Chapter 1
Introduction

1.1 Motivation and General Research Question

The abundant availability of energy is a crucial foundation of modern, industrial societies (Afgan et al. 1998; Haas et al. 2008; Hammond 2004). It is and will be among the very basic factors that allow to sustain or that will erode the welfare of advanced, western societies—and others probably as well. Currently, however, the energy system basically relies on natural resources such as oil, coal and gas. These resources are not renewable, at least in human time horizons. In order to access new reserves, advanced, yet also more risky, technologies need to be applied. The great oil spill in the Gulf of Mexico in the year 2010, is but one example of environmental degradation and economic losses caused by the quest for fossil-fuels. Should fossil energy resources approach depletion without sufficient alternative energy capacity in place, then the welfare of future generations is substantially threatened. In addition, the burning of the resources that fueled industrialization and its spread across the globe led to rising concentrations of CO_2 and other gases in the atmosphere. These gases cause more heat to be trapped in the earth's atmosphere and lead to an increase of average temperatures across the globe. This in turn may shift precipitation patterns, increase the frequency of hazardous weather conditions and quite generally threaten the productive capacity of the biosphere. As scientific knowledge about this grew, demands for ambitious policies have emerged and states have implemented policies aimed at the mitigation of climate change. All in all, however, global energy demand as well as global greenhouse-gas emissions have risen despite all efforts, and they will continue to do so over the next decades.

Nuclear power, often touted as a clean alternative to carbon-based energy, faces different problems. While CO_2 emissions from nuclear power are small compared to coal or gas power plants, nuclear technology entails enormous environmental risks, as the nuclear catastrophe in Fukushima in the year 2011 demonstrates. Furthermore, mining and production of nuclear fission materials cause environmental degradation and could potentially contribute to nuclear arms proliferation. Despite decades of nuclear technology, the secure long-term storage of radioactive waste still poses

M. O. Müller, *Diffusion Dynamics of Energy-Efficient Renovations*,
Lecture Notes in Energy 14, DOI: 10.1007/978-3-642-37175-2_1,

a big challenge. Hence, nuclear power faces strong political opposition in several countries, including Switzerland.

Alternative energy technologies, such as for example wind turbines, biofuels or the various solar-based technologies have been steadily making progress in the technological, the environmental and the economic dimensions. However, over the next one or two decades (and perhaps even longer), they are unlikely to replace fossil-fuels and nuclear generation as the main energy providers. This holds for Switzerland and probably also most other European countries. In order to attain a large share of energy from non-nuclear, low-carbon energy technologies, energy efficiency must be increased such that Switzerland's energy demand is reduced substantially. Energy efficiency refers to reductions in the energy input required to provide a particular service, while keeping the level of service provided constant. In particular, it could entail reductions in the energy demand while welfare levels rise.

Buildings account for nearly half of Switzerland's demand for energy. Further, buildings have an enormous technical efficiency potential, which may even come at negative costs. Due to the long service life of buildings and because energy standards have substantially tightened in recent years, the demand for energy services of older buildings is several times higher than the demand for energy services from recently constructed buildings. Hence, increasing the energy efficiency of aging buildings is crucial for climate and energy policy. Because most buildings are residential, special attention must be given to this type of buildings. Further, multifamily buildings account for the largest share of residential floor space. In conclusion, residential multifamily buildings account for the largest renovation potential.

Current renovation practices, however, clearly fall below the technical and economical potential. In consequence, too little renovations are implemented that increase the energy-efficiency of buildings in line with current construction standards. Motivated by this situation, this study addresses the following general research question:

How can the diffusion of energy-efficient renovations of (residential multifamily) buildings be accelerated in order to reduce Switzerland's emission of CO_2?

In order to address this general research question I will develop a System Dynamics simulation model of the diffusion of energy-efficient renovations and use it to find interventions that might accelerate the diffusion process. To guide the research toward that goal, further, more specific research questions will be developed (see Sect. 1.3).

The introduction proceeds as follows. In Sect. 1.2 I review several streams of research that are related to the subject of this study. From that review I conclude that my work addresses a societally relevant and scientifically interesting gap in the literature. In a next step, in Sect. 1.3, I provide a series of more specific research questions. Using specific research questions will help to further focus my study. Further, I discuss what aspects need to be excluded from the study. In Sect. 1.4

I explain the conceptualization and the structure of the study and introduce a series of conventions. In Sect. 1.5, I briefly introduce the main theories and some key definitions and concepts which I will use. Finally, in Sect. 1.6, I briefly elaborate on the institutional background within which this study was conducted.

1.2 Relevant Streams of Research

A wealth of publications, both scientific and for the general public, address issues directly and indirectly related to energy efficiency in buildings. In order to position this study relative to the literature and in order to show the research gap it aims to address, I briefly introduce the most important streams of research. Note that the actual literature review is mostly provided in Chap. 3. Due to the broad scope of this study, it is not possible to review all the publications that touch upon its different aspects. Therefore, I had to focus on the most relevant studies.

1.2.1 Main Contributors to the Research Field

In the research field "energy in buildings" there are specific persons and institutions that have contributed several of the most important publications for the Swiss context. Probably the most important players are governmental agencies, in particular Switzerland's Federal Office for Energy. The Federal Office for Energy is crucial because it commissions studies within several research programs.[1] Particularly relevant is the research program "energy in buildings".[2] However, the actual research within this research program is mostly carried out by specialized contract research firms or research groups at universities and similar public institutions. Typically, in research commissioned by the federal office for energy, there is a focus on direct relevance for decision-makers in public and private organizations. Further, these reports quite often develop a synthesis regarding their specific subject. Offices in several cantons and in big cities commission and publish studies related to energy in buildings as well. For example, the city of Zürich's construction department[3] reports on a broad series of initiatives in the context of sustainable construction and management of buildings.

In academia, there are several organizations that have repeatedly contributed toward government research programs. Research originating from the Center for

---

[1] See http://www.bfe.admin.ch/themen/00519/00636/index.html, accessed 24 Aug 2011, for an overview of the office's energy-related research programs.

[2] See Meier et al. (2002) and http://www.bfe.admin.ch/forschunggebaeude/index.html, accessed 24 Aug 2011, for that particular research program.

[3] See in particular the website of its office for sustainability in construction, http://www.stadt-zuerich.ch/hbd/de/index/hochbau/nachhaltiges_bauen.html, accessed 24 Aug 2011.

Energy Policy and Economics (CEPE)[4] at the Swiss Federal Institute of Technology in Zürich (ETHZ) has been very important in investigating investor preferences and behavior, cost dynamics for energy-efficient technologies, and the importance of co-benefits of energy efficiency in buildings. Recently, Tep-energy[5] was created as a spin-off from CEPE, to provide research and consulting in the domains of energy, buildings and economics with a focus on economical and technical aspects. Further, researchers in several research groups in the broader ETH domain have published relevant contributions such as energy models or strategy recommendations that include the stock of buildings (also see Sect. 4.2). At the University of Applied Sciences Northwestern Switzerland, the Institute for Energy in Construction[6] has been instrumental in the development of the Minergie standard. It also has contributed research on pilot regions for the 2000 watt society, sustainable construction and renovation strategies, among others. At the University of St.Gallen, the Institute for Economy and the Environment[7] has conducted studies on the marketing of energy-efficient buildings and sustainability in the construction industry. Further, several doctoral dissertations with some relevance for energy in buildings have been submitted to university departments that do not have a particular specialization in the domain of energy in buildings.[8] In addition to such core contributors, the literature published in international scientific journals is a crucial source for many aspects related to energy in buildings.

