example [79]. This intermediary organization initiates demonstration projects, disseminates information and strengthen the collaboration between actors from various fields (including regions and municipalities to support the innovation process at a regional and local scale).

The SFOE could also play a major role as an important platform for giving direction to the field. With the growing number of demonstration projects best practices could be made available. The experts argued that in general more applied research is needed. Some interviewees suggest the formulation of a more coherent strategy or a roadmap. Such issues should receive more attention from the SFOE. Collaboration between the involved actors is another topic. Some experts argue that, for example, hydrogen producers already compete with each other in this very early stage, instead of forming coalitions and support technology diffusion. Others would like to see a more institutionalized knowledge exchange.

3.6.3.3 Market niches and protected spaces

According to the literature, the lack of a market environment or the lack of any market perspective in the near future is a severe barrier that hinders developments at the *Entrepreneurial Stage* [74]. Market niches and protected spaces (so-called technological niches) such as flagship projects and proto-markets may play an important role to overcome those. This is in line with the assessment of experts who see a strong need for action in this area, and stress the importance of further end-user involvement (demand-side). Hence, further testing of promising applications and application contexts is an important next step. Niche markets and protected spaces enable learning processes not only about technology but also about the articulation of user preferences and required regulatory adjustments [15]. In addition, they provide the opportunity to gain field experience, and to prove that the technology actually works. The identification of promising market niches and the development of well-functioning actor networks within these niches should be the main objective. This needs to be accompanied by a pragmatic infrastructure build-up. Hence, selectors (national or local governments) should support the establishment of protected spaces, and enactors should identify market niches as much as possible. A choice experiment is a possible instrument for the early identification of such market niches [77].

3.6.4 Medium-term support strategies

Given that the (structural) barriers of the *Entrepreneurial Stage* are overcome, the TIS may then enter a *System Building Stage*. Developments at this stage are in particular driven by a concerted involvement of enactors and selectors (increasingly incumbent firms) [74].

3.6.4.1 Determine market formation policies/strategies

The experience and information gathered at the previous stage help to determine which promising niches should be supported. A comprehensive assessment of the niche based on added value (individual vs. social added values [80]) and selection environment considerations is important to decide what kind of strategy is appropriate. Based on the appraisal, tailored support strategies can then be determined such as product-specific financial incentives, government procurement programs, or regulations that may support the technology (e.g. ban of conventional technology). There is wide agreement that hydrogen and fuel cells are unlikely to emerge in markets without decisive policy support and incentives [53].

3.6.4.2 Advocacy coalition

Whether the dynamics at the *System Building Stage* develop further is (often) the outcome of a political negotiation process [74]. Therefore, enactors and supportive selectors should form political coalitions that lobby for the adjustment or creation of institutions that support TIS development, especially in the form of market creation policies [74]. There is wide agreement among experts that the financial incentives for market formation are very unsatisfactory. Enactors and selectors should also develop a strategy for the management of expectations that navigates a careful balance between formulating a plausible future, and overpromising expectations (e.g. 'hype'), which can hinder the further development of the innovation system [81].

3.6.4.3 National expansion

To sustain the dynamics of the *System Building Stage*, enactors and selectors should get together and induce even more selectors to enter the TIS [75]. *"This implies the expansion of existing networks into the incumbent system. This expansion is necessary because the further development of the emerging technology asks for up-scaling, which means that large investments are required."* [74] p. 237 Hence, the TIS needs to develop from a local fragmented system to a national integrated system. Enactors and supportive selectors may support this process by further increasing the visibility [74] of the technology (including e.g. promotion measures). At this stage, a systemic infrastructure build-up also becomes necessary. Another topic is the establishment of measures to ensure the availability of skilled personnel.

3.7 Policy implications: transition roadmap

Based on these insights, we developed a roadmap, which aims to facilitate the coordination of the further build-up of the innovation system (see Figure 3-2). It is conceptualized as a ‘framing roadmap’ that is appropriate for the formative stage of the innovation system. Thus, the roadmap projects a possible pathway of development, but without any technical details. It consists of two parts: first, the previously discussed short-term support strategies (i.e., activities that support the shift from the *Entrepreneurial Stage* to the *System Building Stage*) and second, the medium-term support strategies (i.e., activities that support the shift from the *System Building Stage* to the *Market Stage*).

Figure 3-2: The theoretically grounded transition roadmap.

Science & technology push stage	Entrepreneurial stage	System building stage	Market stage

Strategic issues	Activities	Responsibility for implementation
Drawing in selector support	▪ Further increase the number of practically and commercially oriented projects (international collaborations) ▪ Lobby for resources from national government, local governments (cantons) and utility companies (e.g. public transport, energy producers) ▪ Adjust conditions for market-oriented R&D funding ▪ Shape a policy environment that settles practical issues related to basic infrastructure, licensing procedures, safety standards, etc.	▪ Governments & technology developers ▪ Technology developers & adopters ▪ Government & CTI ▪ Especially governments
Coordination and collaboration	▪ Coordinate the integration of research institutes that are active in related fields ▪ Coordinate the identification and integration of missing actors in the value chain ▪ Support the process of drawing in further actors (e.g. technology adopters) ▪ Disseminate information (e.g. make available of best practices) ▪ Provide coherent direction to the field (e.g. roadmap)	▪ SFOE & HYDROPOLE ▪ SFOE & HYDROPOLE ▪ SFOE & HYDROPOLE ▪ SFOE & HYDROPOLE ▪ SFOE
Market niches and protected spaces	▪ Identify promising market niches ▪ Develop well-functioning actor networks (supply-chains) within the niches ▪ Support the establishment of protected spaces (flagship projects & proto-markets) ▪ Pragmatic infrastructure build-up	▪ Technology developers & adopters ▪ Technology developers & adopters ▪ Especially governments ▪ Governments & technology developers

Science & technology push stage	Entrepreneurial stage	System building stage	Market stage

Strategic issues	Activities	Responsibility for implementation
Determine market formation policies	▪ Assessment of the identified niches to determine tailored support strategies	▪ SFOE & technology developers
Advocacy coalitions	▪ Build-up of advocacy coalitions (political networks) that may facilitate lobbying activities ▪ Lobby for specific support policies that provide stimulation for a market ▪ Develop a strategy for the management of expectations	▪ Technology developers & adopters ▪ Technology developers & adopters ▪ Technology developers & SFOE
National expansion	▪ Induce further actors to enter the TIS ▪ Increase the visibility of the technologies on a national level ▪ Develop measures to ensure the availability of skilled personnel ▪ Systemic infrastructure build-up	▪ SFOE & HYDROPOLE ▪ Technology developers & adopters ▪ Governments tech. developers ▪ Governments & technology developers

3.8 Conclusions

The aim of this study is to evaluate the performance of the innovation system around fuel cell and hydrogen technologies and to determine the current state of the technology in Switzerland. A sound understanding of the specific strengths and weaknesses of the system is an important condition for the elaboration of coherent support strategies to enhance the build-up of a well-performing innovation system. The assessment is based on the concept of the technological innovation system (TIS). The results show that well-functioning knowledge networks and a high-quality knowledge base have been established in recent years. However, only very few entrepreneurs have yet utilized those to explore the market. In order to enhance the performance of the innovation system and to move it into the next development stage, strategy and policy initiatives should to be focused on the identified 'weak' system functions, i.e. especially *Entrepreneurial activities*, *Market formation*, and *Resource mobilization*. However, the study also indicates that a coherent and concerted strategy is still missing.

We propose to use the TIS approach as the basis for the development of a transition roadmap, which supports the coordination of the further build-up of the innovation system. Such a theoretically grounded roadmapping approach allows the elaboration of a tailored intervention strategy that considers the development stages of a TIS and specifically addresses 'weak' functions. The roadmap also contributes to the fulfillment of the two system functions *Guidance of the search* and *Creation of legitimacy*.

Linking the TIS approach with roadmapping is an important contribution to the roadmapping literature, because it grounds roadmapping in theorizing about socio-technical transition. This helps to overcome the limitation of traditional (hydrogen) roadmaps that are in most cases not theoretically grounded [55]. The insights from literature can help to articulate promising pathways for long-term system building. The approach applied in this study proved to be successful and offers pragmatic yet coherent support strategies. It fulfills important criteria that are indicative for the utility of transitions roadmaps: First, roadmap credibility is enhanced by applying a reasonable assessment approach that includes expert knowledge. Second, desirability of the addressed system building goals is substantiated by its discussed potential to contribution to the build up of “cleaner” socio-technical systems, in our case the transport system. Third, utility is increased since the logic of the intervention strategy is based on theorizing and is made transparent. Fourth, adaptability can be ensured, if the roadmap is adopted by an institutionalized actor network that considers the instrument itself useful.

Finally, a number of caveats need to be noted regarding the present study. First, this project used a theoretical sampling by including experts from the supply-side, the demand-side, the knowledge structure, the government structure, and the intermediary structure of the innovation system. However, the sample size is relatively small. In addition, the current study was limited by not including broader voices from citizen perspectives (e.g. NGOs, interested or concerned citizens). As such, critical voices were not explicitly included. This would imply that the used questionnaire is adjusted accordingly. Second, roadmap adaptability remains an important issue. As previously mentioned, a roadmap should be an instrument for the ongoing management process [54]: Further research might explore how to establish an institutional context (e.g. a partnership between government and industry groups) in which a roadmapping process can be effectively maintained (learning and re-evaluation) since it should be avoided that the roadmap is just a one-off document.

4 Thesis Part III: What policy strategy is needed beyond the initial protective space? A niche comparison of electric two-wheelers in Switzerland

4.1 Abstract

This study performs a comparative niche analysis based on the technological innovation system (TIS) framework. The investigation describes both, the successful and stagnating up-scaling process of two niche innovations (e-bicycles and e-scooters) encompassed by the same TIS. The findings confirm previous theorizing concerning typical stages and processes in the build-up of a TIS. It contributes additional evidence that the TIS framework runs the risk to miss influential processes of niche up-scaling, because it does not pay much attention to the system's environment. We empirically show that beyond the initial protective space, which shielded the niche innovations from selection pressures, the *interplay* between product characteristics, niche characteristics and the selection environment (regime) is critical for the product-specific diffusion pathway of an emerging technology. At this stage, *product-specific maneuvering* becomes critical in terms of fitting and supporting empowerment of niche innovations. The proposed multi-criteria appraisal can be used to support practitioners' strategy choice concerning fit-and-conform or stretch-and-transform empowerment.

4.2 Introduction

In sustainability transitions research, niches have been given a prominent role as a source for radical innovation. They provide a temporary 'protective space' for the development of such innovations [3]. Schot and Geels [15] p. 618 describe these protected spaces as *"proto-markets created by a coalition of actors to test and develop new technologies with the aim to develop larger market niches."* Initial protection is regarded as crucial because the performance of radical innovations may not be competitive within the regime specific selection environment [4]. Therefore, such protective space is essential to shield the innovation against the prevailing selection pressures [4]. However, despite their importance, theorizing about niches and niche protection is still at an early phase of development [64]. Further work needs to be done to achieve a better understanding of niches concerning their development and their wider influence [82]. So far little attention has been paid to niche up-scaling, i.e. what happens when niche innovations move beyond the initial protected space and interact with the wider environment [64] [82]. In this respect, the present study aims to make a contribution to the current literature with a historical niche comparison. Hendry and Harborne [83] p. 778 point out that *"understanding innovation depends at root on good qualitative descriptions of processes, whether in the firm, industry or other kind of system."* The technological innovation systems (TIS) approach is a suitable conceptual framework for the analysis of such processes. The basic idea of the framework is that a technological innovation system needs to be built-up to make large-scale diffusion of a technology possible (see e.g. [11]; [84]). A TIS analysis provides insights in this build-up process. This paper will focus on electric two-wheelers. Since a TIS usually encompasses several niches or application contexts [14], we consider the two niche innovations electric scooters and electric bicycles (e-bikes) as being part of the very same TIS.

In Switzerland, electric scooters and electric bicycles have both been available since the 1990s. However, the launch and distribution of e-scooters on the market are not satisfactory, whereas e-bikes have been a story of success, in recent years. This different diffusion can be observed in many other countries, too. E-scooters are an interesting option, because they can significantly contribute to a reduction of greenhouse gas emissions, air pollution, energy consumption, noise emissions and traffic space. Moreover, they can substitute a considerable amount of car mileage.

The objectives of this research are to investigate the historical development of the two niche innovations (e-bikes and e-scooters) encompassed by the same technological innovation system, and to analyze how different boundary conditions influence the choice or direction of further strategic maneuvering at the stage when niche innovations move beyond the initial protective space.

Hendry and Harborne [83] p. 788 stress that *"accurate qualitative descriptions of long-term innovation processes can enrich many areas of theory."* By providing such a qualitative description this study contributes to a better understanding of niche up-scaling, and it derives important policy and management implications based on the findings. Methodically, we performed an innovative comparative niche analysis, i.e. a comparison of two niche innovations encompassed by the same TIS. The advantage of such a niche comparison is that it provides insights into which boundary conditions and factors make a difference between success and failure in up-scaling and diffusing niche innovations. In addition, we developed a more precise coding scheme for the analysis of the processes.

The paper is organized as follows: previous theorizing informing our research is summarized in Section 2, followed by a description of the methodological approach used in this study in Section 3. Section 4 and 5 present the results of the TIS analysis and the multi-criteria appraisal, respectively. In section 6, we discuss the findings and formulate policy implications. Finally, the key conclusions of the study are presented in Section 7.

4.3 Literature review and conceptual framework

Niches have been conceptualized as protected spaces in which radical innovations mature and in which actors of a TIS typically assemble and coordinate actions [3] [14]. Hence, a TIS usually encompasses several niches [14]. Smith and Raven propose a framework to better understand and systematically analyze the dynamics of protection in sustainability transitions [4]. They differentiate three types of processes: shielding, nurturing and empowering. Shielding refers to processes that keep away selection pressures from mainstream selection environments. Nurturing refers to processes that support the development of an innovation within shielded spaces. Empowering, finally, involves processes that make niche innovations competitive within (relatively) unaltered selection environments (fit-and-conform) or processes that restructure mainstream selection environments in a manner favorable to the niche (stretch-and-transform).

Concerning **shielding** Smith and Raven [4] p. 1027 make a distinction between passive and active niche spaces: They define passive protective spaces as *“generic spaces that pre-exist deliberate mobilisation by advocates of specific innovations, but who exploit the shielding opportunities they provide.”* In contrast, active protective spaces are *“those spaces that are the result of deliberate and strategic creation by advocates of specific path-breaking innovations to shield regime selection pressures.”* Shielding also plays a decisive role in a recently developed taxonomy by Schot and Geels [15]. Based on a literature review they identified four different types of niches that are present in technical change: the technological niche, the breakthrough niche, the regime internal market niche and the regime external market niche. The difference between these niches results from differentiating between two dimensions: (1) whether niches are internal to the prevailing socio-technical regime or whether they are isolated from it; (2) whether rules for design and use of a specific technology are stable or unstable within the niche.
According to the typology, a technological niche is a niche that is shielded form the socio-technical regime(s) and exhibits no stability of rules. It forms a protected space that has been deliberately created by actors and is supported by specific institutions [3]. Learning processes that take place within the niche are not only about technology but also about the articulation of user preferences and required regulatory adjustments [15]. Eventually, these learning processes may result in the articulation of a clear demand. In this manner, a technological niche may develop into a market niche [15]. Schot and Geels point out that *“a technological niche is not a mechanism that can produce a new technological species by itself”* [15] p. 618. Nevertheless, they argue that it is an important mechanism since the three other niche patterns mentioned above might be initiated through the existence of such technological niches. Compared with technological niches, market niches feature stable rules, i.e. it is clear (or clearer) for producers and users what kind of product is needed. The typology differentiates two types of market niches: regime internal market niches that operate within the socio-technical regime and feature low protection/isolation from it and regime external market niches that are shielded from the regime. Schot and Geels argue that the shielding can stem from cognitive, social and/or spatial distance. Cognitive distance means that regime actors do not regard the market niche as important (e.g. because it is perceived as too small). Social distance originates from products that serve specific social groups. Spatial isolation arises from application in a geographical area where specific conditions apply. This is in line with the previously mentioned concept of passive protective spaces.

