Matthias Otto Müller

Diffusion Dynamics of Energy-Efficient Renovations

Causalities and Policy Recommendations

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For Daniela
For Idalina, Rudolf and Richard

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Part I
Introduction: Questions and Approach of the Study

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

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

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[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 rel-
evant 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 instru-
mental 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 orga-
nizations 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 Interna-
tional Energy Agency (IEA) which is part of the Organization for Economic Cooper-
ation and Development (OECD) is an authoritative source on issues of energy supply
and demand. It publishes extensively and with a broad scope. The Intergovernmental

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[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,

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[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 build-
  ing materials that were sourced mostly locally, produced in a sustainable manner,
  do not emit toxic substances. In addition, health aspects in construction are impor-
  tant.[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 aver-
  age 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.

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[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.

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[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

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[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).

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Chapter 2
Research Design and Methods

2.1 Introduction

The goal of this study is to develop a quantitative, dynamic simulation model of the diffusion of energy-efficient renovations and using it to understand how the diffusion of energy-efficient renovations can be accelerated. In order to develop the simulation model, I drew on a wide range of empirical and theoretical contributions found in the literature, and I also conducted my own empirical research. What I eventually arrived at is a synthetic, empirically grounded, dynamic theory in the form of a System Dynamics simulation model. The research design implemented in this study might best be described as *computer-assisted theory building with System Dynamics*.[1] This chapter is structured as follows. In Sect. 2.2, I describe the research design. In Sect. 2.3, I discuss the specific methods I used, and in Sect. 2.4, I discuss and reflect on the research design and methods used in this study.

2.2 Research Design

2.2.1 Systems Thinking and Theory Building

Definition of a Theory

According to Schwaninger and Groesser (2008, p. 448) a theory can be defined as a "structured, explanatory, abstract and coherent set of interconnected staetents about a reality." Theories can be differentiated according to their range as *general*

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[1] In a recent article, Schwaninger and Groesser (2008) describe System Dynamics as model-based theory building. The research design of this study was strongly influenced by that article. However, in order to stress the theory building aspect rather than the simulation tools used to implement it, I here consciously use this term to describe the research design employed.

theories, *middle-range theories* or *local theories*. While general theories attempt to provide highly generic or overall explanations of a wide range of phenomena, local theories attempt to explain highly specific situations (Schwaninger and Groesser 2008, p. 450). Middle-range theories are "theories that lie between the minor but necessary working hypotheses that evolve in abundance during day-to-day research and the all-inclusive systematic efforts to develop a unified theory that will explain all the observed uniformities of social behavior, social organization and social change" (Merton 1968, p. 39, quoted in: Schwaninger and Groesser 2008, p. 450). The theory I aim to develop is best classified as a middle-range theory. While theories can be developed based on a range of languages, I will specifically use a semimathematical language.

Semimathematical Languages for Dynamical Theories

Hanneman (1988, p. 17) differentiates between static and dynamic theories. Static theories focus on covariation and generally take the form "the greater the X, the greater the Y." In contrast, the focus of dynamic theories is on the process of change as the object to be explained. Theorizing that deals explicitly with dynamic processes may be more appropriate than static analysis if the goal is to understand change (Hanneman 1988, p. 19).

Furthermore, in order to build dynamic theories, Hanneman (1988, pp. 20–27) sees three different approaches that can be taken:

- *Everyday language*, enriched with generally accepted scientific writing principles (e.g., consistent use of terms, obligation to quote, etc.), is the most common form to express theoretical statements about change processes. However, theoretical statements made in everyday language have a tendency not to specify the relations among concepts precisely enough. Hence, the quality of the theory may be diminished by the characteristics of language.
- *Mathematical language*: Using mathematics for theory building has the advantage that all of the information included in a statement must be made explicit. However, mathematics may become inadequate once the issue under study gets more complex. Hanneman (1988, p. 25) argues that "most mathematical languages for stating theories of dynamics are more powerful than we need for simple problems, and not sufficiently powerful for complex ones."
- *Semimathematical languages* are the "languages" embodied in softwares such as Matlab, VENSIM, Stella/iThink or Powersim. On the one hand, they aim to overcome the practical, technical and stylistic limitations mathematical languages have in the context of building rich dynamic theories. On the other hand, they aim to overcome the limitations of everyday language (Hanneman 1988, p. 25). Semimathematical languages are systems of equations at heart but they facilitate the use of long, expressive variable names.

The stock-and-flow diagrams used to describe my simulation models are visual representations of the semimathematical language embodied in the software I use.

By underlaying stock-and-flow diagrams with equations in the computer program "VENSIM," a dynamic theory is expressed in a semimathematical language.

System Dynamics

System Dynamics (SD) was developed by Jay W. Forrester in the late 1950s and early 1960s by applying control principles from electric engineering to management and economics (Lane and Oliva 1998, p. 219). System Dynamics is best described as a methodology which can be used to describe the structure of causality driving change process. It can also be used to elicit the behavior brought about by complex structures of causality. In order to do so, change processes are modeled as dynamic systems, as a set of equations. Basically, any kind of change process can be modeled as a system, regardless whether it stems from the physical, ecological or social domain. Ideally, System Dynamics models are developed to meet a specific purpose. It is crucial that they represent reality in such a way that they are adequate representations of the specific aspect of reality under study. By comparing the model with observations of reality and improving it, a useful and empirically grounded description of the aspect of reality under study gradually emerges.

The central building blocks of a System Dynamics model are called *stocks*. They are changed over time by in- and out*flows*. The dynamics of a system can be shown to result from the interactions between its stocks and flows over time, in particular from circles of causality called *feedback-loops* (see Sects. 2.3.5 and 2.3.6). Usually, auxiliary variables are used to control flows.

Elements of the System Dynamics Modeling Process

According to Sterman (2000, p. 85), "there is no cookbook recipe for successful modeling, no procedure you can follow to guarantee a useful model. Modeling is inherently creative." However, this does not mean that modeling should proceed ad-hoc. In order to guide the modeling process, several logical steps have been proposed in the System Dynamics literature. I found the following:

- Richardson and Pugh (1999, p. 16) propose the following seven stages: (1) system identification and definition, (2) system conceptualization, (3) model formulation, (4) analysis of model behavior, (5) model evaluation, (6) policy analysis and (7) model use or implementation.
- Sterman (2000, p. 85) conceptualizes the System Dynamics modeling process as consisting of the following five steps: (1) problem articulation (boundary selection), (2) formulation of dynamic hypothesis, (3) formulation of a simulation model, (4) testing, (5) policy design and evaluation.
- Citing Maani and Cavana (2000), Jackson (2003, p. 69) reports (1) problem structuring, (2) causal loop modeling, (3) dynamic modeling, (4) scenario planning and modeling, (5) implementation and organizational learning as the distinct steps towards the development of an SD model in the context of management.

- In addition, the following eight heuristic principles for model-based theory building by Schwaninger and Groesser (2008) have important implications for the System Dynamics modeling process: (1) Issue orientation, (2) Formalization, (3) Generalization, (4) Validation, (5) Explanation, (6) Falsification, (7) Process design, (8) Concept of learning.

As can be seen from the examples above, there is some variation in the processes found in the literature. Yet fundamental discrepancies regarding how modeling should proceed do not seem to exist. Further, all contributions insist that modeling is of an iterative nature, and hence these steps should not be considered to be strictly sequential. Reviewing the modeling processes found in the literature, I identified the following four steps which serve the requirements of my study best (in brackets the corresponding chapters are given).

1. Description of the problem situation (Chaps. 3, 4 and 5)
2. Development of a dynamic hypothesis (Chap. 6)
3. Quantitative modeling and testing (Chap. 7, Appendix C)
4. Scenario and policy analysis (Chap. 8)

2.2.2 Related Methodologies

The research design of this study is partially inspired from other social science research methodologies, in particular Soft Systems Methodology (SSM) and Grounded Theory, which both can be seen as epistemically related to System Dynamics. SSM enriches the systemic perspective of System Dynamics, whereas Grounded Theory provides useful insights into theory building. Grounded Theory contributes to the research design of this study the concept of 'theoretical sampling' of data or interviewees, its insistence on iterative research and the provision of methodical guidance in the analysis of the interviews.

Soft Systems Methodology

Soft Systems Methodology (SSM) was developed over the last few decades by Peter Checkland and colleagues at Lancaster University. At the core of SSM lies the insight that most situations can be usefully analyzed by treating them in a systemic way. By developing systems-thinking models of a problem situation, a debate over culturally feasible and systemically desirable changes can be initiated among participants of the problem situation. This shared understanding of the problem situation then forms the basis for taking action in order to improve the situation.[2]

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[2] Seminal publications on SSM are Checkland (1993, 2005) or Checkland and Scholes (1998).

At a very basic level, the concept of the *system* refers to the idea that a set of elements are connected together and form a whole. More precisely, Checkland (1993, p. 317) defines a system to be

> (...) a model of a whole entity; when applied to human activity, the model is characterized fundamentally in terms of hierarchical structure, emergent properties, communication, and control. (...) When applied to natural or man-made entities, the crucial characteristic is the emergent properties of the whole.

Consequently, *Systems Thinking* makes use of the concept "system" to order thinking about the world. In SSM this is contrasted with the notion of *Systems Practice*, which implies using systems thinking to initiate and guide actions that are taken in the real world (Checkland 1993, p. 4).[3] This is done by setting "some constructed abstract wholes (often called 'systems models') against the perceived real world in order to learn about it" (Checkland and Scholes 1998, p. 25).