Private research companies have produced voluminous and highly informative reports on various aspects of energy in buildings. They frequently cooperate with each other as well as with authors in academia. It is standard practice to have a group of experts oversee and guide such studies. Private research companies with a substantial track record in the domain of energy in buildings in Switzerland include Amstein+Walthert,[9] Econcept,[10] ECOPLAN[11] and INFRAS.[12] Professional organizations and non-profit organizations also provide scientific reports on energy in buildings. For example, the Swiss association of engineers and architects (SIA)[13] provides guidelines and norms that were developed by working groups of members.

On the international level, several organizations play a crucial role. The International Energy Agency (IEA) which is part of the Organization for Economic Cooperation and Development (OECD) is an authoritative source on issues of energy supply and demand. It publishes extensively and with a broad scope. The Intergovernmental

[4] See http://www.cepe.ethz.ch. Accessed 24 Aug 2011.

[5] See http://www.tep-energy.ch. Accessed 24 Aug 2011.

[6] See http://www.fhnw.ch/habg/iebau. Accessed 24 Aug 2011.

[7] See http://www.iwoe.unisg.ch. Accessed 24 Aug 2011.

[8] See, for example, Bornstein (2007), Lalive d'Epinay (2000), Kost (2006), Schulz (2007) Stahel (2006) or Van Wezemael (2005).

[9] See http://www.amstein-walthert.ch. Accessed 24 Aug 2011.

[10] See http://www.econcept.ch. Accessed 24 Aug 2011.

[11] See http://www.ecoplan.ch. Accessed 24 Aug 2011.

[12] See http://www.infras.ch. Accessed 24 Aug 2011.

[13] See http://www.sia.ch. Accessed 24 Aug 2011.

Panel on Climate Change (IPCC) is the authoritative source on issues related to climate change. In addition to its review of natural science findings, it also compiles extensive reports on different sectors and reviews policies and instruments.

1.2.2 Major Contributions

In the following, I briefly introduce some research that turned out to be relevant for understanding the diffusion of energy-efficient renovations. Note that I consciously focus on simply outlining streams of research. I do not attempt to show extensively what insights were developed, as this will be done in Chap. 3.

1.2.2.1 The Stock of Buildings, Energy Use and Renovation Practices

Due to the economic importance of the stock of buildings, of the construction industry and of the real-estate market, the stock of buildings has been an object of research for a long time. However, energy issues in the stock of buildings first gained prominence in the aftermath of the energy crisis of the 1970s. Then, first regulations addressing energy use in buildings were implemented. Yet, with low energy prices in the following decades, interest in energy issues in buildings somewhat faded. Later, in the years after 2000, rising energy prices and the emergence of a discourse on climate change caused the stock of buildings to move into the center of environmental policy and partially even public discourse.

Insights into the structure of the stock of buildings until recently came mostly from Switzerland's population census that was carried out every ten years. In the census, detailed data was obtained for building characteristics such as number of flats, number of rooms in each flat, occupants, and many more. However, while data regarding renovation expenditures were obtained, these do not allow to distinguish energetically relevant investments such as façade insulation from other investments. Later, a few studies began to investigate the frequency and characteristics of renovations, based on surveys (POLIS 2007; Econcept and CEPE 2005; Jakob and Jochem 2004; Gerheuser 2004; Jakob et al. 2003). Summarizing the situation, BFE (2005, p. 3) argue that in far too many renovations the opportunity is missed to implement energy-efficient building designs. Further, the potential of replacing aging buildings with state-of-the-art new constructions is mostly missed. That last statement is based on the study by Ott et al. (2002) which compares the renovation of buildings with the demolition and reconstruction of buildings regarding the energetic and ecological consequences. The study concludes that reconstruction can be an ecologically and economically viable alternative, in particular in buildings which can hardly be made to conform with the demands of the market for living space.

While detailed insights into energy-related renovation activities are rare, a substantial body of knowledge exists on the energy demand by the stock of buildings. In particular, the contributions from the Federal Office for Energy's energy perspectives

(Hofer 2007; Wüest and Gabathuler 1991; Wüest and Partner 1994) as well as several simulation studies (Kost 2006; Siller et al. 2007; Schulz 2007; Filchakova et al. 2009; Catenazzi 2009; TEP and ETH 2009). All in all, the stock of residential, commercial and public buildings demand about 45 % of Switzerland's final energy demand (BFE 2005, p. 3). All of these studies find or assume that the average energy demand per square meter has been falling in new constructions. However, information on the energy demand of the stock of buildings are more difficult to obtain (Econcept and Amstein+Walthert 2007).

In Switzerland, the visions of a 2000-watt-society, respectively of a 1-ton-CO_2-society, name the stock of buildings as crucial aspects of achieving such goals. In particular, Koschenz and Pfeiffer (2005) analyzed the potential of residential buildings in Switzerland. They find that the energy demand by the stock of buildings could be reduced by about the factor 1.8, and the share of energy from fossil systems by about the factor 2.4. In order to achieve such reduction goals, however, substantial efforts are required and technology alone will not be able to achieve it. Rather, economical and sociocultural aspects need to gain importance (Koschenz and Pfeiffer 2005, p. 11). The publication "steps towards a sustainable development" (Jochem 2004) is a broad, programmatic study rather than a study on one single issue: It aims to show that the vision of a 2000-watt-society is technically feasible. While the treatment of energy in buildings is brief, the study is important because it calls for a broad program for research and development in the future and stresses the importance of the built environment's contribution. In conclusion, a wealth of studies highlight the relevance of the stock of buildings for policy goals in the domains of energy and climate policy. However, before I comment on the literature discussing policies, I first briefly comment on technological aspects of energy-efficient building designs.

1.2.2.2 Technology and Economics of Energy Efficiency in Buildings

There is a voluminous literature which focuses on technical and architectural questions related to energy-efficient building designs, mostly written for engineers and architects (see for example Krimmling 2007). While technical details are important for practitioners in the construction industry, they are not very relevant for my study. This is because I will operate with the term "energy-efficient building designs" rather than elaborating in detail on the technical complexities which need to be considered when designing and implementing energy-efficient building designs.

Nevertheless, I will draw on contributions which address technological and economical changes in energy-efficient construction. As is typical for innovations, energy-efficient building designs have made substantial technological progress and achieved substantial cost reductions. In particular, I will extensively rely on studies of technological change and innovations. Further, the literature on the economics of energy-efficient building designs and selected components such as windows, insulation material and ventilation systems is crucial. In this domain, several studies need to be mentioned.

CEPE and HBT (2002) contains an extensive report on marginal cost for investments into energy-efficiency in residential buildings. The study analyzes cost dynamics as well as the energetic and non-energetic benefits derived from such investments. The study finds that in the years preceding it, substantial progress was achieved, both in regards to the costs as well as the technological capabilities. This progress was brought about by learning effects and economies of scale—and the authors expect substantial progress in the future (see also Jakob and Madlener 2004; Jakob 2006).