Raven provides an insightful matrix, which may be used for differentiating the development potential of regime internal market niches [85]. The axes of the matrix set regime stability in relation to niche stability (stability of rules). In a situation with stable niche rules, as is the case with a regime internal market niche, Raven argues that high stability in the regime prevents a fast expansion of that niche. This is because regime actors are not or only limitedly interested in the niche innovation, and niche actors generally will be in direct and severe competition with the regime actors for market share. While in a situation with low regime stability the proactive participation of regime actors enables a rapid expansion of that niche. Hence, according to this matrix, niche development interrelates with the dynamics of prevailing regimes.

Whenever shields are established or mobilized this provides a space for **nurturing** an innovation. Two conceptual frameworks have been developed for the study of processes that support the development of an innovation: the strategic niche management (SNM) approach and the technological innovation systems (TIS) approach. The key nurturing processes in the strategic niche management literature are the processes of articulating promising expectations, social learning and actor network building [3] [7]. The TIS approach looks at nurturing of innovations from a systemic perspective. A TIS is the network of actors, institutions (e.g. norms, regulations) and technologies that influence the generation, diffusion and utilization of a new technology [57] [58]. These elements are interrelated and form the structure of the system. Such a system needs to be build-up to enable large-scale diffusion of a technology. A proper analysis of this build-up process should consider what actually happens to the structure of the TIS. Hence, it is also reasonable to analyze the key activities, so called system functions, that develop within a TIS. These system functions are considered as classes of activities that contribute to the development, diffusion and use of technological innovations, namely *Entrepreneurial activities*, *Knowledge development*, *Knowledge diffusion*, *Guidance of the search*, *Market formation*, *Resource mobilization*, and *Creation of legitimacy* (see Table 4-1 for definitions). They need to run smoothly in order that the system performs well [84].

However, some researchers in the field criticize that the TIS framework *"is inward oriented and does not pay much attention to the system's environment."* [14] p. 610 The success of innovations is mainly explained by the performance of the equivalent innovation system. This way, however, the framework runs the risk to miss influential processes. Smith and Raven [4], for example, point out that the approach arguably underplays the shielding of emerging innovation systems against mainstream selection pressures. They argue that a *"TIS analysis will find it difficult to explain mass-market diffusion of path-breaking innovations, because that would inevitably involve many interactions between an emerging system and its environment."* [4] p. 1029

An extended theoretical focus and further empirical work is needed to address these interactions in more depth. This study applies the TIS framework as it provides a well-elaborated and detailed concept for understanding nurturing of niches. However, niche comparison allows comparing divergent development with further theorizing. With our niche comparison approach we seek to contribute to these open issues. Aim of the research is the reconstruction of niche development in the light of the above-mentioned conceptual frameworks. The following four questions form the focal point of the research:

1. Which stages of build-up processes can be identified within the TIS?

2. What happens when the two niche innovations move beyond the initial protective space (and challenge the existing regimes)?

3. How should the successful/retarded diffusion of niche innovations be explained?

4. How do different boundary conditions influence the choice/direction of further strategic maneuvering at the stage when niche innovations move beyond the initial protective space?

Table 4-1: Functions of technological innovation systems. [11] [66]

Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers perform the innovative (pre-)commercial experiments, seeing and exploiting business opportunities.
Knowledge development	Technology R&D are prerequisites for innovations, creating variety in technological options and breakthrough technologies.
Knowledge diffusion	This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government and market.
Guidance of the search	This function represents the selection process that is necessary to facilitate a convergence in technology development, involving policy targets and expectations about technological options.
Market formation	This function comprehends formation of new (niche) market by creating temporary competitive advantage through favorable tax regimes, consumption quotas, or other public policy activities.
Resource mobilization	Financial and human resources are necessary inputs for all innovative activities, and can be enacted through, e.g. investments by venture capitalists or through governmental support.
Creation of legitimacy	The introduction of new technologies often lead to resistance from established actors, or society. Advocacy coalitions can counteract this inertia and lobby for compliance with legislation/institutions.

4.4 Material and methods

In order to answer the research questions we adopt a two-step approach: In a first step, we perform a TIS analysis to identify the structures that are in place and to clarify the current state of the emerging innovation system or the niches it encompasses (Research Questions 1-2). In a second step, a multi-criteria appraisal is carried out: First, to explicate the divergent development of the two niche innovations and second, to identify adequate strategies that are needed beyond the initial protective space (Research Questions 3-4).

A method for the identification and evaluation of structures, system functions and their historical development is the event history analysis as proposed by Hekkert et al. [11]. This method, developed by Van de Ven and Poole [86] [87], provides a conceptual and practical guideline for the systematic collection and analysis of (mostly) qualitative historical data. The approach conceptualizes development/innovation processes as sequences of events ([87, 88]). The following actions were taken:

- **Data collection:** Over the past 30 years, the Swiss Federal Office of Energy (SFOE) has been cataloguing research, development and demonstration projects in the energy sector in Switzerland, focusing on those partly or fully financed by public institutions. This publicly accessible data sources (consisting of the complete list of research projects, the project database and the annual reviews by the program heads at the SFOE) ensured high quality and full availability of data throughout the period examined and across the two niches. In addition, data was gathered from annual reports, periodicals, newspapers, and further databases of the public sector (see Appendices III-A and III-B).
- **Classification scheme:** Based on previous research [61] [74] [89] a classification scheme for events was constructed and refined (see Table 4-2 and Appendix III-C). This scheme was then used as a guide for the identification of events in each text.
- **Database construction:** A database was developed containing the events in chronological order (see also [89]). In total, about 350 events were collected (see Appendix III-D).
- **Mapping events to system functions:** Each event was allocated to an event type that corresponds to a system function. In Table 4-2, an overview is provided of event types that correspond to each system function.
- **Intercoder reliability:** To improve reliability another researcher verified the allocation of events to event types. Intercoder reliability in content analysis is the extent to which two or more independent coders agree on the coding of the content with the application of the same coding scheme.
- **Graphical representation:** As a starting point for the analysis, the events were outlined in graphs per year and per system function. This gives a visible presentation of the functional pattern over time (see Appendix III-E).
- **Narrative:** To obtain an understanding of how innovation processes took place a narrative was constructed. This narrative provided the basis for all further analysis.

Considering the previously mentioned limitations of the TIS approach, we perform a multi-criteria appraisal as a supplement to the TIS analysis. The appraisal includes product, niche and regime characteristics. To analyze niche characteristics we apply Schot and Geels' classification scheme for different types of niches. The scheme allows for a characterization of the identified niches. Concerning regime characteristics we refer to the matrix developed by Raven [85]. Finally, Lancester [29] stresses the importance of product characteristics: What consumers often want is not so much a specific product but a particular bundle of characteristics. In this respect, added value considerations might be insightful. Steinberger-Wilckens [80] points out that historic comparisons of the market entry of different technologies reveal that cost and economic competitiveness alone did not determine market diffusion. The added value offered to consumers is critically important and compensates, in some cases, for otherwise completely uneconomic performance [80]. He differentiates added values on an individually accessible and observable level and added values on a global level (e.g. environmental benefits) [80].

Table 4-2: Event types that correspond to each system function.
(Own table based on [61] [74] [89])

System functions	Event types
Entrepreneurial activities	- Projects with a commercial aim started - Projects with a commercial aim stopped - Demonstrations started - Demonstrations stopped - Portfolio expansions - Organizations entering the market
Knowledge development	- Prospective studies - Laboratory trials - Prototypes developed - Pilots
Knowledge diffusion	- Reports - Conferences - Exhibitions - Workshops - Alliances between actors - Joint ventures - Setting up of branch organizations - Setting up of platforms
Guidance of the search	- Expectations positive - Expectations negative - Promises positive - Promises negative - Research outcomes positive - Research outcomes negative - Policy targets - Standards - Roadmaps - Awards - Label
Market formation	- Financial support for the technology's use - Regulations supporting niche markets - Regulations hampering niche markets - Generic tax exemptions - Lack of tax exemptions - 'Obligatory use'
Resource mobilization	- Financial capital - Refusal of financial capital - Infrastructure developments
Creation of legitimacy	- Lobbies / Advice pro - Lobbies / Advice contra

4.5 Results of the TIS analysis

We summarize our detailed event history analysis in a chronological narrative. For the e-bike case, we identified four stages of niche formation (science and technology push, entrepreneurial, system building, and market stage ([75] [61] [74])) and only three for the e-scooter case (science and technology push, entrepreneurial, system building stage). The narrative is presented in terms of the most important events contributing to the system functions. For each stage we reflect on the structural impacts on the TIS, and the kind of functions that are developing.

4.5.1 A network of pioneers and knowledge base (1985-1990)

By the mid 1980, alternative modes of transport had gained widespread attention in Switzerland due to the growing environmental movement and the worsening air pollution problems in urban areas [7]. An open network of pioneers [7] consisting of amateurs and small start-up firms emerges in the second half of the 1980s focusing on the development of lightweight electric vehicles (LEVs). Hoogma et al. [7] p. 61 point out that *"one of the most important events in the formation of the social network around LEVs was the 'Tour de Sol'."* This rally for solar powered prototype vehicles and commercially available LEVs is carried out annually from 1985 to 1992. The vehicles mostly have three or four wheels, but from the beginning a few bicycles with solar trailers and first prototypes of electric motorcycles participate. In the course of the rally, a program of crash tests and technical regulations for the vehicles are set up. A yearly national conference (including detailed proceedings) facilitates the diffusion of tacit and codified knowledge among the involved actors.

4.5.1.1 Impact on TIS

A main impact is the formation and professionalization of a small but growing actor network in which a shared vision is constructed and knowledge is exchanged. In the context of the 'Tour de Sol' the build-up of more formal institutions (e.g. search routines and quality standards) leads to the establishment of a knowledge base on electric vehicles (build-up of knowledge structures and supply-side). Considerable practical experimentation during this episode leads to a large application diversity (variety creation): prototypes of many different electric two-, three- and four-wheelers are developed and tested. Hoogma et al. [7] classify the developments in Switzerland as a bottom-up approach initiated by concerned citizens. The pioneers put LEVs on the agenda, compared to a top-down approach, in which policy-makers try to push industry to develop and introduce electric vehicles (as it happened for example in California). At this point of time, government actors are not part of the TIS yet. Garud and Karnøe [90] highlight "bricolage" processes that predominated the development of the Danish wind turbine innovation system in the 1970s. It is interesting, that the observed early developments in Switzerland have several elements in common with this "bricolage-style" of innovation identified in Denmark. The actors take a path of scaling up simplistic prototypes in small manageable steps of practical experimentation to more sophisticated and better functioning designs. The modes of learning involved are learning by doing, learning by using and learning by interacting. At the end of the episode, the bottom-up developments in Switzerland create expectations about the marketability of electric two-wheelers among a variety of actors.

This episode is dominated by *Knowledge development*, *Knowledge diffusion*, *Guidance of the search* and *Resource mobilization*. All the other system functions are either absent or relatively weak.

4.5.2 Entrepreneurial activities and a proto-market (1991-2000)

By the early 1990s, the environmental movement lost some of its earlier momentum [7]. Nevertheless, these years are characterized by first entrepreneurial activities. Several pioneers want to start projects with a commercial aim and therefore lobby the government for subsidies to improve their electric two-wheeler prototypes. Governmental resources are granted in the form of project-specific subsidies. In the same period of time, the idea of a governmental promotion program for LEVs is discussed for the first time at a workshop initiated by the network of pioneers and organized by the Swiss Federal Office of Energy (SFOE). Initially, the idea is not given high-priority. A while later, however, a participant reintroduces the idea at the annual LEV conference and the SFOE becomes interested. The SFOE then provides financial resources to carry out a feasibility study for a large-scale experiment. Shortly afterwards, the study reveals the practicality of such a large-scale test. The start of the test in Mendrisio in June 1995 is a key event of this episode. In addition, a number of partner communities also participate in the test. One objective of the large-scale test is to support the diffusion of LEVs by a series of promotional measures, most notable a large subsidy on the purchase price (electric two-wheelers received up to 50% subsidy). For further details about the large-scale test see [7]. As early as 1994, first e-bike regulations in terms of approval for road use (e.g. necessity of type tests, requirements to have a driver's license and to wear a helmet) are adopted. One year later, the regulations for slow e-bikes (with a maximum speed of 20 km/h) are eased, the start-up company 'BKTech' (the developer of the 'FLYER' e-bike) is founded and the manufacture of first small batch series of Swiss e-bikes are realized. This time also marks the beginning of several research collaborations between start-up companies and universities. Finally, interim reports form the large-scale test and sale numbers reveal a promise of a market for electric two-wheelers.

4.5.2.1 Impact on TIS

An important outcome of the pioneers' lobbying activities is that government agencies, users, etc. are drawn into the TIS for the first time. This leads to a build-up of an intermediary structure and demand-side structures. Formal institutions are adjusted such as specific regulations for e-bikes. The collaboration of producers and universities reflects a shift from "learning by doing" and "learning by using" to a more R&D-led "learning by search" mode. This shift from experience-based learning to science-based learning [83] plays an important role in discovering, enhancing and validating commercially viable products. A key impact is the installation of the government large-scale experiment that provides a temporary protective space for the niche innovations. This technological niche enables important learning processes and early user-producer linkages that result in the articulation of a clear demand for electric two-wheelers. Hence, at the end of the episode, the technological niche selection process allows for the identification of a market niche for e-bikes and e-scooters respectively, which also implies an uncertainty reduction.

This episode is also characterized by a strong fulfillment of *Knowledge development*, *Knowledge diffusion*, *Guidance of the search* and *Resource mobilization*. What sets it apart from the previous episode is the important role of *Entrepreneurial activities* and *Creation of legitimacy*. The presence of a temporary proto-market implies first *Market formation*.

4.5.3 E-bikes: system building (2001-2007) and boom (2008-2010)

The years 2001 to 2003 turn out to be pivotal for the developments around e-bikes in Switzerland. It is a time of many ups and downs. In order to get access to the European market (where speed restrictions for e-bikes are in place), Swiss developers lobby in Europe for the approval of their fast e-bikes. In Switzerland, the setting up of 'NewRide', a platform organization promoting the diffusion of electric two-wheelers, is a key event. 'NewRide' actively mobilizes municipalities, cities and firms that help to diffuse the knowledge about electric two-wheelers among potential end-users. In addition, some of the municipalities and cities provide subsidy on the e-bikes' purchase price.

The Swiss e-bike producers 'BKTech' and 'Velocity' face severe financial difficulties, because of underperforming sales and a lack of funding. By the end of 2001, 'BKTech' goes bankrupt, which causes considerable uncertainty in the TIS. However, the management team organizes a rescue through a buyout, and takes over the business activities of 'BKTech'. The successor company 'Biketec' has been established in December 2001. At the very same time, 'IntelliBike', a demonstration project of a university of applied sciences, is able to attract considerable funding and shows the promising technological potential of e-bikes.

One of the first activities of the newly established company 'Biketec' is to carry out a comprehensive survey among 1.500 existing clients. The results reveal important customer needs and various technological limitations of the e-bike: the vehicle is too heavy, has a too short cruising range, and the handling is complicated. Based on these insights, decisive product improvements are implemented. The use of a lithium ion accumulator (for the first time in Europe) helps to improve the cruising range, as well as to reduce the vehicle weight, and a very-low step-through bicycle frame enables an easy access. In addition, a new business model and marketing strategy is developed. The segment of older people becomes center of attention, and collaborations with popular tourist destinations are established to provide test drives.

In 2003, an adapted policy environment leads to an easing of restrictions. Type tests and the moped insurance are no longer necessary for e-bikes. In the same year, the fast Swiss e-bikes get approval in Europe, which enables first export activities. Furthermore, the platform organization 'NewRide' succeeds in drawing in a large number of new municipalities, builds up a network of e-bike dealers, and e-bikes are brought to mind among potential customers again and again through a new touring exhibition. The market leader 'Biketec' sells 1.000 units of its new Flyer-C-model in 2003 alone. E-Bikes producers in general make large improvements regarding reliability, performance of the battery, and vehicle weight.

As from 2005, e-bike sales in Switzerland rise sharply, doubling each year (see Figure 4-1). About two years later, an increasing number of incumbent bicycle companies place their own e-bikes on the market (see Figure 4-2), and wholesalers and discount stores offer in their shops for the first time electric bicycles. In 2010, the e-bike industry takes on the financing of the 'NewRide' e-bikes activities. Sales are booming and the company 'Biketec' exports more than 50% of its production.