For this study this means that the term "system model" should be understood to be synonymous with the terms "(local) theory" and "model," *as long as the theory- or model-building endeavor relies on a systems thinking perspective*. It is possible to fully integrate SD and SSM.[4] However, I do not aim to integrate SD and SSM in this study. Rather, SSM is used to provide selected concepts such as the concept of the problem situation used in Chap. 3, as well as a general methodical guidance.

Grounded Theory[5]

The beginning of grounded theory can be traced to the publication of a book entitled *The discovery of grounded theory* by Glaser and Strauss (1967). Since then, a large body of social science research has been produced with this methodology. Grounded theory is to be understood as a conceptually condensed, methodologically justified and internally consistent collection of proposals that have proven useful for the production of rich theories within the context of social sciences (Strübing 2004, p. 7). Grounded Theory heavily relies on an iterative research process that focuses on the repeated comparison of theoretical concepts with empirical data (Oxford Dictionary of Sociology 1998, grounded theory).

2.2.3 Description of the Research Process

The research design, as I described it above, had to be further specified. In particular, appropriate methods had to be chosen and applied in a sensible and efficient manner.

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[3] See Jackson (1991, 2000, 2003) for introductions into the broad field of Systems Thinking.

[4] See for example Lane and Oliva (1998), Rodriguez-Ulloal and Paucar-Caceres (2005) or Paucar-Caceres and Rodriguez-Ulloal (2006).

[5] The following discussion of grounded theory is highly stylized towards its usefulness for this study. See Strübing (2004) or Flick (2005, Chap. 15) and the literature quoted therein for a more comprehensive discussion of Grounded Theory as a standalone research methodology.

1. Orientation and clarification of research questions
- Discussions with funding organizations
- Exploratory expert interviews
- Explorative desktop research, seminar papers

2. Interviews
- Selection of interviewees
- Systematic expert interviews
- Transcription of interviews
- Analysis of transcripts
- Workshop with experts

3. Development of analytical chapters
- Analysis of the societal problem situation
- Building stock model (small model)
- Actors in the societal problem situation
- Feedback perspective

4. Quantitative modeling
- Development of model structure
- Development of plausible behavior
- Model testing and adaptation

5. Policy analysis
- Regulations obtained from the small model
- Analysis of intervention points
- Analysis of policy packages

Desktop research

Testing and verification

Fig. 2.1 The research process of the study

Figure 2.1 summarizes the most important steps of the research process in a linear fashion. Of course, several iterations between the different phases occurred, and in consequence the research process was anything but linear. In the following, I report on the research process. Further details on methods are provided in Sect. 2.3.

Orientation and Clarification of Research Questions

The study started from a desire to address the general question.[6] Due to the complexity of the whole situation, System Dynamics quickly emerged as the methodology of choice. However, as a first step, more specific research questions had to be developed. This entailed an orientation phase. During the orientation process, informal discussion with experts and colleagues proved helpful. Furthermore, exploratory desktop research and some exploratory expert interviews helped to develop preliminary insight into the societal problem situation under study and into the research

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[6] It reads as follows: How can the diffusion of energy-efficient renovations of (residential multifamily) buildings be accelerated in order to reduce Switzerland's emission of CO_2? (also see page 4).

literature. During this phase, I wrote a series of seminar papers for the mandatory doctoral coursework at University of St. Gallen. The coursework proved quite helpful as it allowed me to begin to structure the results from exploratory research, and to clarify the research design, methods and conceptualization of this study. The feedback gained in this early phase significantly helped to shape the study.

Interviews

Between fall 2007 and summer 2008 I prepared and conducted a series of systematic expert interviews. Specifically, I selected and contacted interviewees involved with recent construction projects in the city of Zürich. Based on the insights obtained from the orientation phase, I prepared a questionnaire and used it to conduct open, semi-structured expert interviews. The interviews were recorded, transcribed and later analyzed regarding their content. The systematic interviews contributed to an enriched understanding of the societal problem situation. They allowed me to understand drivers and barriers to the diffusion of energy-efficient renovations from the perspective of practitioners. Further, I could identify the major actors involved in the societal problem situation. In addition, I attempted to develop a causal loop diagram explaining the diffusion process based on the insights from the systematic interviews. These insights were discussed at the first workshop with a group of practitioners (see Müller and Ulli-Beer 2008).

Development of Analytical Chapters

The orientation phase and the interviews made me realize how complex the societal problem situation was. In order to structure the many aspects, I chose to develop four analytical perspectives. There, I analyzed the societal problem situation (Chap. 3) and I developed a small simulation model of the dynamics of the building-stock (Chap. 4), which would later serve as a module in the large simulation model. Further, I analyzed actors (Chap. 5) and developed an explanation of the diffusion of energy-efficient renovations (Chap. 6). These chapters served as the basis of the development of the large System Dynamics model.

Conceptualizing these analytical chapters helped me to develop an aggregate perspective that was nevertheless grounded in the stories and insights obtained in the interviews. Comparing the—rather awkward—causal loop diagrams presented in Müller and Ulli-Beer (2008) with the much more precise and consistent causal loop diagram presented in Chap. 6 exemplarily shows how I gradually arrived at a more aggregate perspective.

Quantitative Modeling

Developing the structure of the large simulation model was substantially facilitated by the analytical chapters, as I could draw on the insights presented there. In contrast,

it was much more difficult to calibrate the model. This was because I hardly ever had time series data of the variables used in the model. Therefore, I often had to draw on non-numerical data in order to elicit a plausible model behavior. For the same reasons, I generally could not test quantitatively how well the model reproduced empirical behaviors and therefore I had to rely on plausibility considerations instead.

Ultimately, developing the structure, calibrating the model's behavior and testing the model were closely related activities. Typically, I would run the model after every change in the structure to ensure that the change improved the model. When the model failed to produce the expected behavior, I would change its structure or parameters until I was satisfied with the results. Similarly, policy analysis also contributed to model testing as implausible results lead to several improvements in both models.

Policy Analysis

In a System Dynamics context, policy analysis is the practice of using a simulation model to find interventions which affect one or several reference modes in a desired manner. In my study I used both, a small model of Switzerland's stock of buildings and a large model of the diffusion of energy-efficient renovations, to conduct policy analysis. The small simulation model was used to run several scenarios representing different policies. Policy recommendations were elicited based partially on the simulation results. In the case of my large simulation model, I systematically analyzed how certain parameters responded to a 50 % increase after the year 2010. In addition, I analyzed several sets of intervention levers.

Continuous Activities

Between summer 2006, when Dr. Ulli-Beer and me wrote a proposal for funding, and early 2012, when this study was completed, spectacular changes occurred in the societal problem situation addressed by this study. The literature, both scientific and from practitioners, addressing the fields of climate change, energy use and buildings developed spectacularly. Therefore, I conducted desktop research and testing and verification of my results throughout the research process.

2.3 Methods

2.3.1 Literature Review

Reviewing the literature is a routine component of academic writing. Because this study is mostly a synthesis of existing knowledge, it is appropriate to consider the literature review as an important methodical component. A limitation of the broad

scope of my study is that I cannot claim to have a comprehensive knowledge of the literature relating to all the aspects of my study.

I primarily selected publications according to the contribution they could make towards the development of the model. This means that I also relied on non-peer-reviewed publications from fields of practice, such as the construction industry or governmental offices. I deemed such contributions to be important regardless whether they were peer-reviewed or not. Throughout the research process, I distinguished between the following three types of publications.

- Articles in peer-reviewed journals or publications which underwent other kinds of rigorous review by peer scientists.
- Scientific reports from or for practitioners, for example from government agencies or contracting research agencies.
- All other types of reports of practitioners, which do not adhere to scientific standards but may nevertheless provide insight into domains where there is no scientific literature.

Using the fist two types of publications posed no special difficulties. The literature published in peer-reviewed journals provided both empirical and theoretical insight. The rich and extensive literature produced or commissioned by government agencies proved to be particularly useful regarding empirical aspects. Publications of the third type sometimes also provided important insights. However, I was much more critical to publications of that type and tried to triangulate their validity with other sources where possible.

2.3.2 Selection of Interviewees

The question, whom to interview, is an important aspect of any method which relies on interviews. Several approaches can be found in the literature. In survey research, statistical representativeness is the 'gold standard' of empirical work. This is typically achieved by randomly selecting members of the population studied Diekmann (1999). When face-to-face interviews are preferred to mail or phone surveys, statistical representativeness can generally not be achieved for practical reasons. This is because face-to-face interviews easily take 1 or 2 h, and statistical representativeness easily requires 200 or even much more interviews. However, the idea that the sample of persons interviewed should be representative of the population under research is not alien to researchers using face-to-face interviews. For such methods, several distinct approaches are described in the literature (Flick 2005, Chap. 7). A frequently used approach, called *theoretical sampling*, was developed in the context of the Grounded Theory methodology (Glaser and Strauss 1967). There, the selection of interviewees is guided by the research process itself. As new insights emerge during the research process, researchers need to find new interviewees from whom they expect new insights into the phenomena under study (Flick 2005, p. 102). Another approach is to determine important categories across which the sample of

Table 2.1 Sample of the explorative interviews

Frequency	Description of interviewees
4	Senior researchers at institutions of higher education
1	Senior member of Zürich's construction department
1	Executive member of a building association in Zürich
1	Architect in the city of Aarau

interviewees needs to vary and then select interviewees such that all categories are represented.

In my study, I used an approach somewhere between the openness demanded by Grounded Theory and the confinement of pre-determined categories. Actors within the value creation chain involved with the renovation of buildings were selected according to quite pre-determined categories. Yet, those categories were partially based on the insights from the exploratory interviews. Actors outside the value creation chain were selected during the research process as their importance became evident. My research design, as introduced above, relies on three different types of expert interviews, namely *exploratory expert interviews*, *systematic expert interviews* and *validating expert interviews*. In the following, I briefly describe the interviewees in these three types of interviews.