Amstalden et al. (2007) analyse the profitability of energy-efficient retrofit investments from the perspective of the owners of single-family buildings, based on a discounted cash-flow method (they did not consider co-benefits of energy efficiency in the analyis). They show that policy instruments, such as those used in Switzerland at the time, are crucial in order to push investments into energy-efficient retrofits to profitability. Further, the energy price which is expected for the future is among the most relevant factors for investment decision into energy efficiency. Surprisingly, Amstalden et al. (2007, p. 1828) find that "potential cost degression for energy-efficient retrofits-as anticipated today-is significant but not strong enough to become the relevant driving factor for positive economic assessments within the next 50' years."

Ott et al. (2006) further explore direct and indirect co-benefits of investments into energy efficiency (also see Banfi et al. 2008). For example, well insulated flats are more comfortable because they stay warmer in winter. Ventilation systems guarantee high quality of indoor air without having to ventilate a flat manually. Such co-benefits strengthen the case for energy efficiency as they increase the willingness to pay for flats. With statistical procedures, they could show that single family homes with the Minergie label on average were sold for 9 % more compared to standard buildings (Ott et al. 2006, p. 12).

1.2.2.3 Drivers of and Barriers to Energy Efficiency in Buildings

There is a broad literature on the drivers of and barriers to energy efficiency in buildings. Several contributions discuss the situation in Switzerland. Econcept and CEPE (2005), for example, analyzes problems and barriers to energy efficiency in several areas of policy, economic aspects and framing conditions. Jakob (2007) identifies relevant factors affecting the renovation decision of single family home owners in Switzerland. As a first step, the exogenous economic, technical and legal frameworks are analyzed. As a second step, a survey of owners' perception of those frameworks is reported and as a third step the decision in regards to the renovation of the building envelope is modeled based on revealed discrete choice data. The insights from the analysis are used to elicit policy implications for the promotion of energy efficiency in the built environment. BFE (2004) find several explanations why "best practice" products (such as highly energy-efficient windows, insulation, heat pumps, solar systems and ventilation systems) do not broadly diffuse into the market. Among the reasons are the relatively high complexity of technical systems, the widespread existence of principal-agent-relationships which work against energy efficiency and the conservatism of the construction industry, which partially is due to a lack of education and further training (BFE 2004, p. 9).

Further, there are some contributions discussing the situation in other countries. Sutherland (1991) discusses market barriers to energy-efficiency investments. Schleich (2009) discusses barriers to energy efficiency in Germany. Van Bueren and Priemus (2002) identify barriers to sustainable construction in general. Mlecnik et al. (2010) discuss barriers and opportunities for labels for energy-efficient buildings.

1.2.2.4 Housing and the Construction Sector

Housing and the construction sector are important contexts for the diffusion of energy-efficient renovations. Without acceptance on the market for housings, energy-efficient building designs have no chance of diffusing widely. However, from the perspective of actors in the housing and construction sectors, energy efficiency is mostly only a minor aspect of a broad field of practice.

There are several publications that inform on the housing market in Switzerland. Gerheuser (2004), Brunner and Farago (2004), Schulz et al. (2005) and Gerheuser (2006) all report issues such as the supply of housings, rents and many further aspects of the housing market, mostly based on data from the Swiss population census. Fahrländer and Sotomo (2009) disaggregate the housing market based on social stratum, life style and life phase. This enables the classification of whole areas. In addition to these publications, various publications inform on the current state of the housing market.

Schüssler and Thalmann (2005) report on a survey of building owners and investors. The study finds that the construction sector is very heterogenous and that a surprisingly high share of investment is guided by chance rather than professional market considerations. Van Wezemael (2005) investigates decision making in the renovation of residential buildings and finds a polarization of the practices affecting the stock of buildings. "In addition to the hitherto existing differentation of commercial and non-profit agents, financial professionalization and the corresponding implementation of management tools turn out to be of increasing importance to the conduct of managers" (Van Wezemael 2005, ii). In order to research how content occupants of housings are in general, GFS Bern (2006) conducted a survey among tenants. Interesting insights are that the population is generally very content with their situation.

In the housing and construction sectors, issues related to sustainable construction and the marketing of energy-efficient buildings are particularly relevant for my study. I found the following contributions for the Swiss context. Koller (1995) analyzes the relationship between sustainable construction and the competitiveness of companies in the construction industry. Belz and Egger (2000) provide an exploratory analysis of the costs and benefits of energy-efficient buildings from a sustainability marketing perspective. In order to verify the costs and benefits derived from theoretical reflection, they conduct interviews with inhabitants. In Belz et al. (2005), the possibilities and limits of sustainability marketing in Switzerland's construction sector are analyzed.

1.2.2.5 Civil Society and Policy Change

Energy-efficiency in buildings has become a policy priority because of concerns over energy security and the consequences of a rapid increase of the global average temperature. The rise of these two issues has been accompanied by demands of civil-society actors to implement policies which either alleviate the negative consequences of these two issues or contribute to avoiding them all together. In response to these demands, various policies were considered and implemented. The most relevant contributions addressing climate change come from the Intergovernmental Panel for Climate Change, in particular from its fourth assessment report (Core Writing Team et al. 2007). In the domain of energy, publications from the International Energy Agency (IEA), such as the "World Energy Outlook" (IEA/OECD 2008) are crucial. The IEA further published several studies on energy technology (IEA 2008), on energy in buildings (OECD/IEA and AFD 2008; OECD 2003), and it conducts energy policy reviews of its member countries (OECD/IEA 2007).

A series of publications from political science have analyzed policy change caused by the emergence of issues related to climate change and energy use patterns. Such studies of policy change include theoretical contributions (Sabatier and Jenkins-Smith 1993). Yet there are also contributions which specifically analyze changes in climate policy, energy policy and environmental policy (Kriesi and Jegen 2001; Lehmann and Rieder 2002; Jegen 2003; Ingold 2007).

1.2.2.6 System Dynamics Contributions to the Study of Energy-Efficient Buildings

System Dynamics modeling is routinely applied to energy issues. The only System Dynamics work related to energy-efficient buildings in Switzerland I found was work in progress by colleagues investigating the diffusion of newly constructed energy-efficient buildings (Ulli-Beer et al. 2006; Groesser 2007; Groesser and Bruppacher 2007; Groesser and Ulli-Beer 2008; Groesser 2013).

In addition, I found a small number of System Dynamics contributions addressing issues outside of Switzerland. Elias (2008) contributes a study entitled "energy efficiency in New Zealand's residential sector: A systemic analysis". The study investigates the complex feedback structure driving energy efficiency in New Zealand's residential building sector by means of stakeholder analysis and by causal loop diagram modeling. Ben Maalla and Kunsch (2008) provide a study of the diffusion of micro-systems for combined heat-power, a specific technology for the generation of heat and electrical energy at the same time. The study concludes that market forces alone are probably not sufficient to sustain the diffusion of that technology.

1.2.3 Conclusion: The Research Gap

The presentation of research streams above showed that there is a wealth of information available on the various aspects that are relevant for energy-efficient buildings in general and for the diffusion of energy-efficient renovations in particular. Generally, the literature has a strong grounding in empirical research, technical and economic thinking. It makes valuable contributions towards the understanding of the diffusion of energy-efficient renovations. Further, there are some studies from the social sciences which enlighten particularly on the interconnectedness of public opinion and state interventions. I like to think of the majority of contributions as puzzle pieces. Each contribution represents an informative, intriguing facet of the societal problem situation under study. Yet, there are hardly any contributions which put more than a few pieces together, to stay with the image of a puzzle. A small amount of contributions, mostly emanating from research commissioned by governments, strive for a broad perspective on the societal problem situation. However, I did not find any contribution which combines insights into the building-stock, renovation practices, the technology and economics of energy-efficient building designs, housing and the construction sector with insights into civil society and policy change. Further, most studies do not provide causal explanations for change processes. Based on the review of research streams above, I identify the following gap in the literature:

> There are no contributions in the literature which synthesize the wealth of research available, in order to provide a causal explanation of the mechanisms driving the diffusion process of energy-efficient renovations. While a large body of technical and economic insight is available, there are no studies that extend technical and economic insights into the domain of civil society and policy change. Consequently, there are no studies providing a broad analysis of intervention levers, which include but also go beyond technical and economic considerations.