4.5.3.1 Impact on niche (2001-2007)

An important impact of the system-building activities of the platform 'NewRide' is that actors, especially municipalities and vehicle dealers, are drawn into the TIS in large numbers. That way, new networks are formed and the niche develops from a rather local to a national one. Technology becomes more mature (e.g. due to the new lithium ion battery), meaning that it is now ready for widespread application, and business model testing leads to first successful business case (demand-pull innovation). The easing of institutional restrictions in Switzerland and Europe facilitates market niche formation. At the end of the episode, an accelerating market diffusion process has started. Hence, the technological niche developed into a promising market niche.

In this episode, the set of dominant system functions is similar to those of the previous episode but it includes a more dominant role of *Market formation*.

4.5.3.2 Impact on niche (2008-2010)

In the proceeding two years, a take-off occurs with booming e-bike sales. There is a powerful promise of a mass market. This becomes apparent in bigger numbers of incumbent bicycle companies that enter the market. Firms do not need to lobby for resources anymore. Instead, the e-bike industry takes on the financing of 'NewRide' e-bikes activities.

All system functions are fulfilled except for the *Creation of legitimacy*. *Market formation* is no longer an issue of politics as a market environment has been created. Now, *Market formation* is taken up as part of regular business activities.

Figure 4-1: Annual sales of e-bikes in Switzerland.[6]

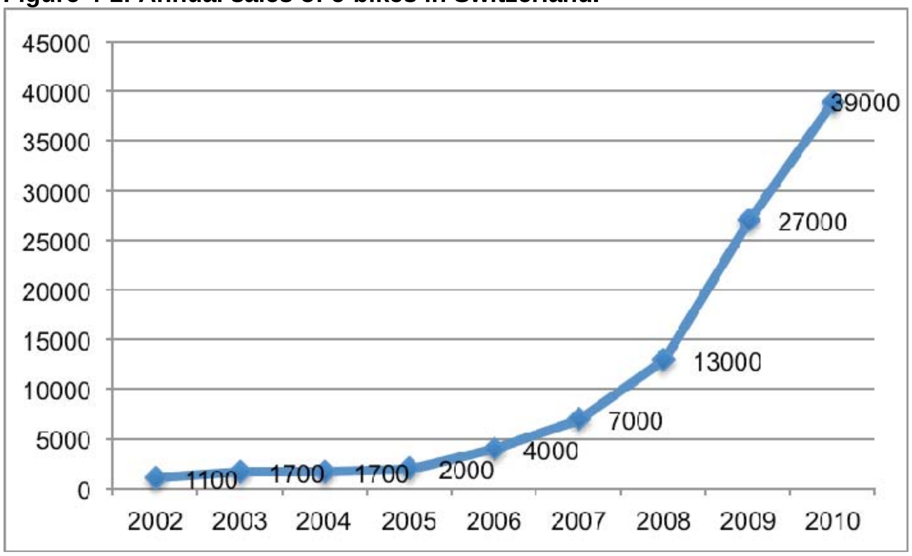
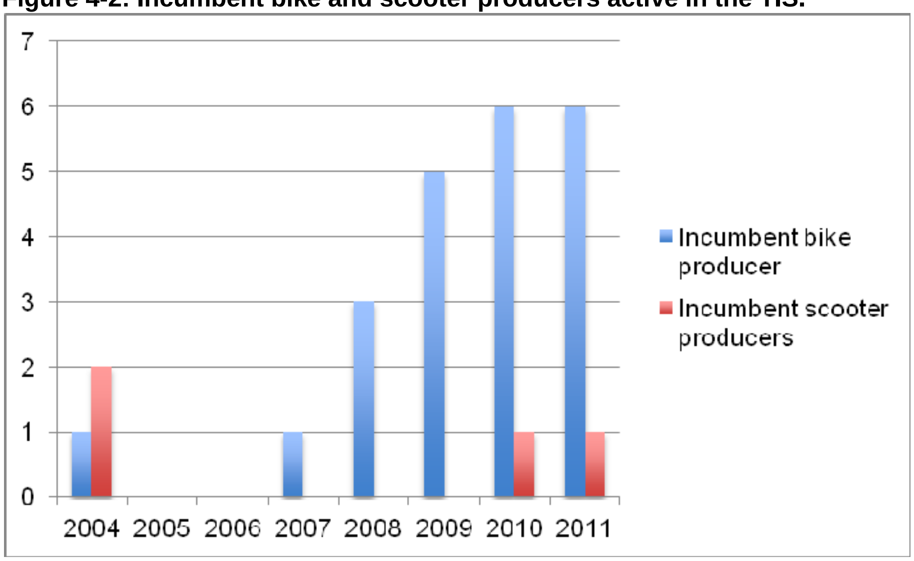


Figure 4-2: Incumbent bike and scooter producers active in the TIS.[6]



[6] Own figure based on NewRide's annual reports (2001-2011).

E-scooters: system building and stagnation (2001-2010)

A different and more restrained development can be observed in the case of the e-scooter niche. Notwithstanding, some initial conditions for the diffusion of e-scooters and e-bikes after the end of the large-scale test in 2001 are comparable: The test reveals a promise of a market for both types of electric two-wheelers and the newly established platform 'NewRide' supports their launch on the market with promotional measures. In 2002, a first small batch series of e-scooters of a Swiss start-up company is produced, and an e-scooter rental service is established in a municipality. However, both projects are not as successful as hoped. In 2005, the final report of a feasibility study performed by a university of applied sciences reveals that it is technically possible to build an e-scooter, which features a performance that will satisfy potential customers. The biggest hurdles that remain to be overcome are of economic nature: Battery prices and business models are key factors. Technological progress (e.g. the availability of lithium ion accumulators) leads to the development of further prototypes. In 2006, a parliamentary motion regarding the implementation of noise and an exhaust-gas tests as well as an eco-label for motorcycles and scooters is submitted. Four years later, a parliamentary request is submitted claiming exhaust and noise emissions limit values for scooters and motorcycles. However, the requested measures have not been implemented, yet. In 2008, a life cycle assessment study of the Swiss Federal Laboratories of Materials Science and Technology shows that e-scooters represent a clear-cut improvement in terms of the environment in comparison with petrol scooters. A key event in 2006 is the decision of the Swiss Post, Switzerland's largest logistics company, to start a small pilot with letter delivery e-scooters. Positive experiences lead two years later to the purchase of 250 e-scooters. In 2010, the Swiss Post has the biggest e-scooter fleet in Europe (1000 vehicles). It decides that its entire fleet of around 7.500 scooters will be 100 percent electric by 2016, at the latest. However, except for the sales to the Swiss Post, the diffusion of e-scooters is rather stagnating (see Figure 4-3). The unsatisfactory sales figures lead, in 2009, to the launch of a government-funded e-scooter research project, which should support their market diffusion process, contribute towards their technical development and analyze their effects on the environment.

4.5.3.3 Impact on niche

As mentioned previously, 'NewRide' succeeds in drawing in actors (especially municipalities and vehicle dealers) and forming networks. At the end of the episode, the majority of the biggest cities are participating in the e-scooter research project. However, the number of vehicle dealers offering electric scooters remains relatively small (see Figure 4-4) and incumbent scooter firms are de facto absent (see Figure 4-2). The high fluctuation rate of small e-scooter suppliers leads to uncertainty and poses a risk for vehicle dealers (e.g. due to spare parts which are no longer available) (see Figure 4-5). Nevertheless, technology becomes more mature which leads the Swiss Post to convert its entire scooter fleet. The articulation of a clear demand from this leading customer has an important influence on the direction of search, whereas the business model testing of other e-scooter companies is less successful up to now. Sales figures are modest and the e-scooter supply is unsatisfactory for a long time. However, in this episode, the technological niche developed into a market niche. At least, the Swiss Post example indicates this. Finally, in spite of the availability of more environmental friendly e-scooters and several parliamentary motions the pressure on petrol scooters is not increased.

In this episode, the set of dominant system functions is the same as in the e-bike case from 2001 to 2007.

Figure 4-3: Annual sales of e-scooters in Switzerland.[7]

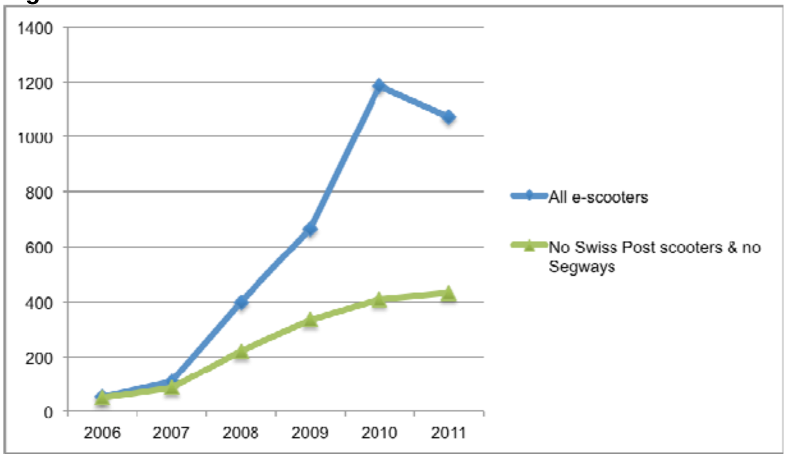


Figure 4-4: E-bike and e-scooter dealers in Switzerland.[7]

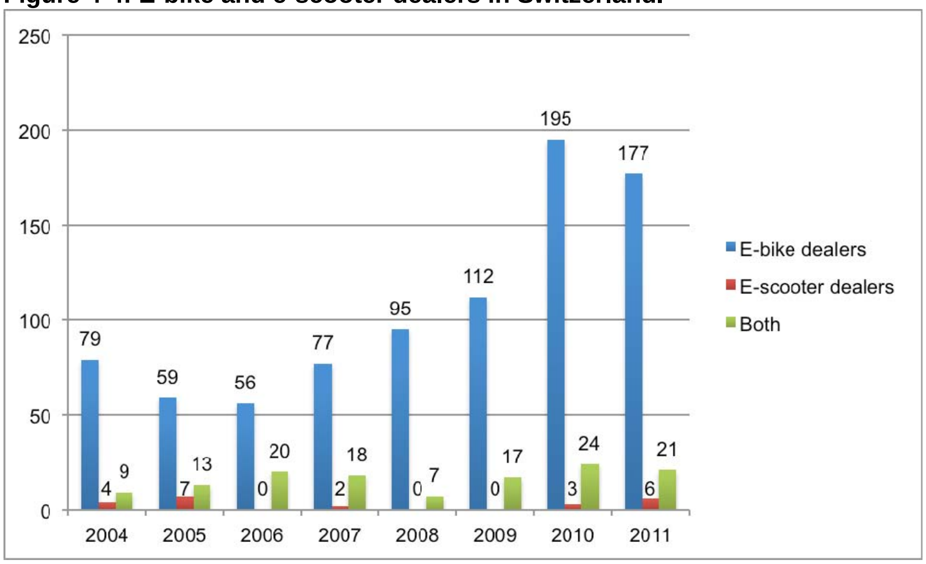
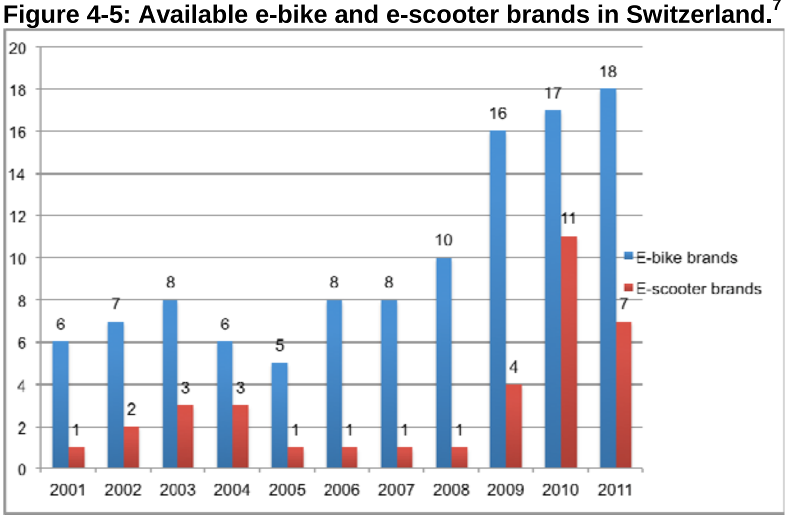


Figure 4-5: Available e-bike and e-scooter brands in Switzerland.[7]



[7] Own figure based on NewRide's annual reports (2001-2011).

4.6 Multi-criteria appraisal

This section describes the results of the multi-criteria appraisal, which was applied as a supplement to the TIS analysis.

4.6.1 Product characteristics

Thanks to the electric motor, e-bicycles offer additional product characteristics differentiating them from conventional bicycles. These observable ***individual* added values** enable faster and more comfortable riding, carrying loads more easily, riding uphill or against head wind with ease, etc. Therefore, it can be argued that an e-bike is a new product or new form of mobility (motorized cycling) that is substantially different from the original lineage. The high sale numbers make clear that buyers are willing to pay extra for a high performance in some dimension. By contrast, today's e-scooters feature varied product characteristics, thereby representing a substitute rather than a new product. They don't offer any direct benefits for the individual buyer but reduce society's costs in terms of, for example, noise, local emissions and CO_2 emissions. These are ***social* added values**. The abstract nature of the added values might be a prime reason for the slow diffusion of e-scooters in Switzerland. Hence, it can be observed that the two products feature different types of added values.

4.6.2 Niche characteristics

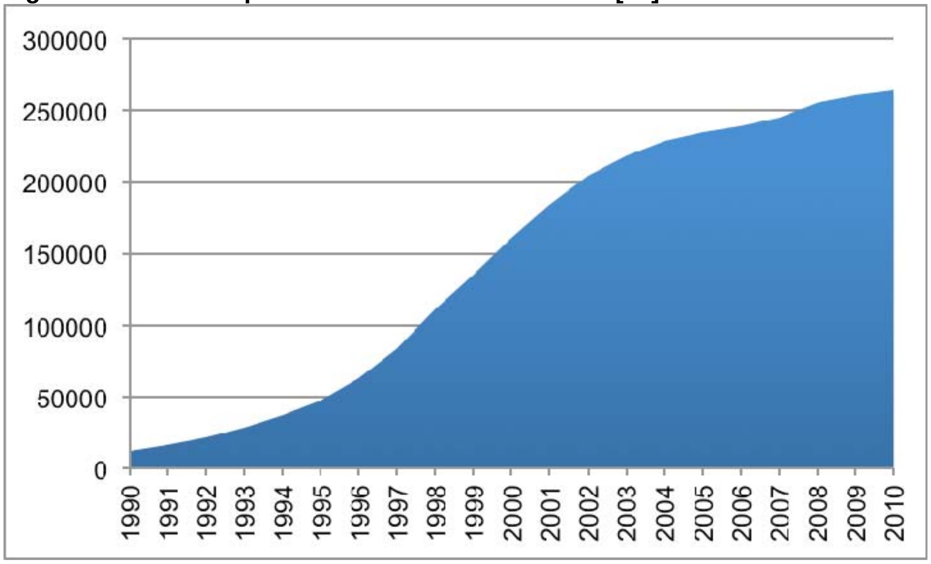
As mentioned in the literature review, isolation/protection from the mainstream markets can stem from specific requirements operating in a market niche. By offering additional added values, power assisted bicycles serve specific social groups (i.e., *social distance*). For example, they enable elderly or handicapped people to continue cycling or to generally improve their mobility. In this regard, the company 'Biketec' points out that without the existence and effective targeting of this social group, it would not have been possible to start up and develop the new market. Another important strategic decision of the company was the early application of e-bicycles in a geographical area where specific conditions apply (i.e., *spatial isolation*). The move to work hand in hand with the tourist business made it possible to provide a vast number of test drives to potential customers in hilly tourism regions, i.e. experience the benefits of power assisted cycling. These very different selection pressures operating in this market niche, and *cognitive distance* provided isolation from mainstream markets. A very different situation can be observed in the e-scooter case. Currently, this is a market niche that features low protection/isolation from the prevailing socio-technical regime. Hence, e-scooters have to compete head-on with petrol scooters for market share. However, the Swiss Post example shows that fringe markets exist that the old technology does not serve well (added values for the Swiss Post).