Exploratory Interviews

In total, I conducted 7 exploratory interviews for this study (see Table 2.1). The interviewees came mostly from institutions of higher education. The interviews with the researchers and the member of the public administration helped to quickly gain insight into the societal problem situation. In contrast, the exploratory interviews with an architect and a member of a building association led to more operational knowledge and exemplarily showed the range of knowledge which could be elicited from practitioners.

Systematic Interviews

In order to find interviewees for the systematic interviews, I searched for recent renovations in or near the city of Zürich.[7] By using recently renovated buildings as a reference, representatives of actors inside the value creation chain could be identified. For each of the reference buildings, I interviewed a representative of the building owner, the responsible architect and a representative of the construction company where possible. All reference buildings were residential multifamily buildings in the

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[7] I am deeply indebted to Dr. H. Gugerli for supporting me in this phase.

greater Zürich area. In line with the scope of this study (as discussed on p. 17), only buildings where the flats were rented to tenants were considered.

A conscious limitation of my sampling for the systematic interviews is that I did not consider tenants. This is for two reasons. First, I thought that building owners base their decisions on their perception of tenants rather than on the actual behavior of tenants. Therefore it seemed much more important to know how building owners perceive the prospects of renting energy-efficient housing. Second, I thought that qualitative interviews with tenants would not be very yielding. In contrast to the other actors in the value creation chain (professional building owners, architects and construction companies), tenants do not routinely rent flats or have professional knowhow in that domain. Therefore, survey methods reaching out to large numbers of tenants would probably provide some insight.[8]

In addition to the experts from the value creation chain, a number of representatives from actors outside of the value creation chain were interviewed in the systematic interviews. These were from various associations. Table 2.2 shows the structure of the sample of interviewees in the systematic interviews.

Validating Expert Interviews

As part of the testing and verification of my work in general and the simulation models in particular, I conducted validating expert interviews. In particular, I discussed different stages of Chaps. 4 and 6 as well as both simulation models with a small number of experts. Table 2.3 shows the composition of the sample of these experts.

Table 2.2 Sample of the systematic interviews

Frequency	Description of interviewees
5	Professional building owners[a]
3	Architects
3	Representatives of construction companies
1	Swiss real-estate association SVIT
1	Swiss tenants' association
1	National association of building associations

[a] Including persons trained as architects who now are employed by building owners as asset managers

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[8] In fact, I am not aware of any empirical research in decision making of tenants. Discrete choice experiments over a statistically representative sample might yield conclusive insights regarding tenants' willingness to pay for energy-efficiency in rented apartments.

Table 2.3 Sample of the validating interviews

Frequency	Description of interviewees
4	Researchers at institutions of higher education
1	City of Zürich's construction department
1	Canton of Berne's energy department (AUE)
1	Federal Office for the Environment (BAFU)

2.3.3 Expert Interviews

Exploratory Expert Interviews

Exploratory expert interviews served as an important starting point. They helped to orient myself in the first phase where I worked on the clarification of my research questions and the research design. Further, they helped me develop the questionnaire for the systematic expert interviews.

For the exploratory interviews, I did not yet have a questionnaire. Instead, I prepared myself for each interview with a mind-map which contained several aspects I wanted the interviewees to elaborate on. Among these were the questions, why and how buildings got renovated and what kind of actors were involved. In two cases, interviewees described the renovation process of a recently renovated building. In other cases, interviewees elaborated more on technological aspects or the institutional context. The exploratory expert interviews might best be characterized as problem-centred expert interviews with a strong narrative element (Flick 2005, Chap. 9).

Typically, an exploratory or systematic interview lasted between 1 and 2 h and proceeded according to the following pattern: At the beginning of each interview, I asked for permission to record the interview and assured my interviewees confidentiality. With one exception, all interviewees allowed audio recording.

Systematic Expert Interviews

In order to gain a deeper, more representative perspective on the societal problem situation, I conducted 14 systematic expert interviews. All of these interviews were conducted with a questionnaire that followed the same logic (see electronic supplement for a typical questionnaire). However, I made some minor adjustments for each interview in order to account for the specific context an interviewee was in. A typical interview proceeded along the following lines:

- In a preliminary step, I asked some questions concerning the professional background of the interviewee. Then, I briefly introduced the different blocks of the interview, in order to give the interviewee an overview of my interests.

- As a first step, I asked the interviewee to elaborate on the motivation for renovating. This question was directed to either the reference building or buildings in general when the interviewee was not involved in a recent renovation.
- As a second step, I asked interviewees to describe the renovation process and identify the actors that were involved. In particular, I asked which actors influenced the energy efficiency of the renovated building. For each such actor, I additionally asked what interest he or she has in energy efficient buildings.
- As a third step, I asked my interviewees what societal actors or what external developments (such as rising energy prices or technological progress) could create pressure towards energy efficiency in renovations.
- Finally, I ended the interview by asking very specific questions that had emerged during the interview or that remained unclear. After the interview, I thanked my interviewees, invited them to participate in a workshop and gave a small gift as a token of appreciation for their time.

The systematic interviews are best described as open, semi-standardized expert interviews (Flick 2005, pp. 117–145). In my expert interviews, the persons interviewed were of interest because of their knowledge in a specific field rather than because of their personal characteristics. Expert interviews are generally conducted with a list of pre-formulated questions (questionnaire). Rather than simply answering "yes" or "no" to the questions of the interviewer, it is common that the participants enter into a dialog. Such interviews are qualified as *open* interviews. Because the interviewer needs to participate in the speech-situation during the interview, it is unlikely that a questionnaire can be implemented step by step as envisioned prior to the interview. Rather, this type of interview should be characterized as *semi-standardized*: More important than precisely following the questionnaire is that the interviewee takes on the responsibility of presenting an issue according to her or his perspective. This means that my interviews resembled narrative interviews at part. In particular, I tried to give interviewees the "responsibility" for the narration of the situation in the exploratory as well as in the systematic expert interviews. In order to do so, I first asked my interviewees to respond to my general question as extensively as they could. In that first phase, I mostly participated in the speech situation by asking for greater detail or clarifications. Only after interviewees had finished their narrations did I ask more specific questions from my questionnaire. For example, a typical interviewee might name four of five actors involved with the renovation of a building. On my questionnaire, however, I had an extensive list of potentially relevant actors. Once the interviewee finished elaborating, I specifically asked whether the other actors were important or not.

Validating Interviews

As the study progressed, I presented preliminary findings to colleagues and practitioners with particular expertise. The purpose was to test whether my work seemed

reasonable to them and to get further insights in places where the study needed further refinement. These interviews were conducted in a rather informal manner.

2.3.4 Transcription and Analysis of Interviews

Transcription of Interviews

Soon after holding an interview, I transcribed it from the recordings. I transcribed from spoken Swiss-German into written standard German.[9] I took great care not to alter the meaning during transcription. In line with Deppermann (2001, p. 39) I tried to maintain precision on words and significant signs. However, because I was only interested in the content and the information my interviewees stated explicitly, I did not need a sophisticated transcript. Had I intended to perform linguistic or hermeneutic analysis, then much greater precision would have been required. In my case, however, I ignored obviously irrelevant passages and meaningless filling sound from the transcripts.

Coding

I imported the transcripts into MAXQDA,[10] a software that supports the analysis of textual data. I coded the texts with codings that emerged throughout the process (see electronic supplement). During the coding process, spontaneous ideas and insights were written as short, informal memos and linked to the passage in the text which triggered the reaction. I coded the transcripts several times. Initially, I coded the texts in an explorative manner, as I tried to find meaningful concepts and tie them to passages in the text. Later, I coded the texts to ensure consistent application of the codings. In the literature, this has been called "open coding." Open coding is often followed by axial and selective coding. Thereby, researchers aim to bring the concepts identified in a text into relation to each other (axial) and eventually derive the core concepts of the issue under study (selective) (Flick 2005, p. 259).

Interpretation and Use of Text Passages

In my study, I did not apply axial and selective coding in order to develop a theory. Instead, I used the coded passages for content analysis. This means that I switched methodologically from an open approach inspired by grounded theory to the more closed approach of content analysis. The open approach was used to empirically

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[9] Swiss German consists of several distinct dialects which however are generally not written. Instead, standard german ("high german") is used for all written purposes.

[10] See http://www.maxqda.com for further information on the software.

investigate relevant categories. Specifically, I aimed to reduce my material to the core information.

According to Flick (2005, 280f.), content analysis typically relies on three different techniques. The material can be summarized and paraphrased. It can be explicated in order to clarify diffuse or unclear passages by drawing on contextual materials. Or researchers may conduct structuring content analysis which aims to find types, regularities or dimensions. In my study I mainly used structuring content analysis. articularly in Chap. 5 where I describe actors and present different types of actors, I systematically use text passages to justify my typologies argumentatively. In order to do so, I sometimes paraphrase statements of interviewees and explicate the meaning of it. This however mostly contributes to structuring analysis.

I finally translated the quotes I used in the study from German to English. I took great care to stay as close as possible to the wording used by my interviewees. However, if an interviewee answered "yes" to a question, I reformulated the question as a statement.