By addressing this research gap, I contribute to the social sciences. My study should inspire further System Dynamics modeling in the social sciences. Its synthetic and interdisciplinary approach might further inspires social science researchers to conduct societally relevant research based on System Dynamics. Further, I expect that this study also leads to practically relevant insights.

1.3 Research Questions, Scope of the Study and Excluded Aspects

Research Questions

In order to address the general research question it is necessary to devise more specific research questions and further clarify the scope of the study. Each of the following specific research questions will guide a substantive chapter of the study (the corresponding chapter is given below, in brackets). Eventually, they support the development of a simulation model that combines various perspectives and allows to find recommendations.

- **How should the context within which the diffusion of energy-efficient renovations takes place, be described in order to guide subsequent system modeling?** (Chap. 3) This research question will allow to develop an intimate understanding of the whole setting within which the diffusion of energy-efficient renovations becomes relevant. In particular, I will describe that setting as a "societal problem situation". This will show that energy-efficient renovations are nested within larger issues, such as climate change and energy use patterns. By describing and analyzing the context within which the diffusion of energy-efficient renovations takes place, I get the chance to introduce most of the issues that later chapters will draw upon.
- **How should the stock of buildings be modeled quantitatively in order to describe its transformation to high energy efficiency? Further, what insights for public policy can be derived from analyzing the resulting model in different scenarios?** (Chap. 4) These research questions aim at further substantiating the description of the societal problem situation. This will be done by developing a small simulation model of Switzerland's stock of residential multifamily buildings and using it for the analysis of different scenarios for the stock of buildings's CO_2 emissions. Later, the resulting small model will be extended into a larger model of the diffusion of energy-efficient renovations.
- **What groups of actors are involved in the societal problem situation and which ones are particularly relevant? How should the behavioral characteristics of the most important actors be represented in a dynamic simulation model?** (Chap. 5) These research questions focuses on actors. Analyzing actors is important because the diffusion of energy-efficient renovations occurs in a pluralistic setting where differences in interests and power exist among different groups of actors. Understanding which actors affect the diffusion process is crucial, also in regards of developing recommendations. In particular, decision-functions for building owners, tenants, architects and advocacy coalitions will be developed in order to represent different types of them in a large System Dynamics model.
- **What are the most important processes causing the diffusion of energy-efficient renovations?**(Chap. 6) This research question focusses on the causal structure that drives the diffusion of energy-efficient renovations. Before any System Dynamics model can be built, the structure of causality should be clarified. In particular, a feedback perspective on the diffusion of energy-efficient renovations in the form of a causal loop diagram will be developed.
- **How should the diffusion of energy-efficient renovations be represented in a rich System Dynamics simulation model? Further, what can be learned from that model?** (Chap. 7) Ultimately, the goal of this study is to build a System Dynamics simulation model of the diffusion process of energy-efficient renovations. While the previous research questions lead to the establishment of four distinct analytical perspectives, this question now calls for a model that integrates these perspectives. In particular, the small model of the stock of buildings

developed in Chap. 4 will be extended, based on the results of the other research questions. The resulting large model is described and used to derive insights into the diffusion process. In addition, the tests used to assure the quality of the large simulation model are described.

- **Based on the analysis of the large System Dynamics model and the analytical perspectives, what recommendations can be given to accelerate the diffusion of energy-efficient renovations as well as the reduction of CO_2 emissions?** (Chap. 8) This research question guides the elicitation of recommendations. In particular, it calls for an analysis of intervention levers found in the model. However, selected results brought about by addressing the other research questions will be used to find further recommendations.

Scope of the Study

The study is carried out for *residential*, *multifamily* buildings in Switzerland. Residential, multifamily buildings are selected because they account for a large share of the built environment. Further, in this study I focus on buildings with *rented flats*. This is because the relationship between building owners and tenants is particularly interesting. This relationship is frequently characterized as a "user-investor-dilemma," where building owners shoulder the cost of investments into energy-efficiency, whereas tenants benefit from reduced energy costs. In particular, I assume that all flats in residential, multifamily buildings are rented to tenants rather than occupied by the actual owner of the flat. Obviously, this is a simplification, as individuals have the possibility to purchase a flat within a multifamily building. Yet, I deem this simplification to be useful because now I can abstain from constantly having to deal with the different rationalities at work in rented and self-occupied living space.[14]

Further, I focus on *heating* and I exclude energy requirements for warm water, appliances and the like. Hence, statements on energy efficiency in buildings generally refer to the energy efficiency of the building hull. This is influenced by the thermal qualities of components such as walls, insulation materials, windows, roofs, balconies and heat losses through ventilation systems. The higher the energy efficiency of the building hull is, the less heat escapes from within the buildings, the less heat needs to be replaced by heating systems and the less energy is required.

While this study focusses on the contributions that efficiency strategies can make, there remain doubts whether efficiency strategies are enough. If efficiency gains are compensated by increased demand, the net reduction of the energy demand may be reduced or even fully compensated. In such a situation, sufficiency strategies might prove sustainable. This refers to the reduction of the demand for energy. However,

[14] For all flats in all kinds of buildings, Schulz and Würmli (2004, p. 15) find that about 60 % are used by tenants and almost 27 % of flats are buildings that are occupied by the inhabitants (single-family homes). About 8 % of flats are occupied by owners of the flat but not of the building (condominiums). For purely residential buildings with three or more flats Schulz and Würmli (2004, p. 17) find that 21.5 % of the buildings are owned by owners of condominiums.

since sufficiency strategies are politically much more difficult to attain, the potential of efficiency strategies probably needs to be realized first.

Excluded Aspects

In addition to the energy efficiency of a building, a wide range of further aspects are generally considered to be important determinants of the sustainability of buildings. However, in this study, I excluded most of these aspects in order to reduce complexity. Nevertheless, since these exclusions are practically relevant, I briefly list the most important of such aspects.

- **Green or ecological construction** refer to an approach that goes beyond energy aspects as criterion for sustainability. In particular, it encourages the use of building materials that were sourced mostly locally, produced in a sustainable manner, do not emit toxic substances. In addition, health aspects in construction are important.[15]
- The amount of energy used to **heat water** has no direct relation with the energy efficiency of the building. Instead, it is related to the number of persons who live in a building and the amount of warm water demanded by them.
- The specific amount of energy that is used to heat a building partially depends on the **behavior of occupants**. User behavior refers to issues such as the temperature to which a building is heated, how and how frequently a building is ventilated. While user behavior accounts for the variability of energy service demand among identical buildings, the level of energy-efficiency implemented explains the average of energy services demanded over a random population.
- **Grey energy** is the energy that is used to produce construction materials, build a building and dispose of the building. It is influenced by issues such as what kind of materials are used in construction, the origin of construction materials, and many more.
- Constructing buildings far away from urban centers and public transport may **induce mobility** as inhabitants are forced to incur longer commutes and might be more likely to use ecologically problematic modes of transports, such as cars instead of public transport.
- There is a direct link between the **technology used to generate heat** and the emission of greenhouse-gases. For example, the sustainability of a rather inefficient building substantially depends on whether it is heated with an oil heating or whether it is heated with a wood oven. While energy is wasted with each technology, the environmental impact differs substantially.