Regarding the stability of rules operating within the niches, it can be observed that they are no longer highly unstable as they were in the technological niche. Stable rules for the design and use evolved. For example, based on the survey results, the FLYER C-Series was very much tailored to the needs of the end-users (low step-through frame, top-quality components, etc.) and equipped with the latest technology. Tourism fairs rather than two-wheeler exhibitions moved in the focus of promotion. In the e-scooter case, the TIS analysis shows that such knowledge is missing to a large extent. The e-scooters that are produced for the Swiss Post are an exception here. Based on these insights, it can therefore be argued that in the e-bicycle case the technological niche developed into a *regime external market niche* whereas in the e-scooter case it developed into a *regime internal market niche*.

4.6.3 Regime characteristics

Currently, the permitted exhaust emissions of motorcycles and scooters in Switzerland (and Europe) are substantially higher in comparison to passenger cars. As previously mentioned, parliamentary motions have not changed the situation. Legislation seems to be in favor of the incumbent petrol-driven technology. This becomes apparent in the booming petrol scooter sales of the last 15 years (see Figure 4-6). Hence, there is much to suggest that there is high stability in the regime.

Figure 4-6: Stock of petrol scooters in Switzerland. [66]



4.7 Discussion

The results show that the technological niche provided an initial protective space that shielded both niche innovations from mainstream selection pressures. However, as the government large-scale experiment came to an end in 2001, conditions for further niche development started to vary widely.

In the e-bike case, the niche then developed in a regime external market niche. This means that the niche moved from an active protective space to a passive protective space. But the protective function as such was maintained. The successful business model of the company 'Biketec' was an incentive for many incumbent bicycle companies, vehicle dealers and retailers to enter the niche. Legitimacy was mainly achieved through the education of potential users about the individual added values the product has to offer. A proper vehicle classification enabled conformance to the established institutions. As mentioned in the literature review, Smith and Raven [4] label this as **fit-and-conform empowerment**. The niche innovation became competitive within (relatively) unchanged selection environments. Only modest lobbying and government interventions (e.g. easing restrictions) were necessary to enable/facilitate widespread diffusion of e-bikes.

In the e-scooter case, the conditions turned out to be different. The niche has developed in a regime internal market niche implying that it is no longer shielded from mainstream selection pressures and faces severe competition from petrol scooters. The very low participation of incumbent scooter companies and vehicle dealers indicates that there are insufficient incentives and/or pressures for organizations to enter the niche. This may be due, not least, to the fact that the incumbent regime features high stability. According to Raven [85] this set-up prevents a rapid expansion of the niche.

Achieving legitimacy here will, arguably, be a more difficult process. The abstract nature of the social added values is (only) one aspect of the problem. There is also the fact that *"in many cases of low-carbon innovation, conformance will be difficult to achieve since institutions are locked-in to established technologies and tend to block the development of new technological options"* [84] p. 110. Current legislation seems to be in favor of the incumbent petrol scooter technology and the fit-and-conform strategy, that has been applied so far, appears to be inappropriate. Based on these insights, it can be argued that a **stretch-and-transform** strategy should be chosen. An advocacy coalition may, therefore, need to convince broader social actors that the rules of the game have to be changed to create incentives and/or pressures for the participation of incumbent scooter producers, vehicle dealers, etc. Today, the awareness of the problem about exhaust emissions is not widespread. Thus, a critical mass of supporters does not exist yet. Soft measures such as the implementation of an eco-label for scooters or awareness building measures (e.g. publication of the life cycle assessment studies results), which point to the new dimensions of the (niche) rules, may help to overcome this. This strategy may create capabilities and attract resources that empower participation in political debates [4]. Eventually, when niche advocates have gained some strength and political power, the advocacy coalition may lobby for tougher exhaust emissions standards for scooters. This also weakens the stability in the incumbent regime. In addition, such standards may also trigger an efficiency increase of the existing petrol technology as recent developments in the car sector have shown.

Besides the challenges in creating legitimacy for the technology, the TIS analysis revealed that another institution-related system function still is weak: *Guidance of the search*. This function involves the process of strengthening the incentives and/or pressures for organizations to enter the technological field [78]. If the niche is to develop further, a wide range of actors must perceive entrepreneurial opportunities and enter the niche [84]. As previously mentioned, this is not the case at the moment. The participation of important actors (e.g. incumbent firms) is unsatisfactory. The system function also covers mechanisms that have an influence on the direction of search within the niche, in terms of different markets, business models, etc. [10]. However, successful business models haven't been developed yet. The TIS analysis revealed a lack of knowledge among suppliers about customer needs.

The experience of ‘Biketec’ has shown that such knowledge is of prime importance. A study by Freeman and Soete [12] pp. 204-218 also stresses this importance: by testing 200 factors they showed that the most decisive factor whether innovations became commercial successes or failures was the extent to which firms understood user needs from the very beginning of the innovation effort. An absence of customer knowledge implies uncertainty, and a lack of competence regarding a segmentation of the market and business model development. In this regard, the Swiss Post activities represent an exception: in collaboration with the respective e-scooter developer the product was very much tailored to the needs of this important end-user. But demand-pull, rather than technology-push forces initiated it. However, it can best be explained by a successful fit-and-conform strategy.

Taken together, the results of this study support observations made in recent research. Bergek et al. [84] point out that the two functions *Guidance of the search* and *Creation of legitimacy* are particular problematic with respect to low carbon innovations. The functions are both closely related to the institutional framework. And Smith et al. [82] p. 445 stress that *“public policies tend to positively engage with promising opportunities (niche building) in isolation. Understandably, the politically contentious, coercive dark side of sustainability transitions, principally putting pressure on regimes, is done with much greater timidity“.* In this respect, structures that support nurturing (e.g. provision of a protected space in the form of a large-scale experiment, the platform organization ‘NewRide’) seem to be well established in Switzerland. However, there is a need for policy initiatives that may support stretch-and-transform empowering.

Based on the findings, we argue that beyond the initial protective space *the interplay of* product characteristics (especially added values), niche characteristics (the type of niche) and regime characteristics (regime stability) is critical for niche up-scaling. At this point, an assessment of these characteristics is important to decide whether a fit-and-conform strategy or a stretch-and-transform strategy is appropriate. The TIS analysis is necessary but not sufficient for such a decision. In the e-bike case, for example, the very few identified activities concerning the creation of legitimacy would have indicated the necessity of further support from advocacy coalitions, according the TIS approach. However, our study gives evidence that the forming of such political networks was not necessary because of the isolation from the prevailing socio-technical regime(s). Without a systematic review of the product characteristics and the system’s environment, the TIS approach runs the risk to miss such influential processes. Hence, the TIS analysis is insufficiently differentiated and too inward oriented in order to propose policy and strategy recommendations for single products or applications. An additional multi-criteria appraisal is beneficial to formulate tailored recommendations once a niche innovation moves beyond the initial protective space. Consequently, the case study results suggest that beyond the initial protective space, technology-specific policies alone are not sufficient. From that point on, product-specific policies and strategies become decisive.

4.8 Conclusions

The purpose of the current study was to investigate the historical development of two niche innovations encompassed by the same technological innovation system (TIS): the successful diffusion of e-bikes and the stagnating e-scooter development in Switzerland. The aim was to analyze how different boundary conditions influence the choice or direction of further strategic maneuvering at the stage when niche innovations move beyond the initial protective space. Thus, this study set out to create deeper insight into the up-scaling process of niche innovations.

Therefore, we performed a comparative niche analysis based on the TIS framework. The advantage of such a niche comparison is that it provides insights into which boundary conditions and factors make a difference between success and failure in up-scaling and diffusing niche innovations. Considering the limitations of the TIS approach, we also applied a multi-criteria appraisal as a supplement to the TIS analysis.

The present study confirms previous theorizing and contributes additional evidence that the TIS framework runs the risk to miss influential processes of niche up-scaling, because it is inward oriented and does not pay much attention to the system's environment. This has important implications for the choice of support strategies beyond the initial protective space. Nevertheless, a TIS analysis enables the identification of 'weak' system functions and guides, in this respect, further support activities for the successful build-up process of an emerging innovation system. This is decisive for the increasing stability of niche-specific rules and coherent system building.

The findings of this study have important policy and management implications. A first recommendation is that product characteristics (especially added values), niche characteristics (the type of niche) and regime characteristics (regime stability) should be taken into account when niche innovations move beyond the initial protective space as they are critical for the up-scaling process. The proposed multi-criteria appraisal of these boundary conditions and factors can be used as a guideline for practitioners to inform them to pursue either a fit-and-conform strategy or a stretch-and-transform strategy as suggested by Smith and Raven [4]. In a situation, where a regime *external* niche innovation offers *individual* added values and faces no direct competition from regime actors, we suggest to pursue a fit-and-conform strategy. In a situation, where a regime *internal* niche innovation offers *social* added values and faces severe competition from regime actors, we recommend to pursue a stretch-and-transform strategy. Another important practical implication is that beyond the initial protective space technology-specific policies and strategies alone are not sufficient. From that point on, tailored product-specific policies become more important in order to support the up-scaling process of niche innovations.

It is recommended that further research be undertaken in the following areas: First, further empirical evidence of niche comparisons are needed in order to elaborate the base for strategic maneuvering and policy formulation. Second, more systematic attention can be given to the proposed multi-criteria appraisal. In its present form, the appraisal provides only a preliminary distinction and therefore has to be refined further. Examples of such refinement could include dominant design considerations and technology-specific characteristics that either favors the participation of newcomers and incumbents in the TIS building phase.

5 General conclusions

The main objectives of this dissertation were to enhance the (theoretical) insights into the dynamics of niche processes and to identify possibilities to intervene in these processes. The following prime conclusions can be drawn from the present research (more specific conclusions can be found in each main chapter of the thesis):

The findings of the first study provide an understanding of the mainstream selection environment in which a hydrogen-powered street sweeper has to assert itself. It was shown that dominant user practices such as the fleet-decision making structures and vehicle-operating practices make street sweeper fleets a promising technological platform for the early implementation of hydrogen fuel cell vehicles. Stated user preferences revealed that a market niche for hydrogen driven street sweepers exists in both Switzerland and Germany. In addition, it was also shown which improvements of product characteristics could significantly enhance the overall preference for hydrogen-powered sweepers. Hence, these insights can facilitate the formulation of tailored support strategies (e.g. specific *shielding*) for the niche innovation.

The results of the performance assessment of the innovation system around fuel cell and hydrogen technologies in Switzerland have shown that well-functioning knowledge networks and a high-quality knowledge base have been established in recent years. However, only very few entrepreneurs have yet utilized those to explore the market. In order to enhance the performance of the innovation system and to move it into the next development stage, strategy and policy initiatives should to be focused on the identified ‘weak' system functions, i.e. especially *Entrepreneurial activities*, *Market formation*, and *Resource mobilization*. The findings of the assessment were then used as the basis for the development of a transition roadmap, which supports the coordination of the further build-up (*nurturing*) of the innovation system. Such a theoretically grounded roadmapping approach allows the elaboration of a tailored intervention strategy that considers the development stages of a TIS and specifically addresses ‘weak' functions of the innovation system.

The last study has gone some way towards enhancing our understanding of the up-scaling process (*empowering*) of niche innovations. The findings of the comparative niche analysis based on the TIS framework have confirmed previous theorizing regarding typical stages and processes in the build-up of a TIS. They also contribute additional evidence that the TIS framework runs the risk to miss influential processes of niche up-scaling, because it does not pay much attention to the system's environment. This has important implications for the choice of support strategies beyond the initial protective space. At this stage, *product-specific maneuvering* becomes critical in terms of fitting and supporting empowerment of niche innovations. It was shown that the *interplay* between product characteristics, niche characteristics and the selection environment (regime) is critical for the product-specific diffusion pathway of an emerging technology. The proposed multi-criteria appraisal can be used to support practitioners' strategy choice.

5.1 Significance of the findings and implications for practice

The current dissertation was unable to identify and confirm different ‘motors' (generalized forms of circular causation) in the formative stage of an emerging innovation system. However, it confirmed previous theorizing regarding typical stages and system behavior in the build-up process of a TIS. The present thesis also makes several noteworthy conceptual contributions and refined the classification scheme for the functional analysis including more precise definitions.

Different instruments have been proposed in this thesis, which may be useful for future practice. The tools can be used to develop targeted interventions aimed at making the niche processes (shielding, nurturing, empowering) more effective. By building an understanding of the market niche potential of an application at an early stage the choice experiment can help to reduce the risk that investments and developments become obsolete. By enabling insights into the mainstream selection environment the instrument can also be used for the mobilization or creation of (tailored) protective space for the application. A theoretically grounded transition roadmap allows decision-makers to identify the points in an innovation system where intervention is likely to matter the most and may facilitate the coordination of stage-specific activities. Finally, the proposed multi-criteria appraisal may help to determine an appropriate strategy for niche up-scaling and therefore avoiding possible costly sidetracks. Consequently, the instruments may also help to reduce uncertainty and inform decision-makers about the direction of the search process (and thereby contribute to the improvement of an important system function).

Taken together, the findings of this research highlight the importance of prospective planning and coordination in innovation system dynamics. The identification of the current state of an innovation system is decisive for the formulation of product-specific support strategies. It was also shown that considerable time-spans (e.g. 20-30 years in the e-bike and e-scooter cases) are necessary to develop and diffuse new transport technologies. These insights support the idea that institutionalized platforms, which provide a space for learning, could play an important role in niche processes. The use of the proposed instruments should not be a one-off exercise but needs to be undertaken continuously. An established institutional arrangement that is long-term orientated can facilitate this process. In addition, such an institutionalized platform can support the entry of further actors, coordinate their actions, mobilize resources, initiate demonstration projects, support a portfolio strategy, and enhance the visibility of the technology.

5.2 Recommendations for further research

This thesis has thrown up many questions in need of further investigation. The respective recommendations for further research can be found in the main chapters of the thesis. In general, the adaptability of the proposed instruments remains an important issue because they may be used as tools for the ongoing management process of niche building. Hence, further research might explore how to establish an institutional context in which niche processes can be effectively supported (learning and re-evaluation). In this respect, the question arises whether pilot and demonstration projects are sufficient for such an ongoing learning process. Or are more institutionalized and long-acting platforms for learning necessary? It is suggested that such questions are investigated in future studies.

6 Appendices for Thesis Part I

6.1 Appendix I-A: Online survey including choice experiment

PAUL SCHERRER INSTITUT

PSI

Herzlich Willkommen bei der Umfrage "Kehrfahrzeug-Fuhrpark und alternative Antriebe"

Besten Dank, dass Sie diese Untersuchung mit Ihrer Teilnahme unterstützen!

Das Ausfüllen des Fragebogens dauert ca. 15-20 Minuten. Sie können die Umfrage jederzeit unterbrechen und diese zu einem späteren Zeitpunkt abschliessen.

Bitte geben Sie den Anmeldecode ein, den Sie per Post erhalten haben und drücken Sie auf den Pfeil:

Code:

Falls Sie auf Probleme stossen sollten, kontaktieren Sie bitte: stephan.walter@psi.ch / Tel. 056 310 27 44

Diese Umfrage ist Teil eines Projekts am Paul Scherrer Institut (PSI), das sich mit der Verbreitung neuer Technologien in Nischenmärkten beschäftigt. Dabei möchten wir erheben, welches die Bedürfnisse der Verantwortlichen von Kehrfahrzeug-Fuhrparks sind.

Die Umfrage besteht aus zwei Teilen:

- **In TEIL 1 stellen wir Ihnen allgemeine Fragen zu Ihrem aktuellen Kehrfahrzeug-Fuhrpark.**
- **In TEIL 2 bitten wir Sie jeweils ein bevorzugtes Kehrfahrzeug aus verschiedenen Varianten auszuwählen.**

Wir versichern Ihnen, dass alle Daten streng vertraulich behandelt und in anonymisierter Form ausschliesslich für wissenschaftliche Zwecke verwendet werden.

Für Fragen steht Ihnen Stephan Walter gerne zur Verfügung: stephan.walter@psi.ch / Tel. 056 310 27 44

0% 100%

Angaben zu Ihrem Kehrfahrzeug-Fuhrpark

Wie viele Kompakt- und Grosskehrfahrzeuge stehen bei Ihnen im Einsatz?

[ ] Kompaktkehrfahrzeuge

[ ] Grosskehrfahrzeuge (mit Lkw-Aufbau)

Mit welchem Treibstoff werden die Kehrfahrzeuge betrieben?

- [ ] Diesel
- [ ] Biodiesel
- [ ] Erdgas (CNG)
- [ ] Andere: [ ]

Welches ist die durchschnittliche Nutzungsdauer der *Kompakt*kehrfahrzeuge in Ihrem Betrieb?