2.3.5 Causal Loop Diagrams[11]

Causal Loop Diagrams (CLDs) are a device for graphically describing the feedback structure of systems. Specifically, CLDs are used to depict the structure of causality between variables rather than the structure of correlation between variables. A causal loop diagram consists of variables that are linked with an arrow according to the direction of causality: For example, in Fig. 2.2, a positive causal relationship (marked with a "+") is postulated to exist between the *Birth Rate* and the *Population*, and a negative relationship (marked with a "–") is postulated to exist between *Death Rate* and *Population*. This means that a rise in the birth rate causes the population to grow and a rise of the death rate causes the population to shrink.

By coupling several variables and arrows in a feedback loop, an endogenous explanation of a system's causal structure is presented. Depending on the dominating polarity, a feedback loop is reinforcing (marked with "R" or "+") or balancing (marked with "B" or "–"). Reinforcing feedback loops strive for exponential growth, whereas balancing feedback loops converge towards a value. By combining reinforcing and balancing feedback loops as well as adding delay, any system can be sketched in a qualitative way.[12]

The example from population biology shown in Fig. 2.2 illustrates the use of CLDs: The higher the number of animals in the population is, the more births occur if fertility remains constant. This loop for itself would cause the population to grow

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[11] This whole subsection is based on Sterman (2000, 137ff., p. 141).

[12] In the System Dynamics literature there is an interesting strain of research investigating system archetypes that aims to find the combinations of reinforcing and balancing feedback loops and delays that constitute the most fundamental (generic) building blocks that make up a larger system. See for example Senge (2006, pp. 389–400), Wolstenholme (2004) and the literature quoted therein.
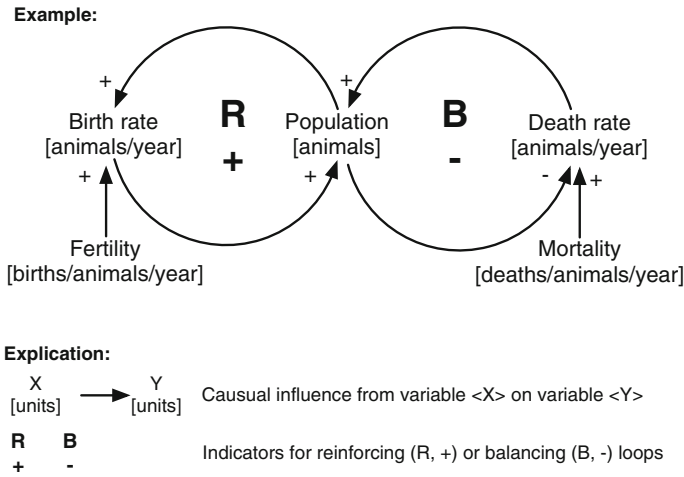
Fig. 2.2 Example of a causal loop diagram from population biology (*top*), including explanation of the symbols (*bottom*) (Sterman 2000, p. 138)

exponentially towards infinity; it is reinforcing (marked with "R"). However, there is a balancing feedback loop which prevents the system from growing exponentially (marked with "B"): Since a rise in the population also causes the death rate to grow, the population is again diminished.

While CLDs are valuable devices for the visualization of a system's feedback structure, they have problematic aspects too. As CLDs cannot provide the same rigor as SD simulation models, they risk oversimplifying an issue as well as remaining vague in important aspects, particularly with regard to distributions and numerical values. Yet, because SD simulation models often are very detailed, CLDs are useful devices for communicating the structures of a SD model.

2.3.6 Quantitative Modeling with System Dynamics

Causal loop diagrams are a useful tool to represent the main structure of causality which gives rise to dynamic complexity (see Chap. 6). Yet ultimately, they do not allow for too much precision, and they cannot be used to analyze the effects of multiple causalities. Quantitative simulation, in contrast, allows to understand how structures of causality produce a system's behavior. In System Dynamics, the use of stock-and-flow-diagrams is well established. These diagrams are a tool to visually represent the basic structure of System Dynamics models. In order to actually produce computer simulations using a computer simulation software (such as VENSIM), such stock-and-flow diagrams need to be specified with the equations and parameters. Figure 2.3 shows the graphic elements that are typically used in stock-and-flow diagrams. This example depicts the same model as introduced above (see Fig. 2.2).

Example:

Explanation:
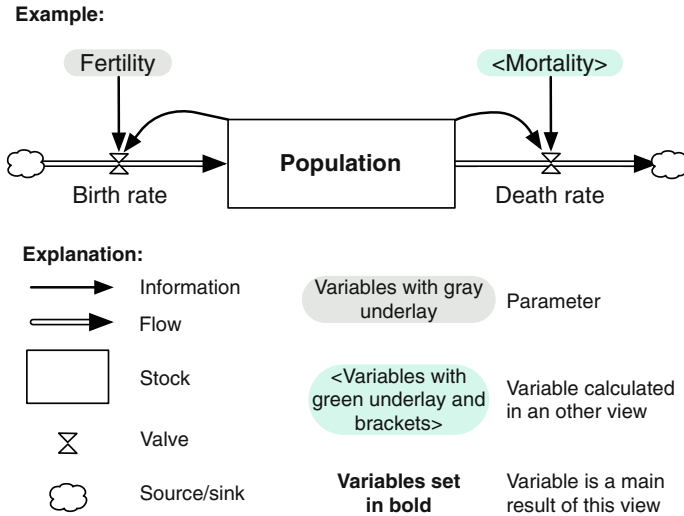
Fig. 2.3 Example of a stock-and-flow diagram from population biology, based on Sterman (2000)

Note that stocks can only be changed by in- or outflows. The rate of flow is controlled by valves. Valves can either be constants or a function of other variables. By recursively making stocks, flows and auxiliary variables dependent from each other, feedback loops of any complexity can be simulated. However, in order to yield a computable simulation model, the equations need to be specified. For example, the POPULATION was modeled as a stock here. Mathematically, all accumulation processes follow the same structure. The value of a stock is defined as an integral of the in- and outflows plus the initial stock. Equation 2.1 shows how the POPULATION stock is calculated in this example.

$$\text{Population}_t = \int_{t_o}^{t} [\text{Birth rate} - \text{Death rate}] ds + \text{Population}_{t_o} \qquad (2.1)$$

Further, the BIRTH RATE is calculated according to Eq. 2.2, as a function of the current state of the population and a parameter.

$$\text{Birth rate}_t = \text{Population}_t * \text{Fertility}_t \qquad (2.2)$$

With these building blocks any kind of system can be represented: Instead of calculating a population of animals, any other countable variable can be substituted. Such variables can be *persons*, *energy-efficient buildings*, the *share of building owners which invest into energy-efficiency*, and so on.

I used a computer simulation program called *VENSIM*[13] was used. VENSIM is particularly well suited because it allows to graphically sketch the model by relying on the stock-and-flow diagrams.[14]

VENSIM allows to replicate a model structure for several instances by using subscripts. Imagine, for example, that the small population model above should be used to simulate the population dynamics of three different countries. While it would be possible to create that model structure three times, it is unnecessarily tedious. Instead, VENSIM allows to use the same model structure to track different instances by giving each instance a subscript value. Internally, VENSIM then calculates the model structure for each instance.[15]

Conventions for the Presentation of Model Structures

When I present model structures, I generally show the stock-and-flow-diagram of the sector, I explain how the important variables are calculated, and I provide the equation. I generally rely on the following conventions:

- I indicate subscripts by stating the subscripts in the variable name. For example, the variable ATTRACTIVENESS OF ENERGY- EFFICIENT HOUSINGS BY TENANT is subscripted by tenant types.
- I shorten variable names by inserting square brackets where adequate. For example, the variable CONSTRUCTION COST COMPONENT OF THE RENT FOR PAINTJOB HOUSING may be abbreviated as CONSTRUCTION COST COMPONENT [...]
- I write all equations without time indices to facilitate readability.

I frequently use the terms "endogenous" and "exogenous". An endogenous variable is a variable which is part of a loop. In the example in Fig. 2.3, the BIRTH RATE is an endogenous variable, because it is calculated as a function of the system itself. In contrast, the variable FERTILITY is exogenous, because it remains unchanged regardless of the state of the system.

2.3.7 Model Testing and Validation

In order to assure the quality of a simulation model, model testing needs to be conducted. In the System Dynamics literature, a large array of tests have been described (Barlas 1996; Sterman 2000; Schwaninger and Groesser 2009). As a model passes

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[13] Specifically, VENSIM®DSS for Windows Version 5.9 was used, running on current versions of Windows XP, emulated by *Parallels®Desktop 5 for Apple Macintosh*, executed on current versions of Mac OS X 10.6 (Processor: 2.3 GhZ Intel Core i5). See http://www.vensim.com, http://www.parallels.com and http://www.apple.com for further information on the software used.

[14] *PowerSim* (www.powersim.com), *Stella/iThink* (http://www.iseesystems.com) and similar software might be just as adequate.

[15] See http://www.vensim.com/subscript.html, accessed 28 June 2011, for a more detailed explanation.

a test, it can be considered to be more valid than before. If a model fails a test, it needs to be adapted so that it becomes better and eventually passes the test. In fact, model testing closely mirrors the evolutionary process: Just as species become adapted to their environment, a model must become increasingly adapted to the available information. Adaptation of a model can be seen to correspond to natural variation and model testing can be seen to correspond to natural selection. As the model is iteratively tested, adapted and tested again, it gradually evolves and becomes better adapted to the available information.

Generally, model tests can be categorized as *contextual*, *structural* or *behavioral* tests. Contextual model tests address questions as to whether the boundaries are adequate or whether the purpose of the model has been clarified sufficiently. Structural model tests address questions as to whether the model structure corresponds with the relevant knowledge of the system. Finally, behavioral model tests investigate whether the model behavior adequately reproduces the observed behaviors (Sterman 2000; Schwaninger and Groesser 2009). I will further elaborate on model testing in Sect. 7.9 and Appendix C.