Methodological considerations lead me to exclude the issues above from the study. However, the study may contribute to an understanding of such issues, nonetheless.

[15] See the website of the *eco-bau* association for further information: http://www.eco-bau.ch. Accessed 02 Sept 2011.

Probably, some of the mechanisms that drive the diffusion of energy-efficient renovations also might explain the diffusion of various aspects of sustainable construction.

1.4 Conceptualization, Structure and Conventions

1.4.1 Conceptualization

With the term "conceptualization" I refer to the specific way this study was conceived and put together. In particular, this refers to how the specific research questions relate to each other and contribute to the investigation of the general research question.

It seems important to me to point out that this study is conceptualized as a synthesis rather than a narrowly focussed analysis, although it does rely on several analytical perspectives. Conducting a synthesis is rather untypical for social science dissertations which often focus on a very narrow issue in order to be able to explore it in depth. Narrow and focussed analysis indeed is a crucial element in the generation of new knowledge. However, the results of such analysis are rarely related to a greater phenomenon and even less frequently do social scientists aim to integrate information from various sources into an explicit understanding of a phenomenon.[16] Nevertheless, studies that aim to synthesize various results seem to be important because they provide pictures rather than "heaps of puzzle pieces". However, synthetic approaches are underrepresented in the teaching and practice of social science research (Ackoff 1999). Typically, social scientists refer to "desk research" or "workshop methods" when asked how synthesis was performed.[17] Formal modeling as an approach to the development of a synthesis is seldom used.

The synthetic character of this study means that it does not make sense to put all the literature review or the presentation and discussion of all theories into dedicated chapters. Instead, I rely on *foundations* to present literature reviews or theoretical concepts when they become relevant. For example, in Chap. 8, I included a section titled "Theoretical Foundation: Defining and Analyzing Collaborative Transformations." In consequence, the concept of collaborative transformations is introduced right before the sections where I will rely on that concept. Using such foundations allows for a better line of argument as it provides background knowledge just as the readers needs it.

[16] As far as I know, dissertations using Grounded Theory and some systems approaches (Soft Systems Methodology, System Dynamics) are notable exceptions. See also Sect. 2.2.

[17] Thanks to Rico Defila for making me aware of this.

1.4.2 Structure

The term "structure" refers to the way the study is represented in a linear, textual report. On the highest level, I structured this book into four parts, as described in the following.

- Part I, titled "Introduction: Questions and Approach of the Study", provides an introduction into the study and presents the research design and methods which were used. It consists of Chaps. 1 and 2.
- Part II, titled "Analytical Perspectives: Toward a Systemic Model of the Problem Situation", presents four substantive, analytical perspectives that I developed in order to inform the development of the simulation model. It consists of Chaps. 3–6.
- Part III, titled "Results: A Synthetic Model for Policy Analysis", is a synthesis of the analytical chapters in part II. Here, I present a large System Dynamics simulation model and use it to conduct policy analysis and formulate recommendations in support of the diffusion of energy-efficient renovations. It consists of Chaps. 7 and 8.
- Part IV, titled "Discussion and Conclusions", discusses the results of this study and provides conclusions. It consists of Chaps. 9 and 10.

As can be seen, the two parts in the middle address substantive matters, whereas parts one and four support the study by framing and commenting on it. On a lower level, the study is organized into ten chapters.

- Chapter 1, "Introduction," aims to equip readers with a general idea of the study and its context without burdening them too much with details. Specifically, the general motivation of the study is stated, the existence of a research gap is claimed and the research questions are introduced.
- Chapter 2, "Research Design and Methods," describes and critically discusses research design and provides a description of the research process. In a next step, the specific methods employed are briefly introduced and the specific implementation of the methods are described.
- Chapter 3, "Climate Change, Energy Use and the Stock of Buildings: Outline of a Societal Problem Situation," provides a literature review and can be considered the starting point of the study. It begins with a discussion of the broad context (climate change and energy) and subsequently narrows the focus to the specific context of the issue under study (energy-efficiency in the renovation of multifamiliy buildings in the greater Zürich region). Instead of remaining purely descriptive, this chapter analyses why the issue under study constitutes a "problem situation". Based on this analysis, the research gap that was claimed to exist in the introduction will emerge more precisely. In consequence, it will become evident that a dynamic, holistic perspective promises practically relevant knowledge in support of a transformation towards a more sustainable solution situation.
- Chapter 4, "A Small Model for the Analysis of the Transformation of Switzerland's Stock of Buildings," presents a small System Dynamics model. That model will serve as the basis for the development of a larger model.

- Chapter 5, "Actors in the Societal Problem Situation," develops a typology of agents that are considered important for the renovation system. Most importantly, agents are evaluated in sight of their interest in energy-efficiency in renovations and in sight of their power on the energy efficiency of the built environment. This chapter mostly relies on insights drawn from original empirical research (interviews and a workshop with system experts).
- Chapter 6, "A Feedback Perspective on the Diffusion of Energy-Efficient Renovation," proposes a dynamic hypothesis of how important agents interact with each other and their environment in order to affect the diffusion of energy-efficient renovations. This chapter presents the main feedback loops that will be implemented into the SD simulation model.
- Chapter 7, "Modeling for Integration: A Rich Model of the Diffusion Dynamics of Energy-Efficient Renovations," integrates selected insights from Chaps. 3–6 in the form of a System Dynamics model. In particular, the small model presented in Chap. 4 serves as the base.
- Chapter 8, "Transformation of the Societal Problem Situation," reports on policy analysis based on the large simulation model and develops a range of recommendations as to how the societal problem situation may be transformed.
- Chapter 9, "Discussion and Conclusions," discusses the research questions underlying the study, and offers conclusions. Further, this chapter discusses the contributions, the strengths and the limitations of the study. It elaborates on further research and discusses potential generalizations.

1.4.3 Conventions

Throughout the remainder of this study, I will rely on a number of conventions that briefly need to be introduced.

Use of Subjective Language

I consciously use subjective language, such as the "I-form". One or two colleagues have commented that this may be perceived as unprofessional, even unscientific, as the ideal scientist should strive for a neutral and objective perspective. I strongly agree with such ideals and aspire to live up to them. Yet, over the course of this study, I had to make numerous decisions, regarding issues such as what to include, which theories to use, and so on. Most decisions did not follow a dichotomy of right or wrong, but rather entailed judgement and weighting of arguments. Further, scientific research entails a moment of creativity which ultimately is bound to the person of the researcher. In order to account for all this, I prefer to explicitly use the I-form. Ultimately, this puts me into the role of an engaged author who presents and justifies the results of his research and thought, but who does not claim to have found the final account of "how things are."

Notational Conventions Used When Referring to Variables

When I refer to variables, I set the name of the variable in SMALLCAPS. Because variable names are often rather lengthy, I use three points in square brackets to denote words left out from the variable name. For example, in a figure I might name a variable EFFECT OF RENT ON ATTRACTIVENESS OF PAINTJOB HOUSINGS FOR TENANTS. Abbreviated, in the text, this could read EFFECT OF RENT ON ATTRACTIVENESS ON PAINTJOB HOUSINGS [...].