[ ] Jahre

0% 100%

Betrieb & Unterhalt

An wie vielen Tagen pro Woche steht bei Ihnen ein Kompaktkehrfahrzeug durchschnittlich im Einsatz?

-- Bitte wählen Sie --

Wie viele Stunden steht bei Ihnen ein Kompaktkehrfahrzeug durchschnittlich pro Tag im Einsatz?

-- Bitte wählen Sie --

Wie viele Fahrer bedienen die Kompaktkehrmaschinen (ohne allfällige Reservefahrer)?

[ ]

Wie viele Personen sind für die Wartung des Kehrfahrzeug-Fuhrparks zuständig?

[ ]

0% 100%

Beschaffung

Welche Beschaffungsart kam bei der *letzten* Kompaktkehrfahrzeug-Anschaffung zur Anwendung?

- Neukauf
- Kauf einer Vorführmaschine
- Occasion-Kauf
- Andere: ______

Wie viel hat das *zuletzt* beschaffte *Kompakt*kehrfahrzeug gekostet?

______ CHF (bitte keine Trennzeichen verwenden)

Wie hoch sind die jährlichen Betriebskosten (Reparatur- Wartungs- und Treibstoffkosten) des zuletzt beschafften Kompaktkehrfahrzeugs? (Durchschnittswert über gesamte Nutzungsdauer)

______ CHF

0% 100%

Betankung

Werden Ihre Kehrfahrzeuge an einer betriebseigenen Anlage betankt?

- Ja
- Nein

0% 100%

Betankung

Welches sind die Gründe, weshalb Ihre Kehrfahrzeuge an einer betriebseigenen Anlage betankt werden?

- Kostengründe
- Zeitersparnisse
- Andere:

0% 100%

Betankung

Welches sind die Gründe, weshalb Ihre Kehrfahrzeuge nicht an einer betriebseigenen Anlage betankt werden?

- Kostengründe
- Mangelnde Platzverhältnisse
- Sicherheitsbedenken
- Gesetzliche Auflagen
- Andere:

0% 100%

Betankung

An wievielen Standorten werden die Kehrfahrzeuge betankt? (ca. in 90% der Fälle)

- Immer am gleichen Tankstellen-Standort
- An verschiedenen Tankstellen-Standorten

0% 100%

Betankung

Wieviele Minuten Fahrzeit ist die nächste Tankstelle von Ihrem Betrieb entfernt?

-- Bitte wählen Sie --

Befindet sich im Umkreis von maximal 15 Minuten Fahrzeit ihres Betriebes eine Erdgas-Tankstelle?

- Ja
- Nein
- Weiss nicht

0% 100%

Alternative Antriebe & Treibstoffe

Hat Ihr Betrieb bereits irgendwelche Fahrzeuge getestet, die mit alternativen Treibstoffen (jegliche Treibstoffe ausser Diesel und Benzin) betrieben werden?

- ○ Ja
- ○ Nein

0% 100%

Alternative Antriebe & Treibstoffe

Um welchen Treibstoff/welche Treibstoffe handelt es sich?

☐ Biodiesel	☐ Flüssiggas (LPG)	☐ Elektrizität
☐ Erdgas (CNG)	☐ Ethanol	☐ Wasserstoff
☐ Biogas (Biomethan)	☐ Bioethanol	☐ Anderes:

0% 100%

Alternative Antriebe & Treibstoffe

Kennen Sie Beispiele von Fahrzeugen (jeglicher Art), die mit Wasserstoff betrieben werden?

- ○ Ja
- ○ Nein

0% 100%

Alternative Antriebe & Treibstoffe

Nennen Sie bitte die Beispiele von wasserstoffbetriebenen Fahrzeugen, die Sie kennen.

0% 100%

Alternative Antriebe & Treibstoffe

Wie schätzen Sie die Entwicklung der Dieselpreise in den nächsten 10-15 Jahren ein?

- Stark sinkend
- Sinkend
- Gleich bleibend
- Zunehmend
- Stark zunehmend

0% 100%

Angaben zum Entscheidungsprozess bei der Kehrfahrzeug-Beschaffung (1 von 2)

Bitte stellen Sie sich nun vor, dass Ihr Betrieb vor einer wichtigen Fuhrpark-Entscheid steht. Dabei geht es um die Frage, ob ein Kehrfahrzeug mit alternativem Antrieb oder ein konventionelles Diesel-Fahrzeug beschafft werden soll.

Bitte beantworten Sie die nachfolgenden Fragen so, wie wenn dieser Entscheid heute tatsächlich anstehen würde:

Würden formale, schriftliche Regeln den Entscheid leiten?

- Ja
- Nein

Würde eine detaillierte Kosten-Analyse *inklusive* einer Fahrzeug-Betriebs-Kostenrechnung durchgeführt?

- Ja
- Nein

Würde der endgültige Entscheid nach einer öffentlichen Ausschreibung (z.B. gemäss Submissionsgesetzgebung) getroffen?

- Ja
- Nein

0% 100%

Angaben zum Entscheidungsprozess bei der Kehrfahrzeug-Beschaffung (2 von 2)

Würde der Entscheid von nur 1 bis 2 Personen gefällt?

- ○ Ja
- ○ Nein

Würde der Entscheid auf oberer Führungsebene getroffen?

- ○ Ja. Von Personen mit folgender Funktion: ________
- ○ Nein

Wäre für den Entscheid eine zusätzliche Autorisierung/Genehmigung durch die höchste Instanz notwendig?

- ○ Ja. Durch folgende Instanz: ________
- ○ Nein

0% 100%

2. TEIL: Wahlsituationen

In diesem 2. Teil der Umfrage stellen wir Sie vor **10 Wahlsituationen**, die Sie bei einer zukünftigen Beschaffung antreffen könnten. Es werden Ihnen verschiedene Kehrfahrzeuge mit alternativem Antrieb sowie jeweils immer das gleiche Diesel-Kehrfahrzeug zur Auswahl stehen. Alle Fahrzeuge werden durch die folgenden Eigenschaften beschrieben:

Treibstoff
Kaufpreis
Betriebskosten
Betankungsdistanz
Umweltbelastung
Lärm-Emissionen

Wenn Sie den Mauszeiger über eine der Fahrzeug-Eigenschaften bewegen, erscheint jeweils eine kurze Beschreibung. Diese ist auf die selbe Weise auch bei jeder der folgenden Wahlsituationen abrufbar (unterstrichene Textstelle).

In allen anderen Eigenschaften unterscheiden sich die Kehrfahrzeuge nicht (z.B. Reichweite pro Tankfüllung, Zuverlässigkeit). Es ist möglich, dass Ihnen Fahrzeug-Varianten präsentiert werden, die noch nicht auf dem Markt erhältlich sind oder dass diese unwahrscheinlich erscheinen. Bitte berücksichtigen Sie diese jedoch so, als wären sie so erhältlich.

0% 100%

Wahlsituation 1 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Erdgas/Biogas	Wasserstoff	Wasserstoff
Kaufpreis	CHF 272'000	CHF 208'000	CHF 160'000
Betriebskosten	CHF 48'000	CHF 27'000	CHF 42'000
Betankungsdistanz	15 Minuten	10 Minuten	20 Minuten
Umweltbelastung	50%	0%	25%
Lärm-Emissionen	Mittel	Tief	Mittel

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

Ja

Nein

0% 100%

Wahlsituation 2 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Erdgas/Biogas	Wasserstoff	Erdgas/Biogas
Kaufpreis	CHF 272'000	CHF 176'000	CHF 240'000
Betriebskosten	CHF 27'000	CHF 30'000	CHF 36'000
Betankungsdistanz	5 Minuten	5 Minuten	10 Minuten
Umweltbelastung	25%	50%	75%
Lärm-Emissionen	Tief	Mittel	Tief

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

Ja

Nein

0% 100%

Wahlsituation 3 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Wasserstoff	Erdgas/Biogas
Kaufpreis	CHF 240'000	CHF 272'000	CHF 208'000
Betriebskosten	CHF 48'000	CHF 36'000	CHF 30'000
Betankungsdistanz	15 Minuten	20 Minuten	10 Minuten
Umweltbelastung	0%	75%	25%
Lärm-Emissionen	Tief	Mittel	Mittel
	○	○	○

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

○ **Ja**

○ **Nein**

0% 100%

Wahlsituation 4 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Wasserstoff	Erdgas/Biogas
Kaufpreis	CHF 176'000	CHF 160'000	CHF 160'000
Betriebskosten	CHF 42'000	CHF 27'000	CHF 48'000
Betankungsdistanz	5 Minuten	15 Minuten	20 Minuten
Umweltbelastung	25%	75%	50%
Lärm-Emissionen	Tief	Mittel	Tief
	○	○	○

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

○ **Ja**

○ **Nein**

0% 100%

Wahlsituation 5 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Erdgas/Biogas	Wasserstoff	Wasserstoff
Kaufpreis	CHF 208'000	CHF 240'000	CHF 272'000
Betriebskosten	CHF 30'000	CHF 36'000	CHF 48'000
Betankungsdistanz	15 Minuten	15 Minuten	5 Minuten
Umweltbelastung	75%	25%	0%
Lärm-Emissionen	Mittel	Tief	Tief

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	**Diesel**
Kaufpreis:	**CHF 160'000**
Betriebskosten:	**CHF 30'000**
Betankungsdistanz:	**5 Minuten**
Umweltbelastung:	**100%**
Lärm-Emissionen:	**Hoch**

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

- Ja
- Nein

0% 100%

Wahlsituation 6 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Erdgas/Biogas	Erdgas/Biogas
Kaufpreis	CHF 176'000	CHF 240'000	CHF 208'000
Betriebskosten	CHF 36'000	CHF 42'000	CHF 36'000
Betankungsdistanz	20 Minuten	5 Minuten	15 Minuten
Umweltbelastung	0%	50%	75%
Lärm-Emissionen	Tief	Mittel	Tief

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	**Diesel**
Kaufpreis:	**CHF 160'000**
Betriebskosten:	**CHF 30'000**
Betankungsdistanz:	**5 Minuten**
Umweltbelastung:	**100%**
Lärm-Emissionen:	**Hoch**

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

- Ja
- Nein

0% 100%

Wahlsituation 7 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Erdgas/Biogas	Erdgas/Biogas
Kaufpreis	CHF 272'000	CHF 176'000	CHF 160'000
Betriebskosten	CHF 30'000	CHF 27'000	CHF 42'000
Betankungsdistanz	10 Minuten	20 Minuten	15 Minuten
Umweltbelastung	0%	50%	75%
Lärm-Emissionen	Tief	Mittel	Tief

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	**Diesel**
Kaufpreis:	**CHF 160'000**
Betriebskosten:	**CHF 30'000**
Betankungsdistanz:	**5 Minuten**
Umweltbelastung:	**100%**
Lärm-Emissionen:	**Hoch**

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

- Ja
- Nein

0% 100%

Wahlsituation 8 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Erdgas/Biogas	Wasserstoff	Wasserstoff
Kaufpreis	CHF 272'000	CHF 208'000	CHF 240'000
Betriebskosten	CHF 48'000	CHF 36'000	CHF 30'000
Betankungsdistanz	10 Minuten	5 Minuten	15 Minuten
Umweltbelastung	25%	0%	50%
Lärm-Emissionen	Mittel	Mittel	Tief

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

Ja

Nein

0% 100%

Wahlsituation 9 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Erdgas/Biogas	Erdgas/Biogas
Kaufpreis	CHF 240'000	CHF 208'000	CHF 160'000
Betriebskosten	CHF 42'000	CHF 48'000	CHF 27'000
Betankungsdistanz	20 Minuten	5 Minuten	10 Minuten
Umweltbelastung	75%	75%	25%
Lärm-Emissionen	Mittel	Tief	Mittel

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

Ja

Nein

0% 100%

Wahlsituation 10 von 10

1) Wenn dies in Zukunft Ihre einzigen Optionen wären, welches Kehrfahrzeug würden Sie anschaffen?

Treibstoff	Wasserstoff	Erdgas/Biogas	Wasserstoff
Kaufpreis	CHF 208'000	CHF 176'000	CHF 160'000
Betriebskosten	CHF 36'000	CHF 48'000	CHF 30'000
Betankungsdistanz	5 Minuten	20 Minuten	10 Minuten
Umweltbelastung	50%	25%	0%
Lärm-Emissionen	Tief	Tief	Mittel

2) Angenommen Ihnen steht zusätzlich das folgende Diesel-Kehrfahrzeug zur Auswahl:

Treibstoff:	Diesel
Kaufpreis:	CHF 160'000
Betriebskosten:	CHF 30'000
Betankungsdistanz:	5 Minuten
Umweltbelastung:	100%
Lärm-Emissionen:	Hoch

Würden Sie in diesem Fall nach wie vor das unter 1) gewählte Kehrfahrzeug anschaffen?

Ja

Nein

0% 100%

Wahlsituationen

Welchen Ansprüchen entsprechen die von Ihnen gewählten Kehrfahrzeug-Varianten am ehesten? (Es ist nur 1 Antwort möglich)

- ◯ Ihren eigenen Ansprüchen.
- ◯ Den Ansprüchen Ihres Betriebes.
- ◯ Den Ansprüchen der Kehrfahrzeugfahrer.
- ◯ Den Ansprüchen der Bevölkerung, Kunden oder Passanten.

0% 100%

Wahlsituationen

Für meine Entscheide zu den Wahlsituationen trifft folgendes zu:

- ◯ Ich habe alle Eigenschaften gleich bewertet.
- ◯ Ich habe einzelnen Eigenschaften ein grösseres Gewicht gegeben.
- ◯ **Eine einzelne** Eigenschaft war jeweils ausschlaggebend für meine Entscheidung.

0% 100%

Wahlsituationen

Falls Sie *einzelnen* Eigenschaften ein grösseres Gewicht gegeben haben, kreuzen Sie bitte an, welche Eigenschaften für Ihre Entscheidungen am wichtigsten waren.

- ☐ Treibstoff
- ☐ Kaufpreis
- ☐ Betriebskosten
- ☐ Kürzeste Betankungs-Distanz
- ☐ Umweltbelastung
- ☐ Lärmpegel

0% 100%

Wahlsituationen

Falls *eine* der genannten Eigenschaften jeweils ausschlaggebend war für Ihre Entscheidung, welche Eigenschaft war das?

- Treibstoff
- Kaufpreis
- Betriebskosten
- Kürzeste Betankungs-Distanz
- Umweltbelastung
- Lärmpegel

0% 100%

Zu Ihrer Person

Für welche Art von Institution sind Sie tätig?

- Gemeindeverwaltung
- Kantonsverwaltung
- Bundesverwaltung
- Privates Unternehmen
- Andere:

Wie gross ist die Fahrzeugflotte (Fahrzeuge jeglicher Art), für die Sie zuständig sind?

Fahrzeuge

Wir bitten Sie uns Ihren Namen, Ihre E-Mail-Adresse sowie Ihre Funktion mitzuteilen. Gerne stellen wir Ihnen die Resultate der Befragung als Dank für Ihre Teilnahme zu.

Zudem wären wir Ihnen sehr dankbar, wenn Sie uns den Namen, die E-Mail-Adresse sowie die Funktion der Person in Ihrem Betrieb nennen könnten, welche einen Entscheid für die Anschaffung von Fahrzeugen mit alternativem Antrieb genehmigen müsste:

0% 100%

PAUL SCHERRER INSTITUT PSI

Hiermit sind Sie am Ende der Umfrage angelangt. Vielen Dank für Ihre Teilnahme!

0% 100%

6.2 Appendix I-B: Results of the Swiss online survey[8] [9]

Appendix Figure 1: AnzahlFzKlein.

Value	Count	Percent
0	19	10.98%
1	114	65.89%
2	20	11.56%
3	10	5.78%
4	4	2.31%
7	2	1.15%
10	1	0.57%
22	1	0.57%
28	1	0.57%
35	1	0.57%

Summary	
N:	173
Min:	0
Max:	35
Mean:	1.78612716763006

Appendix Figure 2: AnzahlFzGross.

Value	Count	Percent
0	142	82.08%
1	20	11.56%
2	4	2.31%
3	2	1.15%
5	1	0.57%
6	2	1.15%
7	2	1.15%

Summary	
N:	173
Min:	0
Max:	7
Mean:	0.375722543352601

Appendix Figure 3: Treibstoff.