2.4   Discussion and Conclusions

In a summary of critiques of System Dynamics, Jackson (2003, pp. 78–82), states the following criticism:

> To those working in specific disciplines and trained in the scientific method, system dynamics seem to jump to building their models without doing their homework. They simply ignore existing theories in the field they are exploring. At other times, if insufficient data are known about an area of concern, they remain prepared to plough on, building their models without bothering to collect all the relevant data that others would regard as essential. Judgement rather than proper scientific research is used to fill in the gaps. (Jackson 2003, p. 79)

The criticism by Jackson, above, boils down to the following basic demands: Modeling requires substantial empirical grounding, a broad knowledge of existing theories in the field of study, and a clear distinction between knowledge and assumptions. That seems all very reasonable, and I absolutely agree with such demands. However, given the fact that research is a process that often needs to start from scratch, a "chicken-or-egg" situation may arise. On the one hand, data collection without a model may be difficult or inefficient. On the other hand, having a model without empirical grounding is obviously not very useful either. I think that Jackson (2003) misses an important point, namely that data-collection and modeling are two mutually dependent operations. Only with a model do we know what kind of data matters, and only a model which is grounded in data matters. Further, I agree with Sterman (2000) who argues that it is preferable to include into the model causal relevant relationships rather than ignoring such relationships on grounds of uncertain or missing data. By including probable causes into the model, even when well-established knowledge is missing, System Dynamicists follow a pragmatic approach. By acknowledging a potentially relevant cause, further empirical research may be

motivated, either by the original modeler, by subsequent researchers, or by model users. An important pre-condition, however, is that each relationship needs to be justified by a discussion of the reasons of including it and by the plausibility of the relationship. Yet ultimately, it is best and most convenient if System Dynamicists can draw on a well-developed literature and on comprehensive data sets.

Ultimately, System Dynamics simulation models are best characterized as empirically grounded, theoretical constructs. In particular, they transcend the simple divide between "qualitative" and "quantitative" approaches. In any model, numerical data from surveys or observations can be integrated with insights generated from "qualitative" research. In order to arrive at useful model structures, any source of information may be relied upon. Non-numerical empirical research methods (often called "qualitative" research methods) can provide a whole range of contributions to computer-assisted theory building with System Dynamics: Information gained from interviews or workshops can help to understand the model context or inform the conceptualization of the model structure. In fact, the System Dynamics literature has developed *group model building* as a method for building models together with practitioners (Vennix 1996; Andersen and Richardson 1997a,b).

A key difference between econometrics and computer-assisted theory building with System Dynamics is that econometrics is about *observation* while System Dynamics is about *representation*. No respectable scientist would approve of "inventing" the data used for the estimation of econometric models. Such an approach would rightfully be classified as fraud. Computer-assisted theory building with System Dynamics works the other way round: In order to build a model of observed reality, model structures must be combined in a way that reproduces observed reality reasonably well and that is useful for the investigation of the issue under study.

Casual observation indicates that empirical data collection in the social sciences is generally not guided by a formal model, at least in the social sciences I know. Instead, a whole 'academic industry' is occupied with relentless testing of hypotheses. Yet, hardly any effort is made to build causal, formal, explicit and dynamic models. Instead, verbal theories are used to deduct hypotheses for empirical testing. In contrast, 'theory building with System Dynamics' would offer the social sciences an approach to guide empirical research and to integrate its results into a formal model.

The research design of my study is perhaps best explained with a metaphor. According to this metaphor, most academic research aims to produce a small, specific, and well-made puzzle-piece. In contrast, my research design aims to put together a picture from the pieces that are currently available.

Reflecting on the research process of my study, I think that there is reason to have confidence in the structure of my model. This is because I could draw on a broad and extensive literature, and because my interviews helped me a lot to describe the structure of the diffusion process. In contrast, the operationalization phase proofed very challenging for several reasons. First, the built environment is incredibly complex, and only for some aspects data and information were found. In addition, obtaining yearly data often proved impossible. I therefore think that the model behavior should be treated as a first, serious approach. Yet further research almost certainly will improve the behavioral validity of the model.

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Part II
Analytical Perspectives: Toward a Systemic Model of the Societal Problem Situation

Chapter 3
Climate Change, Energy Use Patterns and the Stock of Buildings: Outline of a Societal Problem Situation

3.1 Introduction

Climate change issues and energy resource use patterns are the background against which energy-efficient renovations have become relevant. Therefore, my first research question asks: *How should the context, within which the diffusion of energy-efficient renovations takes place, be described in order to guide subsequent systems modeling?* Obviously, this question touches upon a wealth of issues, and it calls for a focussed and systematic approach. I start by introducing the concept of the *societal problem situation* in Sect. 3.2. That concept will shape the perspective of this chapter and guide the study as a whole. In the next two sections I discuss climate change (Sect. 3.3) and energy use patterns (Sect. 3.4). For each of these two interrelated issues I proceed according to the same logic. First, I give an account of the knowledge that has been established by mainstream science as rather certain facts. As a second step I discuss fields of contest among societal actors within each of these issues. This refers to conflicts over different knowledges, values and interests. As a third step I report on policies and instruments that were either implemented or proposed.

In the next two sections, I discuss issues related to the stock of buildings (see Sect. 3.5) in general and the diffusion of energy-efficient building designs in particular (Sect. 3.6). Next, I discuss the institutional context, policies and instruments (Sect. 3.7). I summarize the whole chapter with a summarizing description of the societal problem situation (see Sect. 3.8).

By developing this chapter, I follow two specific goals. First, it want to introduce the concepts and definitions upon which I will draw in the subsequent chapters. Second, I want to show exemplarily how policy problems such as the diffusion of energy-efficient renovations are nested within a larger context.

3.2 Theoretical Foundation: Defining Societal Problem Situations

Theoretical groundings

Social problems have long been a topic of sociological inquiry. The term "social problem" was originally used in early nineteenth-century Europe in order to refer to the (in-)equitable distribution of wealth. Later, as reformers and social scientists in Europe and North America began to address the problematics of social change, the term "social problem" was split into several problems that could be adopted and perhaps solved by interest groups or academic specialities (Schwartz 1997, p. 276). However, only since the early 1970s, a theoretically viable literature emerged which explicitly deals with the generic, structural aspects of social problems rather than material issues (Schneider 1985, p. 209).

Two opposing streams of thought can be identified: The structural functionalist perspective that emphasizes the importance of the study of *objective conditions* and the social constructionist perspective, that emphasizes *subjective definitions*. However, both approaches have failed to provide a viable approach to the sociological study of social problems (Kitsuse and Spector 1973). Recent contributions pursue a middle road between the constructionists' denial of causal relationships between "claimsmaking activities and the conditions those activities presumably concern and the theoretically moribund brands of objectivism" (Weinberg 2009, p. 62).

Operational Research (OR), understood as an interdisciplinary field applying scientific principles to the study and management of real world problems, has a strong problem-orientation. Therefore, it has been positioned closer to technology rather than "pure" science (Keys 1989, 1998; Rosenhead 2009). Initially focussed on mathematical optimization models (sometimes called "hard OR"), operational researchers have increasingly come to realize that the real challenge often is not finding an optimal solution to a well-defined problem. Instead the difficulty lies in finding out just how a real-world setting should be structured. This realization gave rise to a whole series of "soft-OR" methodologies which often are referred to as *problem structuring methods* (Rosenhead and Mingers 2001; Mingers and Rosenhead 2004). Consequently, problem-structuring methodologies address the nature of problems.

The notion conveyed by the term "problem situation" is well established in the operational research literature. For example, Ackoff (1979, p. 99) sees problems as analytical abstractions from messes. Messes are "dynamic situations that consist of complex systems of changing problems that interact with each other." Ackoff (1979) regards problems as being open to solutions based on optimization, while messes require a more thoughtful management approach. Similarly, Checkland (1993 p. 154) describes structured problems as problems that "can be explicitly stated in a language which implies that a theory concerning their solution is available." Unstructured problems are problems that are "manifest in a feeling of unease but which cannot be explicitly stated without this appearing to oversimplify the situation." Rittel and Webber (1973) differentiate between "wicked" and "tame"

problems while Schön (1983) uses the image of a swampy lowland rife with messy, confusing problems that defy technical solutions to refer to problematic situations".[1]

Research on the sociology of social problems highlights the fact that the definition of a problem situation strongly depends on subjective interpretation. For example, Blumer (1971) rejects the view that social problems are primarily based on an objective condition with an objective makeup. Instead, social problems exist primarily in terms of how they are defined and conceived by society. Social problems are always a "focal point for the operation of divergent and conflicting interests, intentions and objectives" (Blumer 1971, p. 300). Focusing more closely on the process of constructing social problems, Kitsuse and Spector (1973, p. 415) conceived of social problems as "the activities of groups making assertions of grievances and claims with respect to some putative condition". Kitsuse and Spector (1973, p. 418) argue that analysts of social problems should focus on the explanation of the "subjective elements" of social problems. In search of a middle way, Weinberg (2009) cautions against focusing purely on the subjective element. Rather, he calls for a more balanced approach that considers the meaning and the causes of the claim-making process.[2]

Definition

I propose to conceptualize societal problem situations as follows:

> A societal problem situation occurs when individuals, societal actors or advocacy coalitions take issue with something (material or immaterial), perceive this condition as a threat to the welfare 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.

The stronger the public's endorsement of a particular position is, the higher is the chance that said position can use the state to implement policies in their interest. This statement holds in principle. Yet, there is not a direct, immediate relationship between the public's endorsement of a position and public policy. The intrinsic logic of the political system influences how claims made by civil society actors are translated into state policies.