Notational Conventions for Describing Model Structures

Notational conventions for causal loop diagrams are discussed in Chap. 2, on p. 27. Notational conventions for stock and flow diagrams are discussed also in Chap. 2, on p. 27.

1.5 Theories and Definitions

I use several theories and terms in my study. In the following, I briefly introduce the most important theories I rely upon and briefly define key terms. I rely mostly on contributions from economics, sociology, political science and the social sciences in general.

Built Environment and Stock of Buildings

The term "built environment" may be defined as the totality of human-made objects in the landscape, such as buildings, roads, bridges, tunnels and so on. The built environment is of cultural rather than of natural origin—although nature and the built environment may intersect. The stock of buildings may be defined as the totality of buildings, as a part of the built environment.

Societal Problem Situation

I use the the term "societal problem situation" to characterize the setting within which the diffusion of energy-efficient renovations matters. In particular, I define a societal problem situation to occur when individuals, societal actors or advocacy coalitions take issue with something (material or immaterial), perceive this condition as a threat to the interests of society at large and succeed at making a substantial share of the general public aware of their claim, such that individuals, societal actors or advocacy coalitions holding distinctively opposed views are compelled to engage in a competition for the general publics' endorsement. See p. 53 for further details.

Diffusion of Innovations

Based on the standard text on the theory of the diffusion of innovations (Rogers 2003), I use the term “innovation” to mean any “idea, practice or object that is perceived as new by an individual or other unit of adoption” (Rogers 2003, p. 12). The innovations most relevant for my study are materials and designs for energy-efficient buildings. The diffusion of innovations is then defined as the “ process in which an innovation is communicated through certain channels over time among the members of a social system” (Rogers 2003, p. 5).

Public Policy

I use the term “public policy” to refer to the totality of policies and regulations, regardless of the institutions involved with them. Statements such as “public policy should support research and development initiatives” allow to formulate recommendations without having to deal with the question as to which institutions are involved. More specifically, I find the definition given by Knoepfel et al. (2007, p. 24) very useful. They defined *Public Policy* as “a series of intentionally coherent decisions or activities taken or carried out by different public and sometimes private actors whose resources, institutional links and interest vary, with a view to resolving in a targeted manner a problem defined politically as collective in nature. This group of decisions and activities gives rise to formalized acts of a more or less restrictive nature that are often aimed at modifying the behavior of social groups presumed to be at the root of or able to solve the collective problem to be solved (target groups) in the interest of the social groups who suffer the negative effects of the problem in question (final beneficiaries).”

Instruments and Interventions

“Instruments” are the tools, measures and particular approaches which can be used to make policies have an effect. Generally, the implementation of instruments is an act of sovereignty and hence implemented by the state or organizations exercising sovereignty on behalf of it. More broadly, the term “interventions” may refer to any kind of conscious, goal-oriented action which aims to change the societal problem situation. Finally, the term “intervention lever” refers to any of the “places to intervene in a system” (Meadows 1997). Intervention levers are all kinds of aspects which may be targeted by interventions.

Actors, Actor Groups, Actors in the Market, Civil Society Actors, etc.

I use the term “actors” in order to refer to entities who act in the real world. “They can either be individual persons or collectives of real persons, such as an organization or a social movement" (Müller et al. 2011, p. 4). More specifically, I use terms like "civil society actors" to refer to all actors who participate in civil society action. Referring to actors in such a generic way avoids having to define more precisely what specific actors are meant, when referring to a specific segment of society.

Advocacy Coalition Framework

The advocacy coalition framework is a theory from political science which aspires to explain policy change in specific domains. The term "advocacy coalition" refers to an aggregate of actors in a policy subsystem, which both "(a) share a set of normative and causal beliefs and (b) engage in a non-trivial degree of co-ordinated activity over time" (Sabatier 1998, p. 103). I will use this theory to model policy change in the domain of energy in buildings.

1.6 Background of the Study

In the year 2005, the study "Diffusion Dynamics of Energy-Efficient Buildings[18] (DeeB)" started at the Interdisciplinary Centre for General Ecology (IKAÖ) at the University of Bern. The aim was to investigate the diffusion of newly constructed single and multifamily residential buildings in collaboration with a group of experts representing various actors (Müller et al. 2011). The plan was to combine elements from economics and psychology into a System Dynamics model of the diffusion process. Funding for the project came from the Swiss National Science Foundation, where Prof. Dr. Ruth Kaufmann-Hayoz, Dr. Susanne Bruppacher and Dr. Silvia Ulli-Beer had proposed the project to be carried out within the context of the National Research Program 54 "Sustainable Development of the Built Environment".[19] Practical work started in October 2005 when a colleague and I joined the team as PhD students and research assistants.

As that study progressed, the decision was made to propose a second project, entitled "Diffusion Dynamics of Energy-Efficient Renovations (DeeR)", which would follow a similar research design. This project was organised as a joint project between IKAÖand the research group "Dynamics of Innovative Systems" at Paul Scherrer Institut, with which the primary academic affiliation of Dr. Silvia Ulli-Beer now is. I then took the role as PhD student in the DeeR study.

At the end of the year 2006, the research proposal for the DeeR study was submitted by Prof. Dr. Ruth Kaufmann-Hayoz and Dr. Silvia Ulli-Beer to the Swiss National Science Foundation, Switzerland's Federal Energy Agency, Novatlantis—Sustainability in the ETH Domain, the City of Zürich and the Competence Center

[18] See http://www.deeb.ch/portrait and http://www.ikaoe.unibe.ch/forschung/deeb. Accessed 12 Sept 2011.

[19] See http://www.nfp54.ch Accessed 12 Sept 2011.

for Energy and Mobility. The research proposal was accepted. In addition, the DeeR study was included as a working package within the research network "Advanced Retrofit of Buildings" that formed part of the "Competence Center for Energy and Mobility" (CCEM, part of the ETH domain).

References

Ackoff RL (1999) Disciplines, the two cultures, and the scianities. Syst Res Behav Sci 16:533–537

Afgan NH, Al Gobaisi D, Carvalho MG, Cumo M (1998) Sustainable energy development. Renew Sustain Energy Rev 2:235–286

Amstalden RW, Kost M, Nathani C, Imboden DM (2007) Economic potential of energy-efficient retrofitting in the Swiss residential building sector: the effects of policy instruments and energy price expectations. Energy Policy 35:1819–1829

Banfi S, Farsi M, Filippini M, Jakob M (2008) Willingness to pay for energy-saving measures in residential buildings. Energy Econ 30:503–516

Belz F-M, Egger D (2000) 'Nutzen und Kosten von Niedrigenergiehäusern: Empirische Ergebnisse einer explorativen Studie'. Diskussionsbeitrag No. 80, Institut für Wirtschaft und Ökologie (IWÖ), Universität St. Gallen

Belz F-M, Sammer K, Pant R (2005) Nachhaltigkeits-Marketing in der Baubranche. Best Practices aus der Schweiz. In: Belz F-M, Bilharz M (eds) Nachhaltigkeits-Marketing in Theorie und Praxis. Deutscher Universitäts-Verlag/GWV Fachverlage GmBH, Wiesbaden