Value	Label	Count	Percent
1	Diesel	161	93.06%
2	Biodiesel	3	1.73%
4	Andere:	12	6.93%

Summary	
N:	173
Min:	1
Max:	4

[8] The results of the German online survey are available on request.
[9] Further scenarios of the choice experiment are available on request.

Appendix Figure 4: Nutzungsdauer.

Value	Count	Percent
0	12	6.93%
1	1	0.57%
5	1	0.57%
6	3	1.73%
7	6	3.46%
8	7	4.04%
9	1	0.57%
10	50	28.9%
11	2	1.15%
12	30	17.34%
13	1	0.57%
14	2	1.15%
15	36	20.8%
16	4	2.31%
18	1	0.57%
19	1	0.57%
20	10	5.78%
24	1	0.57%
25	1	0.57%
30	1	0.57%
75	1	0.57%
100	1	0.57%

Summary	
N:	173
Min:	0
Max:	100
Mean:	12.4219653179191

Appendix Figure 5: Wocheneinsatz.

Value	Label	Count	Percent
1	1 Tag	49	28.32%
2	2 Tage	32	18.49%
3	3 Tage	23	13.29%
4	4 Tage	23	13.29%
5	5 Tage	37	21.38%
6	6 Tage	5	2.89%
7	7 Tage	4	2.31%

Summary	
N:	173
Min:	1
Max:	7
Mean:	2.98843930635838

Appendix Figure 6: Tageseinsatz.

Value	Label	Count	Percent
1	1 Stunde	19	10.98%
2	2 Stunden	5	2.89%
3	3 Stunden	4	2.31%
4	4 Stunden	4	2.31%
5	5 Stunden	10	5.78%
6	6 Stunden	33	19.07%
7	7 Stunden	45	26.01%
8	8 Stunden	45	26.01%
9	Mehr als 8 Stunden	8	4.62%

Summary	
N:	173
Min:	1
Max:	9
Mean:	6.08092485549133

Appendix Figure 7: Fahrer.

Value	Count	Percent
0	8	4.62%
1	50	28.9%
2	73	42.19%
3	21	12.13%
4	7	4.04%
5	4	2.31%
6	2	1.15%
7	4	2.31%
8	2	1.15%
12	1	0.57%
37	1	0.57%

Summary	
N:	173
Min:	0
Max:	37
Mean:	2.38150289017341

Appendix Figure 8: Wartung.

Value	Count	Percent
0	11	6.35%
1	93	53.75%
2	55	31.79%
3	5	2.89%
4	1	0.57%
5	4	2.31%
6	1	0.57%
7	1	0.57%
9	2	1.15%

Summary	
N:	173
Min:	0
Max:	9
Mean:	1.57803468208092

Appendix Figure 9: Finanzierungsart.

Value	Label	Count	Percent
1	Neukauf	139	80.34%
2	Kauf einer Vorführmaschine	9	5.2%
3	Occasion-Kauf	10	5.78%
4	Andere:	15	8.67%

Summary	
N:	173
Min:	1
Max:	4
Mean:	1.42774566473988

Appendix Figure 10: EigenBetankung.

Value	Label	Count	Percent
1	Ja	69	39.88%
2	Nein	104	60.11%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.60115606936416

Appendix Figure 11: EigenBetankungJA.

Value	Label	Count	Percent
1	Kostengründe	46	66.66%
2	Zeitersparnisse	39	56.52%
3	Andere:	13	18.84%

Summary	
N:	69
Min:	1
Max:	3

Appendix Figure 12: EigenBetankungNEIN.

Value	Label	Count	Percent
1	Kostengründe	50	48.07%
2	Mangelnde Platzverhältnisse	33	31.73%
3	Sicherheitsbedenken	11	10.57%
4	Gesetzliche Auflagen	27	25.96%
5	Andere:	34	32.69%

Summary	
N:	104
Min:	1
Max:	5

Appendix Figure 13: AnzahlTankstellen.

Value	Label	Count	Percent
1	Immer am gleichen Tankstellen-Standort	157	90.75%
2	An verschiedenen Tankstellen-Standorten	16	9.24%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.09248554913295

Appendix Figure 14: Betankungsdistanz.

Value	Label	Count	Percent
1	0 (Betriebseigene Tankstelle)	34	19.65%
2	weniger als 5 Min.	82	47.39%
3	5 Min.	42	24.27%
4	10 Min.	8	4.62%
5	15 Min.	2	1.15%
6	20 Min.	1	0.57%
7	25 Min.	1	0.57%
8	30 Min.	2	1.15%
9	mehr als 30 Min.	1	0.57%

Summary	
N:	173
Min:	1
Max:	9
Mean:	2.33526011560694

Appendix Figure 15: Erdgas.

Value	Label	Count	Percent
1	Ja	70	40.46%
2	Nein	84	48.55%
3	Weiss nicht	19	10.98%

Summary	
N:	173
Min:	1
Max:	3
Mean:	1.70520231213873

Appendix Figure 16: AltTreibstoffe.

Value	Label	Count	Percent
1	Ja	40	23.12%
2	Nein	133	76.87%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.76878612716763

Appendix Figure 17: AltTreibstoffeJA.

Value	Label	Count	Percent
1	Biodiesel	2	5%
2	Erdgas (CNG)	28	70%
3	Biogas (Biomethan)	1	2.5%
4	Flüssiggas (LPG)	4	10%
7	Elektrizität	17	42.5%
8	Wasserstoff	2	5%

Summary	
N:	40
Min:	1
Max:	8

Appendix Figure 18: Wasserstoff.

Value	Label	Count	Percent
1	Ja	51	29.47%
2	Nein	122	70.52%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.70520231213873

Appendix Figure 19: EntwDiesel.

Value	Label	Count	Percent
2	Sinkend	1	0.57%
3	Gleich bleibend	34	19.65%
4	Zunehmend	117	67.63%
5	Stark zunehmend	21	12.13%

Summary	
N:	173
Min:	2
Max:	5
Mean:	3.91329479768786

Appendix Figure 20: Regeln.

Value	Label	Count	Percent
1	Ja	123	71.09%
2	Nein	50	28.9%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.28901734104046

Appendix Figure 21: KostenAnalyse.

Value	Label	Count	Percent
1	Ja	123	71.09%
2	Nein	50	28.9%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.28901734104046

Appendix Figure 22: Ausschreibung.

Value	Label	Count	Percent
1	Ja	132	76.3%
2	Nein	41	23.69%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.23699421965318

Appendix Figure 23: AnzahlPers.

Value	Label	Count	Percent
1	Ja	36	20.8%
2	Nein	137	79.19%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.79190751445087

Appendix Figure 24: UpperManagement.

Value	Label	Count	Percent
1	Ja. Von Personen mit folgender Funktion:	119	68.78%
2	Nein	54	31.21%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.3121387283237

Appendix Figure 25: Zustimmung.

Value	Label	Count	Percent
1	Ja. Durch folgende Instanz:	101	58.38%
2	Nein	72	41.61%

Summary	
N:	173
Min:	1
Max:	2
Mean:	1.41618497109827

Appendix Figure 26: Anspruchsgruppe.

Value	Label	Count	Percent
1	Ihren eigenen Ansprüchen.	14	8.09%
2	Den Ansprüchen Ihres Betriebes.	99	57.22%
3	Den Ansprüchen der Kehrfahrzeugfahrer.	15	8.67%
4	Den Ansprüchen der Bevölkerung, Kunden oder Passanten.	45	26.01%

Summary	
N:	173
Min:	1
Max:	4
Mean:	2.52601156069364

Appendix Figure 27: Bewertung.

Value	Label	Count	Percent
1	Ich habe alle Eigenschaften gleich bewertet.	27	15.6%
2	Ich habe einzelnen Eigenschaften ein grösseres Gewicht gegeben.	115	66.47%
3	Eine einzelne Eigenschaft war jeweils ausschlaggebend für meine Entscheidung.	31	17.91%

Summary	
N:	173
Min:	1
Max:	3
Mean:	2.02312138728324

Appendix Figure 28: Gewichtungen.

Value	Label	Count	Percent
1	Treibstoff	42	36.52%
2	Kaufpreis	60	52.17%
3	Betriebskosten	69	60%
4	Kürzeste Betankungs-Distanz	33	28.69%
5	Umweltbelastung	75	65.21%
6	Lärmpegel	39	33.91%

Summary	
N:	115
Min:	1
Max:	6

Appendix Figure 29: Gewichtung.

Value	Label	Count	Percent
1	Treibstoff	6	19.35%
2	Kaufpreis	7	22.58%
3	Betriebskosten	4	12.9%
4	Kürzeste Betankungs-Distanz	1	3.22%
5	Umweltbelastung	11	35.48%
6	Lärmpegel	2	6.45%

Summary	
N:	31
Min:	1
Max:	6
Mean:	3.32258064516129

Appendix Figure 30: Institution.

Value	Label	Count	Percent
1	Gemeindeverwaltung	137	79.19%
2	Kantonsverwaltung	21	12.13%
4	Privates Unternehmen	6	3.46%
5	Andere:	9	5.2%

Summary	
N:	173
Min:	1
Max:	5
Mean:	1.43352601156069

7 Appendices for Thesis Part II

7.1 Appendix II-A: Expert interview[10]

PAUL SCHERRER INSTITUT

Analysis of the Swiss Innovation System around Fuel Cell and Hydrogen Technologies

Interviewee: ______________________________

Interviewer: ______________________________

Date: ______________________________

Location: ______________________________

Time: ______________________________

Duration: ______________________________

	Yes	No
Do you agree that we record the conversation?	☐	☐

……………………………….

[10] The German version is available on request.

Opening questions

- What is your area of responsibility?
- Do you know any Swiss fuel cell applications?

1) Current state of technology and barriers

1. What is the current state of the fuel cell and hydrogen technologies in Switzerland?

   Currently, the technology is predominantly...

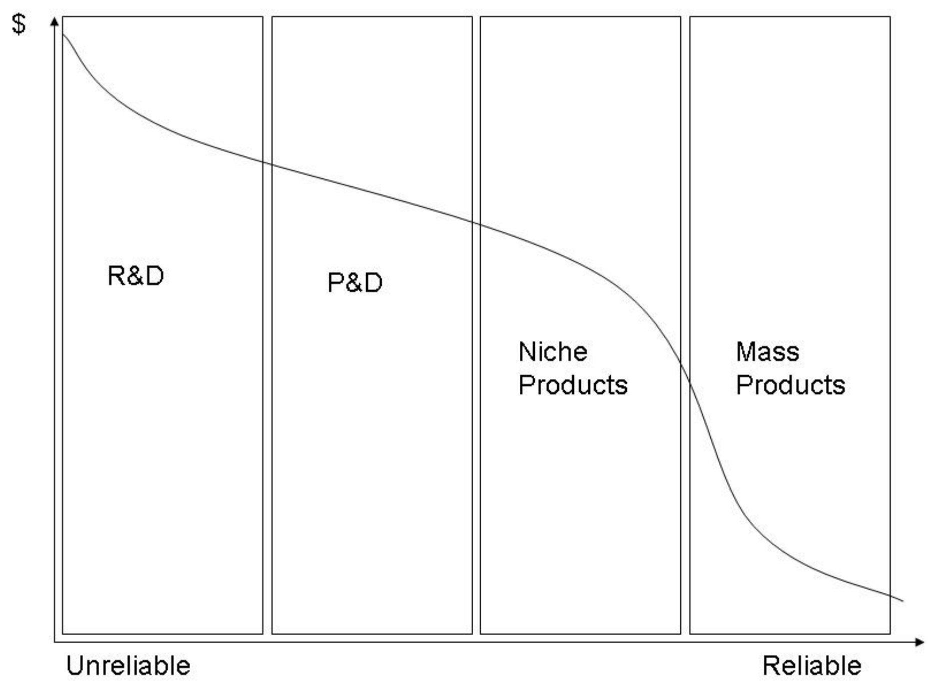
   □ ... unknown, unreliable und too expensive (w.r.t. competitiveness).

   □ ... still unreliable and too expensive but sufficiently improved to allow for practical applications.

   □ ... reliable (i.e. failure-free operation & adequate durability) and beyond the stage of demonstration but is usually still costly. → *Niche products*

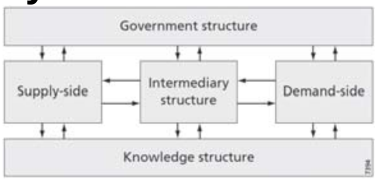
   □ ... reliable but is usually still costly. However, costs may decrease rapidly as the result of mass production. → *Mass products*

   Please comment on the reasons of your choice.



2. Are there barriers that hinder the further development and diffusion of the technology in Switzerland? If so, what are they?

2) Current state assessment of the Swiss innovation system



Please rate the following questions regarding the further technology development (i.e., in order to enter the next stage) using the scale below:

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Please also comment on each rating.

Knowledge development (e.g. R&D)

The number of research and development projects?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The realization of prototypes?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Profound knowledge of (potential) customers, business opportunities and markets?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The quality of the knowledge base as compared to international standards?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Entrepreneurial activities (e.g. pilot & demonstration projects)

Involve projects aimed to prove the usefulness of the technology in a practical and/or commercial environment. An entrepreneur can be a new business entrant, an incumbent company or a public actor.

The number of entrepreneurial projects?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The variety of applications of all these projects?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The number of new actors who decide to run such projects (on an annual basis)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The coverage of the entire value chain by Swiss actors?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Knowledge diffusion

The amount of official gatherings (e.g. conferences, workshops) organized?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The amount of national and international (Swiss participation) networks?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The breadth of these networks concerning involved actors (supply-side, demand-side, knowledge structure, government structure, intermediary structure)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The effect of the knowledge exchange in these networks (w.r.t. technology development)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Guidance of the search

The effect of visions and expectations on the technology development (e.g. hydrogen based mobility, 2000-Watt-Society)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The number of actors who have grate expectations for the development potential of the technology?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The articulation of interests by pilot customers (e.g. financial participation in projects)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

The effect of specific targets (e.g. technology roadmaps), legal regulations and standards set by the government or industry?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Market formation

Financial incentives for market formation (e.g. by creating (temporary) competitive advantage through favorable tax regime) in Switzerland?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Investments in the creation of protected spaces (e.g. proto-market, flagship project)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Investments in promotional measures (e.g. information events and brochures)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Articulation of demand from customers (e.g. purchase intentions, order books)?

☐ Very unsatisfactory ☐ Unsatisfactory ☐ Satisfactory ☐ Good ☐ Outstanding ☐ Don't know

Resource mobilization

Availability of skilled personnel and managers?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Availability of financial capital (e.g. venture capital, government funds, EU funds, diversifying firms)?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Awareness of funding opportunities?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Availability of complementary assets (e.g. network infrastructure, complementary products, consulting services)?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Legitimization

Public interest in the technology and media coverage of the technology?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Resistance to the diffusion of the technology?

☐	☐	☐	☐	☐	☐
Very small	Small	Moderate	Large	Very large	Don't know

Perceived pressure (legitimacy), to make investments in the technology?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

Activity of lobby groups/political networks active in the innovation system?

☐	☐	☐	☐	☐	☐
Very unsatisfactory	Unsatisfactory	Satisfactory	Good	Outstanding	Don't know

3) Next steps

1. What would a desirable future state (vision) of the innovation system look like?

2. What opportunities do you see for your organization?

3. What next steps need to be taken to realize these opportunities?*

4. What next steps need to be taken together with other actors to develop further the innovation system?*

5. Is the participation of non-involved actors necessary to develop further the innovation system? If so, what are they?*

* Time frame:	Short-term:	in 0-3 years
	Medium-term:	in 3-6 years
	Long-term:	in 6-9 years

8 Appendices for Thesis Part III

8.1 Appendix III-A: Data sources for the TIS analysis

Data sources of public institutions

- Annual reviews by program heads at the Swiss Federal Office of Energy from 1987-2010
  (www.bfe.admin.ch/themen/00519/00524/index.html?lang=en&dossier_id=01155)

- List of energy research projects of the Swiss Confederation form 1987-2010
  (www.bfe.admin.ch/themen/00519/index.html?lang=de&dossier_id=01156)

- ARAMIS database: The information system contains information regarding research projects funded or implemented by the Swiss Confederation
  (www.aramis.admin.ch)

- Energy research database of the Swiss Federal Office of Energy
  (www.bfe.admin.ch/dokumentation/energieforschung)

- NewRide documents: Annual reports, numerical data, research reports, etc.