This conceptualization of societal problem situations is intended to capture issues of uttermost societal importance, such as Switzerland's energy use patterns. Here, we see many different actors making claims and demands related to the security, efficiency, economic viability and environmental consequences of the current energy system, which is mostly based on fossil-fuels and nuclear generation. The definition can be applied to any level of society (world, nation, communities), although I would expected that it most often applies to the national level.

Situations where there is widespread consensus on the existence and the nature of a problem may qualify as social, organizational or environmental problems. They

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[1] Most of this paragraph was literally taken from Müller et al. (2011).

[2] see footnote 1.

would not be seen to constitute a societal problem situation. While such problems may nevertheless be a part of a societal problem situation, the societal problem situation is of larger scale. Its definition precludes 'quick fixes.' Instead, societal problem situations are alleviated through *societal transformations*. This means that societies must undergo fundamental changes in specific domains. Depending on what societal problem situation is considered, the domains where change must occur may differ. I would expect that societal transformations in response to societal problem situations occur in many different areas, as various fields of practice search for the appropriate contribution of their field. In chap. 8 will refer to this as a 'collaborative transformation' of the societal problem situation under study.

3.3 Climate Change

3.3.1 Scientific Perspectives on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity" (Core Writing Team et al. 2007, p. 30).

Science of Climate Change

The scientific understanding of climate change emerged out of more than a century of scientific discovery, as the following events, provided by Weart (2008, p. 205), illustrate: In the year 1824, Fourier calculated that if the Earth lacked an atmosphere it would be far colder. In the year 1859, Tyndall discovered that infrared radiation is blocked by some gases and he suggests that changes in the concentration of the gases could cause climate change. In the year 1896, Arrhenius published the first calculation of global warming caused by human emissions of CO_2. In 1977, scientific opinion tends to converge on global warming as the biggest climate risk in the next century and in 1990 the first report by the IPCC says that the world has been warming and that future warming seems likely. In my interpretation this provides some evidence that the work of mainstream science gradually led to an increased recognition of climate change, and of anthropogenic influences on it.

Currently, the negative consequences of anthropogenic influences on the climate have been established by mainstream science. Key elements of the current scientific consensus, as presented by the fourth assessment report of the IPCC (Core Writing Team et al. 2007), are as follows:

- "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (Core Writing Team et al. 2007, p. 30).
- "Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The atmospheric concentrations of CO_2, CH_4 in 2005 exceed by far the natural range over the last 650 000 years. Global increases in CO_2 concentrations are due primarily to fossil-fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil-fuel use. The increase in N_2O concentration is primarily due to agriculture" (Core Writing Team et al. 2007, p. 37).
- "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse-gas (GHG) concentrations" (Core Writing Team et al. 2007, p. 39).
- "It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)" (Core Writing Team et al. 2007, p. 39).
- "Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems" (Core Writing Team et al. 2007, p. 41).
- "For the next two decades, a warming of about 0.2° per decade is projected for a range of SRES [Special Report on Emission Scenarios, MM] emission scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1° per decade would be expected" (Core Writing Team et al. 2007, p. 45). (See the Special Report on Emission Scenarios IPCC (2000) for further detail.)
- "Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the twentieth century" (Core Writing Team et al. 2007, p. 45).
- "Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilized" (Core Writing Team et al. 2007, p. 46).
- There is *high* confidence in a whole range of impacts spanning ecosystems, food, coasts, industry, settlements and society, health and water over all regions of the earth with the risk of abrupt or irreversible changes (Core Writing Team et al. 2007, p. 48–54).

In general, global warming of 2 °C is seen as a limit which should not be exceeded. Over 100 countries have adopted this limit as a guideline to inform mitigation efforts in order to reduce risks from climate change, impacts and damages (Meinshausen et al. 2009). However, substantial policy efforts are required to actually achieve

this goal, as worldwide emissions of CO_2 would have to be drastically cut, soon. However, it remains very uncertain whether even a stabilization can be achieved, as emissions have been rising, not sinking. Meinshausen et al. (2009, p. 1160) warn that "Given the substantial recent increase in fossil CO_2 emissions (20 % between 2000 and 2006 ...), policies to reduce global emissions are needed urgently if the 'below 2 °C' target is to remain achievable." Sadly, such calls for action strongly contrasted with more pessimistic findings. For example, the International Energy Agency expects that "Global energy-related greenhouse-gas emissions still increase by 45 % by 2030" (IEA/OECD 2008, p. 3).

Economics of Climate Change Mitigation and Adaptation

Analyzing the implications of various climate change scenarios is a task to which economics seems best fit. Unsurprisingly, a large stream of research dealing with the welfare effects of climate change and different policy options (adaptation versus mitigation) has emerged (e.g. Toman 1998; Burniaux et al. 2009). According to Barker (2008), mainstream economic thinking focussed on cost-benefit analysis within a single-discipline focus, and generally arrived at the conclusion to postpone climate change. However, the publication of the Stern Review (Stern 2007) marked a radical departure from mainstream economic thinking as it shifted towards multi-disciplinary analysis of risk and uncertainty. Barker (2008, p. 191) concludes that "the discounting of costs and benefits in which risks are converted into certainty equivalents and discounted at market rates has been shown to be misleading and biased. This in turn implies that the economic problem is one of achieving political targets, based on scientific evidence, at lowest costs compatible with equity and effectiveness, rather than with the economics of choosing the targets themselves."

Specifically, Stern (2007) argues that the overall costs and risks of global warming are estimated to be equivalent to losing at least 5 % of global GDP each year if no action is taken. In addition to purely economical effects, climate change would affect "the basic elements of life for people around the world—access to water, food production, health, and the environment. Hundreds of millions of people could suffer hunger, water shortages and coastal flooding as the world warms" (Stern 2007, vi). Shipworth (2007) argues that the publication of the Stern review (Stern 2007) and the IPCC's fourth assessment report (IPCC 2007b) mark a turning point in the worldwide debate on climate change, as it shifted from science to the economics of mitigation versus adaption.

For Switzerland, the expected direct and indirect consequences of climate change on the Swiss economy are relatively moderate until about the year 2050. After then, they rise relatively strong. However, the consequences of climate change are economically bearable in Switzerland if appropriate adaptions are implemented. Hence, public policy is motivated by issues beyond economic damages in Switzerland, such as insurance against unexpected consequences of climate change and international as well as intergenerational justice (ECOPLAN 2007, p. 15).

3.3.2 Climate Change as a Field of Contest

The construction of climate change as an environmental problem of global scale[3] (Demeritt 2001) by science has implications for other fields in society, as it entails a claim for societal responses addressing the problem. However, there is a discrepancy between the scientifically rigorous establishment of climate change as a 'fact' and its acceptance as a real problem in civil society. Regarding the scientific consensus, Anderegg et al. (2010, p. 1) find that "(i) 97–98 % of the climate researchers most actively publishing in the field surveyed here support the tenets of ACC [anthropogenic climate change, MM] outlined by the Intergovernmental Panel on Climate Change, and (ii) the relative climate expertise and scientific prominence of the researchers unconvinced of ACC are substantially below that of the convinced researchers." Similar findings are reported by Doran and Zimmermann (2009).

Yet in my observation, this remarkable consensus among scientists has only slowly been translated into adequate policy measures. Beyond science, climate change still appears controversial in the public and the media. Reddy and Assenza (2009, p. 2999) argue that the disbelief in climate science is "rooted within a skepticism of the environmental movement". However, regarding the media in the United States of America, Boykoff and Boykoff (2004) find that there is a substantial divergence between the scientific discourse and popular discourses. They attribute it to the media's attempt to provide a balanced account on the issue, which may lead to an overrepresentation of climate change skeptics.

Nevertheless, Whitmarsh (2011, p. 1), reporting findings from two surveys in the UK, finds that "denial of climate change is less common than the perception that the issue has been exaggerated." It seems plausible that this applies in other countries too. In Switzerland, a representative survey (LINK 2010) commissioned by the World Wide Fund For Nature Switzerland finds that a majority agrees mostly (23.5 %) or completely (38.1 %) with the statement that global warming and the predicted consequences cause concern. The same study finds that 21.7 % mostly agree, and 46.9 % completely agree with the statement that politics should do more against global warming. In contrast, 7.2 % mostly disagree and 6.3 % completely disagree that politics should do more against global warming.

Given the important role political parties play in agenda-setting and many other aspects of the political process, It is important to also investigate party positions and parliamentary action. While such an in-depth analysis goes beyond the scope of this study, a quick glance at the official positions of Switzerland's major national parties regarding climate change policy nevertheless is informative:

- **SP** The left *social democratic party* demands that the commitments from the Kyoto protocol be implemented with mandatory measures, based on emission-reductions

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[3] The societal construction of reality refers to the way individuals and groups interacting over time and space perceive and interpret reality and thereby give and take meanings. See for example Berger and Luckmann (2003). I do not argue that the scientific community acted illegitimately in any way.

within Switzerland (SP 2008). On the party website[4] I found no statements other than those which corroborate the scientific consensus on climate change.