Ben Maalla EM, Kunsch PL (2008) Simulation of micro-chp diffusion by means of system dynamics. Energy Policy 36:2308–2319

BFE (2004) Best Practice, Marktordnung, Markttransparenz und Marktregelung zugunsten der Durchsetzung energieeffizienter Lösungen am Markt, Forschungsprogramm Energiewirtschaftliche Grundlagen. Bundesamt für Energie (BFE), Bern

BFE (2005) Grundlagen für eine Strategie Gebäudepark Schweiz, Forschungsprogramm Energiewirtschaftliche Grundlagen. Bundesamt für Energie (BFE), Bern

Bornstein N (2007) Three Essays on the Acceptability of Environmental Policy in Switzerland. PhD Thesis, Ecole Politechnique Féderale de Lausanne, Lausanne

Brunner B, Farago P (2004) 'Wohnverhältnisse in der Schweiz 1970 bis 2000. Ein Vergleich ausgewählter Haushaltstypen und Ländergruppen', Bericht im Auftrag des Bundesamt für Wohnungswesen und des Bundesamt für Statistik

Catenazzi G (2009) Advances in techno-economic energy modeling. Costs, dynamics and hybrid aspects. PhD thesis, Swiss Federal Institute of Technology, Zürich

CEPE and HBT (2002) Grenzkosten bei forcierten Energie-Effizienzmassnahmen in Wohngebäuden, Studie des Center for Energy Policy (CEPE) und HBT Architektur und Baurealisation im Auftrag des Bundesamtes für Energie, Bern

Core Team Writing, Pachauri RK, Reisinger A (eds) (2007) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. Intergovernmental Panel on Climate Change (IPCC), Geneva

Lalive d'Epinay AE (2000) Die Umweltverträglichkeit als eine Determinante des Entwurfs. PhD thesis, Eidgenössische Technische Hochschule, Zürich

Econcept and Amstein+Walthert (2007) Vorstudie zur Erhebung von Energiekennzahlen von Wohnbauten. Bundesamt für Energie (BFE), Bern

Econcept and CEPE (2005) Mobilisierung der energetischen Erneuerungspotenziale im Wohnbaubestand, Forschungsprogramm Energiewirtschaftliche Grundlagen. Bundesamt für Energie (BFE), Bern

Elias A (2008) Energy efficiency in New Zealand's residential sector: a systemic analysis. Energy Policy 36:3278–3285

Fahrländer and Sotomo (2009) ‘Nachfragersegmente im Wohnungsmarkt. Konzeption und Überblick’, Fahrländer und Partner AG und Sotomo, Gesellschaft, Politik und Raum, Zürich. http://www.fpre.ch/d/dateien/NaSeWoUeberblick.pdf. Accessed 17 Aug 2009

Filchakova N, Wilke U, Robinson D (2009) ‘Energy modelling of city housing stock and its temporal evolution’. In: Proceedings of the eleventh conference of the international building performance simulation association (IBPSA), 27–30 July 2010, Glasgow, Scotland. http://www.ibpsa.org/proceedings/BS2009/BS09_1068_1074.pdf. Accessed 27 Feb 2010

Gerheuser FW (2004) Wohnversorgung und Wohnverhältnisse. Entwicklungen 1990–2000, Bundesamt für Statistik (BFS), Neuchâtel

Gerheuser FW (2006) Die Wohnausgaben der Eigentümerhaushalte. Ergebnisse der Mietpreis-Strukturerhebung 2003. Bundesamt für Statistik (BFS), Neuchâtel

Bern GFS (2006) Grundsätzliche Zufriedenheit, punktueller Verbesserungsbedarf und dezidierte Vorstellungen rund um die eigene Wohnsituation, Schlussbericht “Wohnmonitor” im Auftrag des HEV Schweiz. GFS Bern, Forschung für Politik, Kommunikation und Gesellschaft

Groesser SN (2007) ‘The structure and dynamics of the residential building: which mechanisms determine the development of the building stock’. Paper presented at the 25th international conference of the system dynamics society, Boston, USA 29 July–2 Aug 2007

Groesser SN (2013) Co-evolution of standards in innovation systems: the dynamics of voluntary and legal building codes. Physica, Heidelberg.

Groesser SN, Bruppacher S (2007) ‘Decisions in the construction planning process: Development of a dynamic model about individual’s energy efficiency intention over time’. Paper presented at the 25th international conference of the system dynamics society, Boston, USA, 29 July–2 Aug 2007

Groesser SN, Ulli-Beer S (2008) ‘Long-term innovation diffusion in the building construction industry: Empirically based theory building’. Paper presented at the 26th international conference of the system dynamics society, Greece, Athens, July 2008, pp 20–24

Haas R, Nakicenovic N, Ajanovic A, Faber T, Kranzl L, Müller A, Resch G (2008) Towards sustainability of energy systems: a primer on how to apply the concept of energy services to identify necessary trends and policies. Energy Policy 36:4012–4021

Hammond GP (2004) Engineering sustainability: thermodynamics, energy systems, and the environment. Int J Energy Res 28(7):613–639

Hofer P (2007) ‘Der Energieverbrauch der Privaten Haushalte, 1990–2035 Ergebnisse der Szenarien I bis IV und der zugehörigen Sensitivitäten BIP hoch, Preise hoch und Klima wärmer’, Studie im Rahmen der Energieperspektiven 2035 des Bundesamtes für Energie (Bern). Prognos AG, Basel

IEA (2008) Energy technology perspectives 2008: scenarios and strategies to 2050. International Energy Agency (IEA), Paris

IEA/OECD (2008) World energy outlook 2008. International Energy Agency (IEA)/Organisation for Economic Co-operation and Development (OECD), Paris

Ingold K (2007) The influence of actors’ coalition on policy choice: the case of the Swiss climate policy. In: Friemel T (ed) Applications of social network analysis: proceedings of the 3rd conference on applications of social network analysis 2006. UVK Medien, Konstanz

Jakob M (2006) Marginal costs and co-benefits of energy efficiency investments: the case of the Swiss residential sector. Energy Policy 34:172–187

Jakob M (2007) ‘The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners’, CEPE Working Paper No. 56 (Version as of March 14). Centre for Energy Policy and Economics, Swiss Federal Institutes of Technology, Zürich

Jakob M, Jochem E (2004) Erneuerungsverhalten im Bereich Wohngebäude, in ‘Tagungsband 13. Schweizerisches Status-Seminar "Energie- und Umweltforschung im Bauwesen. Tagung vom 9./10. September 2004 an der ETH Zürich’

Jakob M, Madlener R (2004) Riding down the experience curve for energy-efficient building envelopes: the Swiss case for 1970–2020. Int J Energy Technol Policy 2(1/2):153–178

Jakob M, Primas A, Jochem E (2003) 'Erneuerungsverhalten im Bereich Wohngebäude', CEPE Working Paper No. 9. Centre for Energy Policy and Economics, Swiss Federal Institutes of Technology, Zürich

Jegen M (2003) Energiepolitische Vernetzung in der Schweiz. Analyse der Kooperationsnetzwerke und Ideensysteme der energiepolitischen Entscheidungsträger. Helbing & Lichtenhahn, Basel

Jochem E (ed) (2004) Steps towards a sustainable development. A white book for R&D of energy-efficient technologies. Novatlantis, Zürich

Knoepfel P, Larrue C, Varone F, Hill M (2007) Public policy analysis. The Policy Press, Bristol