- Curia Vista: Database of parliamentary proceedings
  (www.parlament.ch/e/dokumentation/curia-vista/pages/default.aspx)

- Documents of the transport research program of the Swiss Federal Office of Energy
  (www.bfe.admin.ch/forschungverkehr/index.html?lang=en&dossier_id=03670)

- Annual reports of the Federal Energy Research Commission (CORE)
  (www.bfe.admin.ch/themen/00519/00520/index.html?lang=en&dossier_id=00800)

- Swiss Federal Energy Research Master Plans form 1988-2010
  (www.bfe.admin.ch/themen/00519/index.html?lang=en&dossier_id=00798)

- Project lists and annual reports of the Commission for Technology and Innovation (CTI)
  (www.kti.admin.ch/dokumentation/00077/index.html?lang=en)

- ENET-News and LEM-News

- Annual proceedings of the Tour de Sol from 1985-1992

- Annual reports (hybrid and electric vehicles) of the International Energy Agency (IEA)

Print media[11]

- LexisNexis: Newspaper database (www.lexisnexis.com)
- Archive of the newspaper “Der Bund“
- Archive of the newspaper “Basler Zeitung“
- Archive of the newspaper “Neue Zürcher Zeitung”
- Archive Velojournal

[11] Used key words: E-Scooter, Elektro-Scooter, Elektroscooter, E-Roller, Elektro-Roller, Elektroroller, E-Bike, Elektro-Bike, Elektrobike, E-Velo, Elektro-Velo, Elektrovelo, E-Fahrrad, Elektro-Fahrrad, Elektrofahrrad, Elektrozweirad, FLYER, Velocity

8.2 Appendix III-B: Publicly financed e-bike and e-scooter projects in Switzerland

Projekttitel	Projektnummer	Zeitraum	Gesamtkosten bewilligt	Finanzierung durch	Durchführende Institution	Typ
Batteriebetriebenes Elektromotorfahrrad		Mitte 1991 - 1993		BFE	Priv	
Nickel-Hybrid-Versuchsbetrieb mit Elektromofa		bis Mitte März 1993		BFE	Priv	
Velocity:Proj.z.wirtsch. Umsetzung	144	01.06.1992 - 31.12.1996	129'000	BFE	Priv	
Elektro-Roller KOLIBRI	450	01.04.1993 - 31.03.1997	42'400	BFE, Kt BS	Priv	P+D
Marktstudie für "HyBike"-Hybrid-Elektromotorfahrra	10138	01.12.1993 - 31.07.1996	22'000	BFE, Kt SG	Priv	P+D
Elektrovelo "Velocity"				BFE, Kt BS	Priv	P+D
P+D-Test und Markt- und Energiesparpotential auf	16815	01.01.1996 - 31.12.1997	32'400	BFE, Kt BE	Priv	P+D
Elektrobike Flyer	19409	01.12.1996 - 31.05.1999	23'700	BFE	Priv	P+D
Elektrobike "New Flyer"	19416	01.12.1996 - 31.05.1999	173'600	BFE, KTI	Priv	P+D
MobiLEM-Wohlen 1997	19471	15.12.1996 - 30.04.1998	24'300	BFE	Priv	
KTI - start-up ! Machbarkeitsstudie für die Rahmen	3523.1;1 SUS	01.03.1997 - 22.10.1997	69'000	KTI	ETHZ	
KTI - start-up ! Machbarkeitsstudie für die Antriebs	3516.1;2 SUS	01.06.1997 - 06.08.2004	71'610	KTI	EPFL	
Hauslieferdienst	23465	01.09.1997 - 30.09.1999	13'089	BFE	Priv	
Start-up! New Flyer	3706.1;3 SUS	01.10.1997 - 10.08.2004	901'500	KTI	ETHZ	
MobiLEM-Wohlen 1998	26087	01.01.1998 - 31.05.1999	24'300	BFE		
KTI - start-up ! 'New Flyer'Realisierung einer innova	4076.1;3 FHS	01.09.1998 - 27.04.2001	180'000	KTI	FH Bern	
MobiLEM	32083	01.01.1999 - 31.12.2001	95'000	BFE		
Dolphin Power E-Bike	32743	01.06.1999 - 15.08.2002	30'000	BFE	Priv	P+D
E-TOUR: Electric-twowheelers on urban roads	99.0484-2	01.03.2000 - 31.03.2004	138'758	Bund, Kt BE	Uni, Priv	P+D, Int
E-TOUR: Electric-twowheelers on urban roads	99.0484-1	01.04.2000 - 31.03.2003	19'570			
E-TOUR: Electric-twowheelers on urban roads	99.0484-3	01.04.2000 - 31.03.2003	30'009			
Sytrel E-Bike: Mobitec	40575	01.01.2001 - 31.12.2002	40'000	BFE, Kt NE	Priv	P+D
Spirit of Bike – Entwicklung und Promotion einer ne	UTF 59.14.01	08.01.2001 - 31.12.2002	800'000	BAFU	FH Bern	
New Ride	41298	20.03.2001 - 31.12.2002	58'000			
Bürgschaft Velocity	42901	01.09.2001 - 30.09.2004	91'830	BFE	Priv	P+D
Entwicklung eines effizienten Elektro-Bikes	2001.I.21	10.10.2001 - 19.12.2001	50'000	BAFU	FH Bern	
Ausweitung New Ride auf weitere Kantone	43709	01.12.2001 - 31.03.2003	320'000	BFE, Kt BE	Uni	P+D
E-Management-Integration	45975	01.02.2002 - 31.12.2005	160'000	BFE, Kt BE	FH Bern	A
e-rent	45075	01.04.2002 - 31.12.2005	47'500	BFE, Kt BE	Kant	P+D
CIM 02, nouvelles mobilités	45775	01.07.2002 - 31.12.2004	50'000	BFE	Kant	P+D
NewRide	46182	30.11.2002 - 31.03.2004	490'000			
Finanzielle Anreize für effiziente Fahrzeuge	SVI2001/519	27.02.2003 - 21.07.2006	160'136	ASTRA	Priv	
Finanzielle Anreize für effiziente Fahrzeuge	100262	01.03.2003 - 31.12.2005	66'200	BFE, Bund	Priv	A
Energieeffizienter Leicht-Scooter	47854	01.07.2003 - 31.12.2005	115'744	BFE, Kt BE	FH Bern	A
Elektroscooter Genf	100264	01.08.2003 - 01.10.2003	5'850	BFE	Priv	P+D
NewRide 2004	100250	01.09.2003 - 31.03.2005	594'000	BFE	Uni Bern	
Electric Two Wheelers	101746	01.05.2006 - 31.08.2008	188'223	BFE	Priv	A, Int
E-Bike Reichweitentest	101753	01.08.2006 - 31.12.2008	46'000	BFE, Bund	Priv	A
Entwicklung neue Antriebstechnik für E-Bikes	101981	15.01.2007 - 30.09.2007	135'000	BFE	Priv	A
Multivariate statistische Auswertung des E-Bike Rei	103211	01.07.2009 - 31.03.2010	80'000	BFE		
E-Scooters: Marktentwicklung, Analyse der Akteure	103209	01.07.2009 - 31.12.2013	600'000	BFE		
Co-Finanzierungsbeitrag an das Projekt E-Scooter	ASTRA2010/024	13.10.2010 - 31.12.2013	256'000	ASTRA		

8.3 Appendix III-C: Event type descriptions

System Functions	Event Types	Descriptions
F1: Entrepreneurial Activities **Activities:** Involve projects aimed to prove the usefulness of the emerging technology in a practical and/or commercial environment. **Actors:** An entrepreneur can be a new business entrant, an incumbent company or a public actor (performing market-oriented experiments).	- Projects with a commercial aim started (+) - Projects with a commercial aim stopped (-) - Demonstrations started (+) - Demonstrations stopped (-) - Portfolio expansions - Organizations entering the market	- Technology is explored with a commercial and/or societal goal. → E - Activities are cancelled ahead of schedule. - Verifications of the technology's functionality and suitability for daily use (public opinion impact). → S - Activities are cancelled ahead of schedule. - A (vested) actor explores activities without any previous experience. → S - e.g. foundation of a company → E **E = Enactor:** actors that are closely involved in the development of a particular technology and fundamentally dependent on its success (small technology developers and industries dedicated to particular technologies). **S = Selector:** actors that are engaged with that technology at a distance because they have multiple options (regulators, financers, users, large firms that are able to support multiple technological options).
F2: Knowledge Development → creation of variety **Activities:** Involve learning activities, mostly on the emerging technology, but also on markets, networks, users… **Actors:** Typically fulfilled through universities or other research institutes. Contributions by entrepreneurs are also possible.	- Prospective studies - Laboratory trials - Prototypes developed - Pilots	- e.g. computer simulations, market studies, pre-studies, feasibility studies, surveys, comparison test - e.g. technology studies, technical measurements - … - The crucial tests after the laboratory phase (research relevance). E.g. test drives
F3: Knowledge Diffusion **Activities:** Involve partnerships between actors but also meetings like workshops and conferences. **Actors:** A broad variety of actors and networks.	- Reports - Conferences - Exhibitions - Workshops - Alliances between actors - Joint ventures - Setting up of branch organizations - Setting up of platforms	- e.g. publication of: research outcomes, annual reports, conference proceedings, interim reports - e.g. congress, session, specialist conferences, symposia - e.g. road shows, rally - e.g. training workshops, excursions, meetings of monitoring groups - e.g. cooperation networks, build-up of platform member groups, public private partnerships (PPP) - … - … - Platform = an (innovation) intermediary between the supply-side and the demand-side

F4: Guidance of the Search → selection process **Activities:** Involve activities that shape the needs, requirements and expectations of actors with respect to their (further) support of the emerging technology. Individual choices but also hard institutions (e.g. policy targets). **Actors:** Can be fulfilled through industries or governments.	- Expectations positive (+) - Expectations negative (-) - Promises positive (+) - Promises negative (-) - Research outcomes positive (+) - Research outcomes negative (-) - Policy targets - Standards - Roadmaps - Awards - Label	- Expression of the technology's future positive expectations. (technology producers, users, NGOs) - Expression of the technology's future negative expectations. - Promises by actors with the power to change institutions, complementing the technology. E.g. public call - Promises by actors with the power to change institutions, hampering the technology. - Positive results of research, trials and demonstrations (often mentioned when reports are published). - Negative results of research and trials and demonstrations. - e.g. research focuses, emission reduction targets - e.g. technical regulations, safety standards - e.g. technology roadmaps - Award draws attention to the technology. - e.g. quality label
F5: Market Formation **Activities:** Involve activities that contribute to the creation of a demand for the emerging technology, for example by financially supporting the use of the emerging technology, or by taxing the use of competing technologies. **Actors:** Typically fulfilled by governments through the setting up of formal institutions.	- Financial support for the technology's use - Regulations supporting niche markets (+) - Regulations hampering niche markets (-) - Generic tax exemptions (+) - Lack of tax exemptions (-) - 'Obligatory use'	- e.g. subsidy on purchase of product - e.g. eased regulations (license of vehicle), restrictions/bans/tightening norms of conventional technology - e.g. unfavorable vehicle classifications (requirement to have a driver's licence or to wear a helmet) - e.g. fuel tax exemptions - Expressed lack of tax exemption. - e.g. public procurement plans, directives on public tendering
F6: Resource Mobilization **Activities:** Involve activities like investments and subsidies but can also involve the deployment of generic infrastructures (e.g. refueling infrastructures). **Actors:** Fulfilled by all kind of actors, industries and governments alike.	- Financial capital (+) - Refusal of financial capital (-) - Infrastructure developments (+) - Infrastructure developments (-)	- e.g. public project funding, seed and venture capital, bank loans - e.g. rejection of (public) financial support, cutbacks, expressed lack of subsidies or investments - Generic infrastructures such as educational systems, large R&D facilities or refuelling infrastructures. - Expressed lack of infrastructure developments.

F7: Creation of Legitimacy **Activities:** Involves political lobbies and advice activities on behalf of interest groups. → Urging authorities to reorganize the institutional configuration of the TIS. **Actors:** Typically fulfilled by private actors such as NGOs or industries, usually organized in networks, but public actors may also contribute. Examples: ▪ Regional government urges national government. ▪ Intermediary organization advises regional govern-ment.	- Lobbies / Advice pro (+) - Lobbies / Advice contra (-)	- Pressure on actors in power to change institutions, complementing the technology. - Pressure on actors in power to change institutions, hampering the technology. - Pressure on actors in power to improve technical, institutional, financial conditions for new technology. - Expressed lack of lobby by actors; Lobby for technology that competes with new technology.
Context	- Context technology - Context market - Context external - Context actors/networks - Context institution	- General descriptions of or information about technological characteristics. - Descriptions of market developments. E.g. prices, number of brands - Changes external to the technological innovation system (TIS). - … - …

8.4 Appendix III-D: Examples of genuine events taken from the database[12]

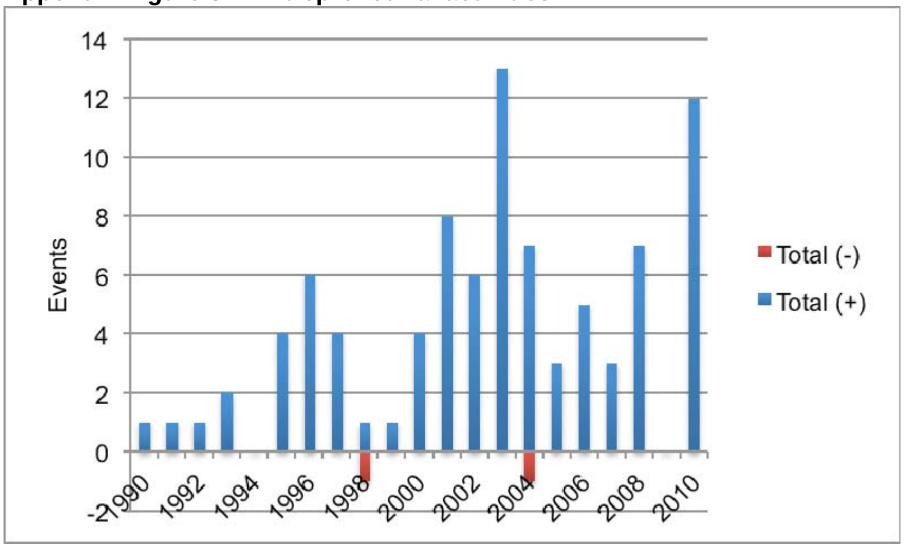
Nr.	Jahr	Referenz	Event-Beschreibung	Event-Kategorie	Funktion
...	1992	Überblicksberichte der BFE-Programmleiter 1992, S.19	Projekt „Batteriebetriebenes Elektromotorfahrrad“: Nach der Erstellung der Gesamtkonzeption und dem Einkauf der aus vorhandenen Benzinmotorfahrrädern übernehmbaren Bauteile im Jahre 1991 konnte in diesem Jahr die Montage des Elektrofahrrades vorgenommen werde.	Prototypes developed	F2
...	1993	ARAMIS 450	01.04.1993 - 31.03.1997: Start Projekt „Elektro-Roller KOLIBRI“	Projects with a commercial aim started (+)	F1
...	1993	ARAMIS 450	Finanzierung „Elektro-Roller KOLIBRI“: BFE, Kt BS (CHF 42'400)	Financial capital (+)	F6
	1994	Basler Zeitung 07.04.2000, S.65 „Das Elektrovelo - ein «reines» Vergnügen“	«In der Schweiz gelten solche Fahrzeuge definitionsgemäss als Motorfahrräder», heisst es zwar in den «Weisungen» des Eidg. Justiz- und Polizeidepartements vom 3. Juni 1994 an die Kantone, aber weiter: «Um die Verbreitung von solchen umweltfreundlichen Fahrzeugen nicht zu behindern, sollen (…) Erleichterungen gewährt werden, die den Besonderheiten dieser Fahrzeuge Rechnung tragen.»	Regulations supporting niche markets (+)	F5
...	2000	Datenbank Energieforschung	Veröffentlichung Publikation "Ökobilanz und Energiesparpotential von muskelkraftverstärkenden Zweirädern am Beispiel des Elektrobikes FLYER" am 01.01.2000 (PubNr: 200116)	Reports	F3
...	2001	NewRide Jahresbericht 2001, S.6	Am 20. März 2001 hat Frau Regierungsrätin Schaer-Born in enger Zusammenarbeit mit EnergieSchweiz das Programm *NewRide* lanciert. Zu diesem Zeitpunkt haben bereits mehrere Gemeinden und diverse Betriebe ihre aktive Teilnahme zugesichert.	Setting up of platforms	F3
...	2001	Der Bund, 15.12.2001 „Zuversicht, doch keine Euphorie bei E-Bike Pionieren“	Das «Intellibike» demonstrierte eindrücklich, dass noch beträchtliche technische Fortschritte möglich sind. Und die Hersteller von marktfähigen Fahrzeugen verfolgen die Entwicklung aufmerksam.	Research outcomes positive (+)	F4
...	2007	NewRide Jahresbericht 2007, S.8	Durchführung Parlamentsanlass (19. Sept.)	Lobbies / Advice pro (+)	F7
...	2010	Curia Vista 15.12.2010	Motion 10.4007 von Nationalrätin Anita Lachenmeier-Thüring „Grenzwerte für Lärm- und Abgasemissionen für Motorräder und Kleinmotorräder“	Lobbies / Advice pro (+)	F7

[12] The complete database containing about 350 events is available on request.