- **Greens** The left *green party* advocate ambitious reduction goals for CO_2 emissions, which go beyond the obligations from the Kyoto protocol. They demand that these emission-reductions be achieved with national policies (Greens 2011). On the party website,[5] I found no statements other than those which corroborate the scientific consensus on climate change.
- **CVP** The centrist *Christian democratic peoples party* is committed to emission-reductions and proposes to follow the targets set out by the European Union. For the year 2020, it aims to achieve a 20 % reduction of emissions compared to 1990 (CVP 2007). On the party website[6] I found no statements other than those which corroborate the scientific consensus on climate change.
- **FDP** The centrist *liberal party* too is committed to emission-reductions, and as the CVP they propose to follow the 20 % emission-reduction goals by 2020 set out by the European Union. The FDP calls for market forces to achieve such reductions (FDP 2010). On the party website[7] I found no statements referring to the scientific consensus on climate change.
- **SVP** Amongst others, the right *Swiss peoples party*[8] advocates that Switzerland discontinue its CO_2-law. It demands that Switzerland should not participate in any post-Kyoto protocol, as long as not all big emitters participate (SVP 2009). In SVP (2009, 4–7) the party concludes that climate changes have been common in the history of the earth. It states that numerous clues exist that the alarming news of the last years, according to which human activities influence the earth's climate, do not correspond to the reality on this planet. They underline that in this century no warming of the climate occurred and that the oceans have cooled. I interpret this to mean, that this party generally contests the scientific consensus.

This constellation, with the left advocating strong interventions and the right wary of costly state interventionism, is a pattern observed frequently in Switzerland's environmental policy making (Kriesi and Jegen 2001; Ingold 2010). Bornstein (2007, 2) argues that because environmental policies also are redistributive and may be uncertain regarding it's costs, "bourgeois parties and organized business traditionally oppose stringent environmental regulation as they fear economic contraction."

This skepticism found among business interests is somewhat mirrored by the frequent view that economic growth is the primary cause of environmental problems. BUWAL (2005, p. 27) reports that in the 1970, this attitude gave rise to demands for zero-growth. Later, the uncoupling of resource use intensity from economic growth was postulated and sustainable economic growth was advocated. In Switzerland, environmental policy succeeded in several areas to uncouple economic growth from

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[4] http://www.sp-ps.ch. Accessed 24 Mar 2011.

[5] http://www.gruene.ch. Accessed 24 Mar 2011.

[6] http://www.cvp.ch/themen/themenuebersicht/umwelt-energie. Accessed 24 Mar 2011.

[7] http://www.fdp.ch. Accessed 24 Mar 2011.

[8] http://www.svp.ch. Accessed 24 Mar 2011.

resource intensity. However, regarding the emission of greenhouse-gases (particularly CO_2 and N_2O) there has only been a relative uncoupling. This means that the emission rates of greenhouse-gases grow slower than the gross national product (GNP) (BUWAL 2005, p. 27).

In recent years, conflict lines over environmental policy have changed. Bornstein (2007) argues that the previous division between the *pro-ecology* and the *pro-growth* coalitions (Kriesi and Jegen 2001) may be changing in the light of increasing scientific evidence about new global challenges such as anthropogenic climate change. In this context, I think that symbolic events and gestures will continue to shape a stronger pro-intervention consensus in Swiss climate policy. Such an event occurred when in 2007 the nobel peace prize was awarded to the IPCC and former US vice-president Al Gore for their "efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change" (The Nobel Foundation 2007).

3.3.3 Public Policies in Response to Climate Change

International Level

As climate change is a problem of global scale, the international level substantially influences Swiss climate policy, and thus warrants some elaboration. In the year 1992, the *United Nations Framework Convention on Climate Change* (UNFCCC) was adopted as one of the three conventions adopted at the 1992 'Rio Earth Summit'. It states the stabilization of the concentration of greenhouse-gases as an objective. The convention now has 193 members, giving it near-universal membership. In the year 1997, the Kyoto Protocol was adopted as a legally binding international agreement within the UNFCC. It entered into force on February 2005 when a sufficient number of parties had ratified it. In the protocol, the majority of european countries, including Switzerland, agreed to reduce their CO_2 emissions over the period from 2008 to 2010 by 8 % compared to the emissions in the year 1990. The Kyoto Protocol states three specific mechanisms to achieve the reductions, namely *emission trading*, the *clean development mechanism* and *joint implementation* (United Nations 2010, various sites).

National Level

Switzerland's climate policy focusses primarily on the reduction of emissions, while adaption to climate change too is seen as important. The country signed the UNFCCC convention in 1993 and the Kyoto Protocol in 2003 (BAFU 2010b). With its commitment to the Kyoto Protocol, the country agreed to reduce its emission rate of greenhouse-gases during the period 2008–2012 to 8 % below its 1990 emission rate. With its CO_2-law, the country reached for a more ambitious reduction goal of 10 %

in the year 2012, relative to the year 1990 (BAFU 2010b). Switzerland seems just on track to achieve the goals of the CO_2 law and the Kyoto Protocol (BAFU 2009a). Regarding future reductions, Switzerland aims to achieve at least 20 % until the year 2020. Under certain conditions, the country might be willing to reduce its emission by at least 30 % (BAFU 2009b). I therefore conclude that Switzerland should be expected to gradually lower its target value for emissions.

CO_2 Law[9]

Switzerland institutionalized its reduction goals and the mechanisms to achieve them in a law called CO_2 law. The law sets a reduction goal of 10 % by the year 2010 as compared to the year 1990. Fossil heating fuels ought to be reduced by 15 %. Propulsion fuels ought to be reduced by 8 %. As a first step, voluntary measures to reduce emissions are requested from enterprises and households. However, the law includes an incentive taxation scheme, should voluntary contributions prove insufficient. Eventually, voluntary measures did prove insufficient and since 2008, the federal council levied a tax of 12 CHF per ton of CO_2. As of 2010, the tax has been set to 36 CHF per ton.[10] The proceeds of the tax (about 630 million CHF at the highest rate) were initially promised to be fully redistributed to the public and enterprises. Yet in 2009, the Swiss parliament decided to use 200 million CHF to subsidize energy-efficient renovations, renewable energy systems and other measures which contribute to emission-reductions (BAFU 2010a, various sites).

Climate Cent

Between 2005 and 2009, a trust with the name 'climate cent' provided about 190 million Swiss Francs to about 8 750 projects, most of them energy-efficiency enhancing renovations of building hulls (Stiftung Klimarappen 2009). It was founded by associations close to fossil-fuel interests and Switzerland's two main enterprise associations (Erdölvereinigung, strasseschweiz, economiesuisse, Schweizerischer Gewerbeverband). It is contractually obligated to reduce CO_2-emissions by 12 million tons over the period 2008–2010, of which at least 2 million tons must be compensated inside Switzerland. It is financed by a tax of 1.5 cents per liter of diesel of gasoline imported into Switzerland (Stiftung Klimarappen 2009b). The climate cent trust has been heavily criticized by environmental organizations and parties on the left, who oppose it because they see it as a tax levied by privates, rather than the government. They see it as economically inefficient and ineffective and maintain that it is a political con-

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[9] See Ingold (2010) and Lehmann and Rieder (2002) for a well informed account of the politics behind the CO_2 law.

[10] This corresponds to 9 cents per liter of heating oil and may be somewhere between 5 and 15 % of the recent end-user prices of heating oil.

cession which fossil-fuel interest make in order to avoid more effective legislation (see Rechsteiner 2003).

3.4 Energy Use

3.4.1 Patterns in Energy Supply, Demand and Use

Global Patterns

The abundance of energy is one of the basic foundations of modern civilizations (Afgan et al. 1998; Haas et al. 2008; Hammond 2004). Around the middle of the twentieth century, consumption, production and the global use of energy has increased massively. This massive expansion has also been termed the 1950 syndrome (Pfister et al. 1996). With the spreading of the market as the main allocation mechanism and the diffusion of the capitalist mentality, global energy use has increased beyond western countries. Fossil-fuels now are the predominant energy resources, and it is widely accepted that the global energy supply will continue to be dominated by fossil-fuels for several decades (IPCC 2007a, p. 255).

However, fossil resources are being depleted at a rate which by far exceeds the formation of fossil oil reservoirs by natural processes. For all practical reasons, this means that fossil-fuels like gas, coal and oil are non-renewable resources. While the amount of fossil global energy resources left is uncertain, a discourse over the future availability of oil as well as other fossil resources has emerged in the scientific literature. At the centre of this debate is the question whether and if when a peak in the global production of oil should be expected. According to an account from Shafiee and Topal (2009), oil is likely to deplete in 34 years, coal is estimated to deplete in 107 years and gas is estimated do deplete in 37 years. They conclude that coal will be the only fossil-fuel remaining after the year 2042. However, voices critical to the idea of an oil peak in the next one or two decades point to the large reserves of non-conventional oil deposits, such as tar sands and bitumen. As oil prices rise, the incentive rises to find new deposits and technologies, and new sources become profitable (see for example Watkins 2006).