Koller F (1995) Ökologie und Wettbewerbsfähigkeit in der Schweizer Baubranche, Schriftenreihe Wirtschaft und Ökologie, Nr. 5, Haupt, Bern, Stuttgart, Wien

Koschenz M, Pfeiffer A (2005) Potential Wohngebäude. Energie- und Gebäudetechnik für die 2000-Watt Gesellschaft. Faktor Verlag, Zürich

Kost M (2006) Langfristige Energieverbrauchs- und CO_2-Reduktionspotenziale im Wohngebäudesektor der Schweiz. Dissertation, Eidgenössische Technische Hochschule Zürich

Kriesi H, Jegen M (2001) The Swiss energy policy elite: the actor constellation of a policy domain in transition. Eur J Polit Res 39:251–287

Krimmling J (2007) Energieeffiziente Gebäude. Grundwissen und Arbeitsinstrumente für den Energieberater. Fraunhofer IRB Verlag, Stuttgart

Lehmann L, Rieder S (2002) 'Wissenschaftliches Wissen in der politischen Auseinandersetzung. Fallstudie zur Genese des CO_2-Gesetzes im Auftrag der Arbeitsgruppe Transdisziplinarität der Energiekommission der Schweizerischen Akademie der Technischen Wissenschaften (SATW)'. SATW Bericht Nr. 34, SATW, Zürich

Meadows DH (1997) 'Places to intervene in a system', Whole earth. http://www.wholeearth.com/issue/2091/article/27/places.to.intervene.in.a.system. Accessed 26 Dec 2011

Meier R, Beck M, Previdoli P (eds) (2002) Bauen, Sanieren, wirtschaftlich Investieren. Rüegger, Glarus, Chur

Mlecnik E, Visscher H, van Hal A (2010) Barriers and opportunities for labels for highly energy-efficient houses. Energy Policy 38:4592–4602

Müller MO, Groesser SN, Ulli-Beer S (2011) How do we know who to include in collaborative research? toward a method for the identification of experts. Eur J Oper Res 216(2):495–502

OECD (2003) Environmentally sustainable buildings. Challenges and policies, Organisation for Economic Co-operation and Development (OECD)/International Energy Agency (IEA) and Agence Française de Dévelopment (AFD), Paris

OECD/IEA (2007) Energy Policies of IEA Countries. Switzerland 2007 Review. Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA), Paris

OECD/IEA and AFD (2008) Promoting energy efficiency investments. Case studies in the residential sector, Organisation for Economic Co-operation and Development (OECD) / International Energy Agency (IEA) and Agence Française de Dévelopment (AFD), Paris

Ott W, Binz A, Kaufmann Y, Seiler B, Mossmann A (2002) Neubauen statt Sanieren? Schlussbericht, Teil 1. Zusammenfassung, Forschungsprogramm Energiewirtschaftliche Grundlagen, Bundesamt für Energie (BFE), Bundesamt für Raumentwicklung (ARE), Bundesamt für Wohnungswesen (BWO), Bern, Grenchen

Ott W, Jakob M, Baur M (2006) Direkte und indirekte Zusatznutzen bei energieeffizienten Wohnbauten. Forschungsprogramm Energiewirtschaftliche Grundlagen, Bundesamt für Energie (BFE)

POLIS (2007) 'Die Renovation der Miet- und Eigentümerwohnungen in der Schweiz 2001–2003. Ergebnisse der Mietpreis-Strukturerhebung 2003', Bericht von POLIS, Politikberatung und Sozialforschung, zuhanden des Bundesamt für Wohnungswesen (BWO), Grenchen

Rogers EM (2003) Diffusion of innovations. Free Press, New York

Sabatier PA (1998) The advocacy coalition framework: revisions and relevance for europe. J Eur Pub Policy 5(1):98–130

Sabatier PA, Jenkins-Smith H (1993) Policy change and learning: an advocacy coalition approach. Westview Press, Boulder

Schleich J (2009) Barriers to energy efficiency: a comparison across the German commercial and services sector. Ecol Econ 68:2150–2159

Schulz TF (2007) Intermediate steps towards the 2000-watt society in Switzerland: an energy-economic scenario analysis. PhD thesis, Eidgenössische Technische Hochschule Zürich, DISS NO 17314

Schulz H-R, Würmli P (2004) 'Miete und Eigentum. Detailauswertung der Gebäude- und Wohnungserhebug 2000'. Studie im Auftrag des Bundesamts für Statistik (BFS), Bern, und des Bundesamts für Wohnungswesen (BWO), Grenchen

Schulz H-R, Würmli P, Farago P, Brunner B (2005) 'Wohnen 2000. Detailauswertung der Gebäude- und Wohnungserhebung', Band 75 der Schriftenreihe Wohnungswesen. Bundesamt für Wohnungswesen (BWO), Grenchen

Schüssler R, Thalmann P (2005) Was treibt und hemmt den Wohnungsbau? Schriftenreihe Wohnungswesen, Band 76. Bundesamt für Wohnungswesen, Grenchen

Siller T, Kost M, Imboden D (2007) Long-term energy savings and greenhouse gas emission reductions in the Swiss residential sector. Energy Policy 35:529–539

Stahel T (2006) Wo-Wo-Wonige! Stadt- und wohnpolitische Bewegungen in Zürich nach 1968. Dissertation, Philosophische Fakultät der Universität Zürich

Sutherland RJ (1991) Market barriers to energy-efficiency investments. Energy J 12(3):15–34

TEP and ETH (2009) 'Gebäudeparkmodell SIA Effizienzpfad Energie. Dienstleistungs- und Wohngebäude. Vorstudie zum Gebäudeparkmodell Schweiz. Grundlagen zur Überarbeitung des SIA Effizienzpfades Energie', Studie im Auftrag des Bundesamts für Energie (BFE). http://www.ibi.ethz.ch/nb/publications/reports/200910_ETH.TEP_Endbericht.Gebaeudeparkmodell.pdf. Accessed 26 Dec 2011

Ulli-Beer S, Bruppacher S, Groesser SN, Geisshüsler S, Müller MO, Mojtahedzadeh M, Schwaninger M, Ackermann F, Anderson D, Richardson GP, Stulz R, Kaufmann-Hayoz R (2006) Understanding and accelerating the diffusion process of energy-efficient buildings: introducing an action science venture. In: 'Proceedings of the 24th international conference of the system dynamics society, 23–27 July 2006', Nijmegen, The Netherlands. http://www.systemdynamics.org/conferences/2006/proceed. Accessed 21 Nov 2010

Van Bueren E, Priemus H (2002) Institutional barriers to sustainable construction. Environ Plann 29:75–86

Van Wezemael JE (2005) Investieren im Bestand. Eine handlungstheoretische Analyse der Erhalts- und Entwicklungsstrategien von Wohnbau-Investoren in der Schweiz- und Entwicklungsstrategien von Wohnbau-Investoren in der Schweiz, Heft 8 der Neuen Folge. Ostschweizerische Geographische Gesellschaft, St. Gallen

Wüest and Gabathuler (1991) Dokumentation Gebäudebestand Schweiz. Impulsprogramm Bau–Erhaltung und Erneuerung, Bundesamt für Konjunkturfragen, Bern

Wüest and Partner (1994) Basisdaten und Perspektiven zur Entwicklung des Gebäudeparks 1990–2030. Bundesamt für Energiewirtschaft, Bern