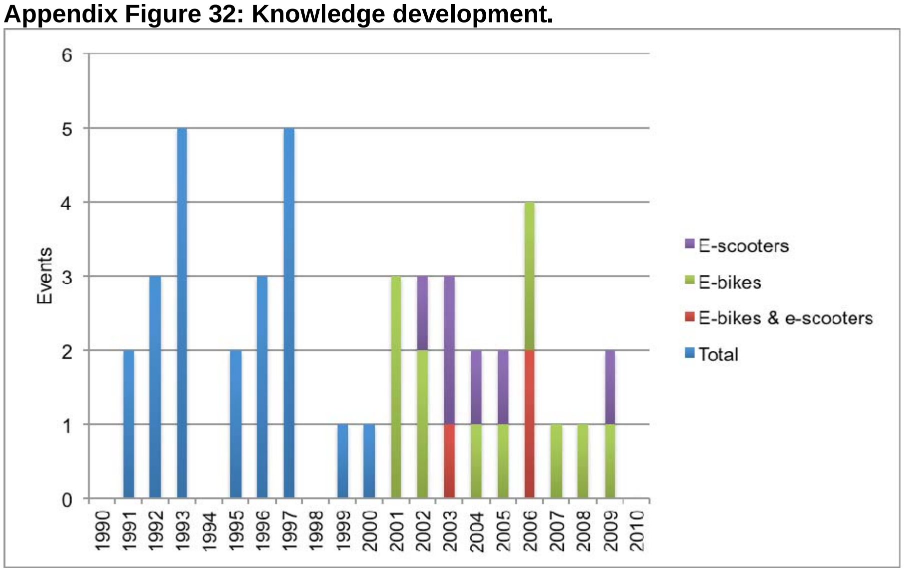
8.5 Appendix III-E: Functional patterns

The following figures present the functional patterns of the system functions (1990-2010). As from the year 2001, a distinction is made between e-bike and e-scooter specific events.

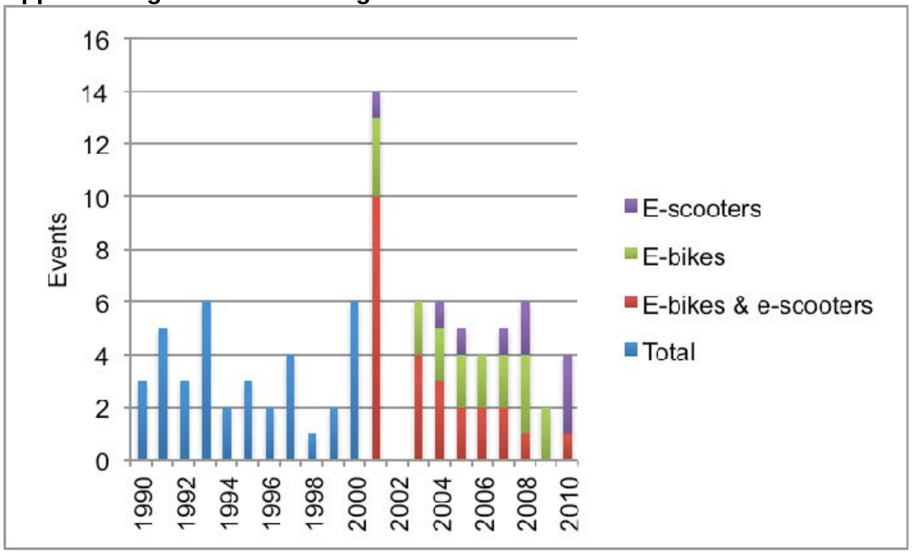
Appendix Figure 31: Entrepreneurial activities.



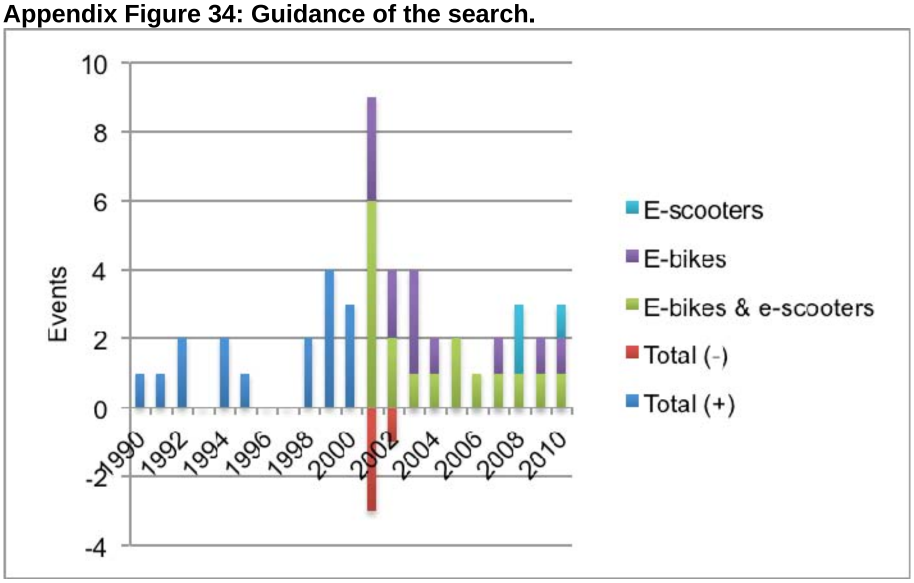
Appendix Figure 32: Knowledge development.



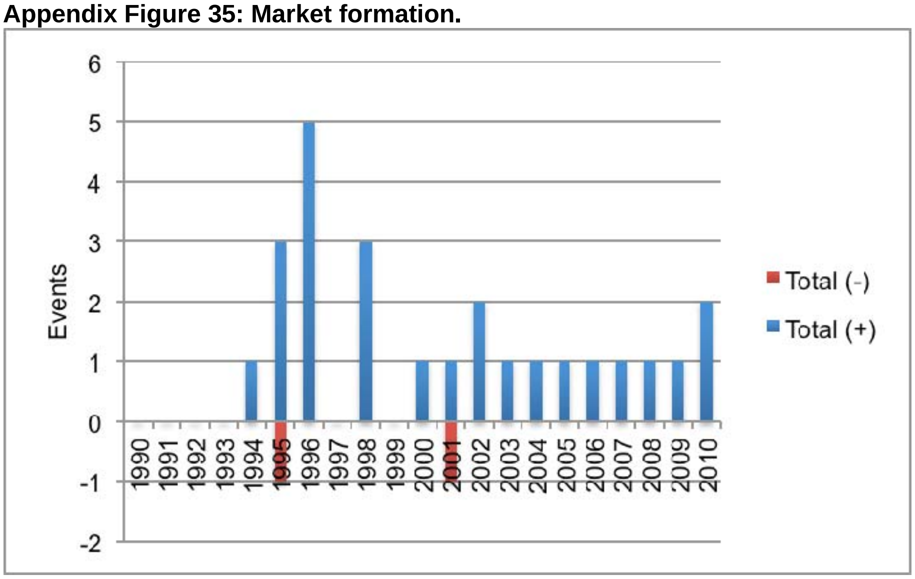
Appendix Figure 33: Knowledge diffusion.



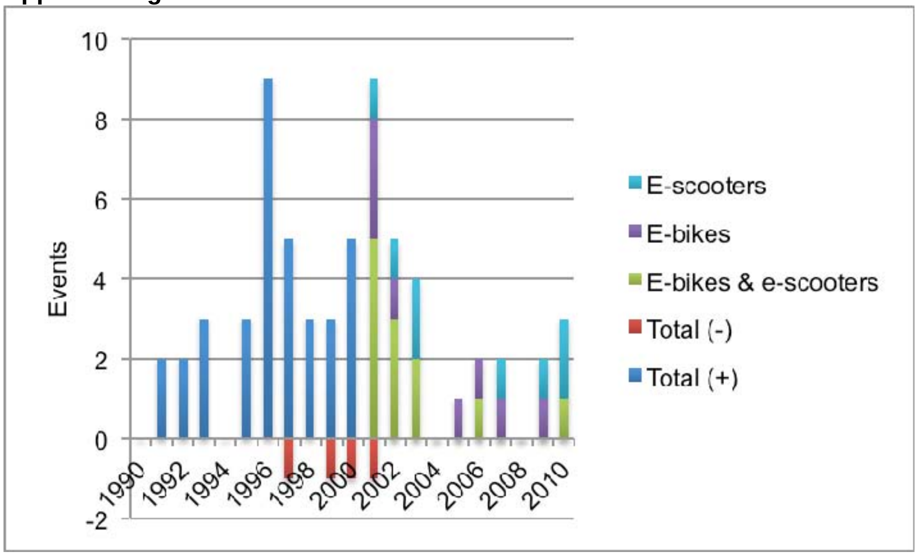
Appendix Figure 34: Guidance of the search.



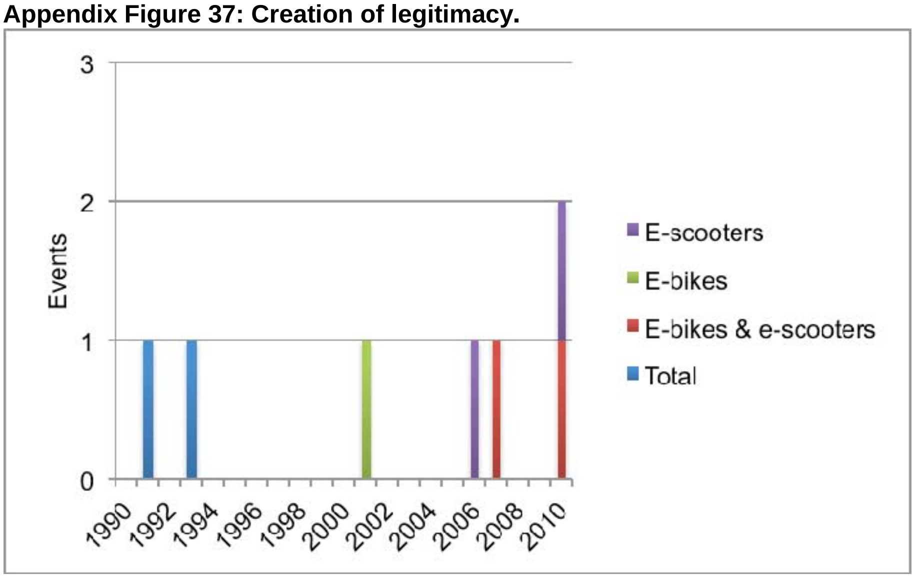
Appendix Figure 35: Market formation.



Appendix Figure 36: Resource mobilization.

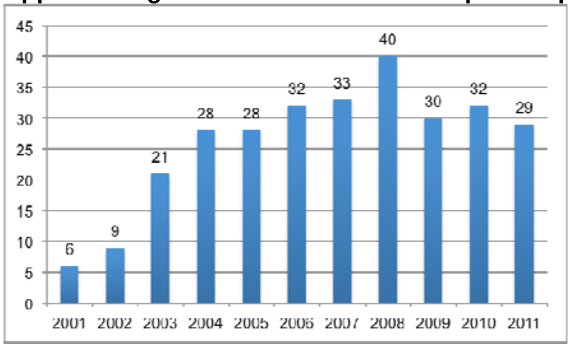


Appendix Figure 37: Creation of legitimacy.

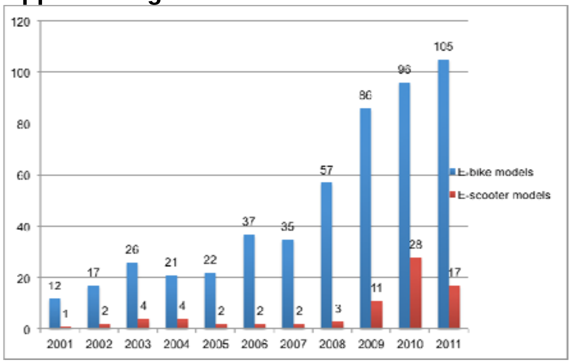


8.6 Appendix III-F: Further numerical data

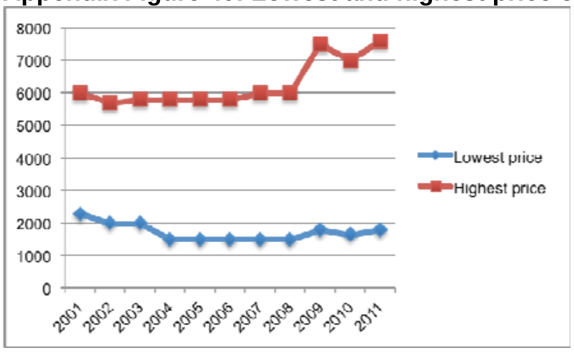
Appendix Figure 38: Number of municipalities participating in the NewRide program.[13]



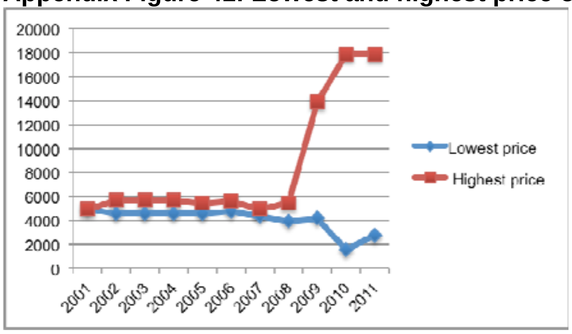
Appendix Figure 39: Number of available e-bike and e-scooter models.[13]



Appendix Figure 40: Lowest and highest price of available e-bikes.[13]



Appendix Figure 41: Lowest and highest price of available e-scooters.[13]



[13] Own figure based on NewRide's annual reports (2001-2011).

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9.2 Curriculum Vitae

Name: Stephan Georg Walter
Born: 11.07.1981
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Academic qualifications

Current: Enrolled in a doctoral program at the Paul Scherrer Institute (PSI) of the Swiss Federal Institute of Technology, Zurich (ETH Zurich).

2008: Master of Science in Economics, University of Bern.

2006: Bachelor of Science in Economics, University of Bern.

Summer Schools

2011: Technological Innovation Systems: Conceptual, methodological and empirical frontiers, Chalmers University of Technology.

2010: Climate-KIC Summer School on Climate Change Innovation, European Institute of Innovation and Technology (EIT).

Employment

2009/5 – 2012/9:
Doctoral student at the Paul Scherrer Institute (Dynamics of Innovative Systems Group).

2008/2 – 2009/4:
Corporate banking assistant at BEKB | BCBE.

Peer-reviewed journal articles

Walter, S., S. Ulli-Beer and A. Wokaun, *Assessing customer preferences for hydrogen-powered street sweepers: A choice experiment.* International Journal of Hydrogen Energy, 2012. **37**(16): p. 12003-12014.

Walter, S., S. Ulli-Beer and A. Wokaun, *A theoretically grounded transition roadmap: The Swiss innovation system around fuel cell and hydrogen transport technologies* (submitted to *Technological Forecasting and Social Change*)

Walter, S., S. Ulli-Beer and A. Wokaun, *What policy strategy is needed beyond the initial protective space? A niche comparison of electric two-wheelers in Switzerland* (submitted to *Research Policy*)

Conference presentations

Walter, S., S. Ulli-Beer and A. Wokaun, *Assessing consumer preferences for hydrogen driven road-sweepers,* 18th World Hydrogen Energy Conference 2010, Essen, 16-21 October

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