While the debate on peak oil mostly focuses on the supply side of the oil market, trends affecting the demand side need to be considered too. Economic growth generally increases demand for energy services. This is because oil is an important production factor for the industry and any capital-intensive agriculture. Further, oil provides households with heat and mobility. Economic growth in the former planned economies and the industrializing south has led to a steadily rising demand for oil. Hence, the International Energy Agency recently concluded that the "era of cheap oil is over" (IEA/OECD 2008, p. 3). This happened while most industrialized countries achieved spectacular efficiency improvement. Taken together, major OECD
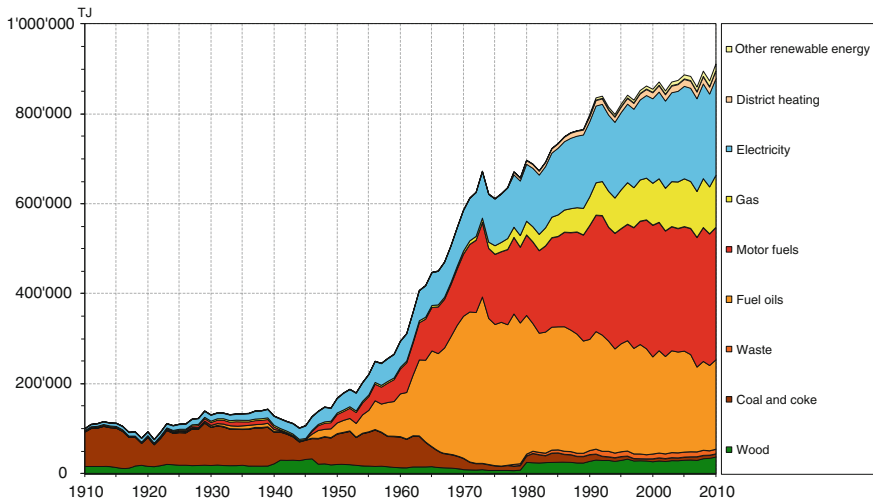
Fig. 3.1 Final energy demand of Switzerland since the year 1910. *Source* BFE (2010, 8)

countries required a third less primary energy to produce one unit of GDP in the year 2000 compared to the year 1973 (IEA 2004; IEA 2005, p. 3).

The Situation in Switzerland[11]

Switzerland used 900 040 Terajoule of final energy in the year 2008. This constitutes the largest amount of final energy ever used in this country (BFE 2009b, p. 2). This corresponds to a demand of about 5100 W per capita, of which some 3000 W come from fossil-fuels. In contrast, the global average energy demand is around 1800 W per capita (Koschenz and Pfeiffer 2005, p. 8).

Figure 3.1 shows the temporal evolution of Switzerland's final energy demand since the year 1910. As can be seen, the country mostly demands energy from fossil sources. According to BFE (2009b, p. 2), 33 % of final energy in the year 2008 was derived from fossil motor fuels (gasoline and diesel), 22 % was derived from fossil combustion fuels (heating oil) and 12.3 % came from (mostly fossil) gas. Among the non-fossil sources, electricity (mostly from hydro and nuclear generation) accounts for 23.5 % of final energy consumption and a rest of 9.1 % comes from various other sources, such as renewables or the use of waste heat. In the year 2008, consumers are estimated to have spent about 5.4 % of Switzerland's gross national product, or the equivalent of 32 640 million Swiss francs for energy (BFE 2009b, p. 2). I conclude

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[11] For further information on Switzerland's energy use patterns, see the yearly energy statistics (BFE 2009b). An extensive review of Switzerland's energy policy is provided in (OECD/IEA 2007). Energy use in buildings is discussed in greater detail in Sect. 3.5.2.

that Switzerland is highly dependent on fossil energy imports. Further, the country gives up a substantial share of its national product in order to do so.

In past decades, however, the country was even more dependent on fossil oil imports. As a consequence of the first oil price shock in the year 1973, Switzerland substantially reduced the total primary energy supply per unit of GDP. The decline in primary energy per unit of GDP was caused by improved energy efficiency in key end-uses and the energy supply, as well as by changes in the structure of human and economic activities (Geller et al. 2006).

Oil and Gas Prices

The different qualities of oil are traded on global or regional commodity markets. For oil there is somewhat of a global price, once transaction costs are ignored. This is because the different qualities are quite homogenous commodities and can be easily transported using pipelines or tanker ships. For gas there is no spot market in Switzerland and there is also no uniform price for gas. Instead, each of the about 100 suppliers sets prices according to its specific situation (Erdgas 2010). As in many other european countries, the price of gas in Switzerland is closely related to the price of oil. This is due to the structure of the contracts between suppliers and buyers (BFE 2005b). This means that oil and gas prices are determined by the interplay of demand and supply on the gas markets. Yet in addition to fundamental aspects like the cost of production, transaction costs or taxes, oil and gas prices are strongly influenced by the traders' expectation about future developments.

Major oil reserves are in regions with social unrest and political instability. Instability can lead traders on the commodity markets to expect reductions of supply. Such expectations can over-proportionally drive up energy prices. This is because the demand for oil is rather insensitive to variations in price. Therefore, even small fluctuations on the supply side may lead to disproportionate price fluctuations. In this context, oil price spikes are often blamed on speculators in the commodity markets. However, IEA/OECD (2008, p. 71) argue that "physical market fundamentals appear to have played the leading role in driving up prices, though financial investors may have amplified the impact."

Estimating future energy prices is a tricky endeavor: Schultz (2008) found that in the year 2005, several experts' estimates were off by almost 100 %. Others were forced to quote unpractically large ranges, putting the price per barrel in a range of 50–105 dollar. Nevertheless, price projections from authoritative sources, such as in the International Energy Agency's "World Energy Outlook", continue to influence the price expectations of consumers and producers alike. These trajectories are not forecasts, but rather price-paths at which supply and demand of fossil-fuels are assumed to be in balance over several years. In contrast, market prices may fluctuate significantly. Specifically, the IEA/OECD (2008, p. 68) assumes that the fossil-fuel price remains on average at $100 per barrel over the period 2008–2015 and then will rise broadly linear up to $122 in the year 2030 (at prices of the year 2007 and US Dollar currency).
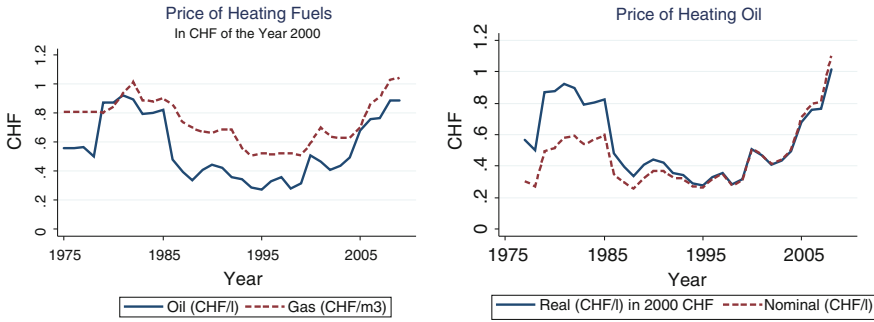
Fig. 3.2 Prices for heating oil and gas. *Source* Switzerland's consumer price index (BFS 2011) and own calculations

Gas and oil based fuels are heavily taxed in Switzerland, as well as in many other developed countries. For example, gasoline (German: Benzin) is taxed about 73 cents per liter and diesel is taxed almost 76 cents per liter. This means that about 40 % of the price paid by consumers is caused by taxes. Heating oil, in contrast, is only minimally taxed, at 0.3 cents per liter (EZV 2010).

Figure 3.2 shows the prices of specific energies in Switzerland over the years 1975–2008. The exhibit on the left shows the price of heating oil and gas in real prices of the year 2000. As can be seen, the prices for gas and heating oil are somewhat correlated. The exhibit on the right shows the price of heating oil, once in nominal prices and once in real prices. This exhibit illustrates an interesting point, namely the fact that the price spikes after 2005 seem much less drastic in real terms than in nominal terms. At current prices, the price for heating oil has almost doubled compared to the maximum in the years 1980–1985. In real terms, however, prices have only very recently begun to exceed historic maxima. In addition, Switzerland's per-capita income has substantially grown over that time period. I conclude that even at currently high prices, heating oil is still more affordable for the Swiss population than it was in the 1980.

3.4.2 Energy Policy as a Field of Contest

Swiss energy policy can be traced to the first oil crisis in 1973, when the country's strong dependence on energy imports became evident. In response, the federal council urgently demanded a national energy policy in order to ensure energy security. The expert commission charged with developing strategic options gave three base recommendations: Other energy carriers should substitute oil in order to reduce the dependency from foreign supplies of a single resource, research into alternative means of energy supply and alternative appliances should be promoted, energy sav-

ing programs should be developed in order to increase the efficiency of energy use (Linder 1999, p. 162; Jegen 2003, Sect. 3.2).

In 1980, the federal council proposed a revision of the constitution which would have allowed the implementation of a national energy policy based on the three recommendations proposed by the commission. The two chambers of parliament accepted this constitutional amendment with minor alterations. Yet in a popular ballot in 1983, it was rejected. While a majority of citizens voted for it, it was defeated by a majority of cantons which rejected it. In consequence, there was no constitutional foundation for a federal energy policy. It took seven more years until the federal authorities presented a new article. Compared to the article proposed first, this revised amendment gave less power to the federal level. In sum, it took 17 years until the federal government got the constitutional foundation for a national energy policy (Linder 1999, p. 162; Jegen 2003, Sect. 3.2).

Traditionally, Swiss energy policy has been primarily concerned with electricity. The electrical industry served a highly regulated and cartelized market and focussed on supplying ever-increasing demand (Kriesi and Jegen 2000, p. 29). However, with the nuclear accidents in Tschernobyl and Harrisburg (Three Mile Island Incident) a strong opposition against nuclear power plants emerged, and a fierce debate on energy policy ensued. In the nineteen seventies and eighties "the struggle about nuclear power had all the characteristics of a contest about basic policy images" (Kriesi and Jegen 2000, p. 30). Eventually, a moratorium on the construction of new nuclear power plants was accepted. With the decline of nuclear power's fortune new issues emerged, such as energy efficiency and, in the second half of the 1990, the liberalization of the market for electricity. In the meanwhile, a balance of power had been established between the two conflicting groups, which made it difficult to reach binding decisions (Kriesi and Jegen 2000, p. 30).

Party Positions

As in the case for climate change, I propose to investigate party positions as an indicator of conflict lines. A quick glance at the official positions of Switzerland's major national parties regarding energy policy is informative:

- **SP** The left *social democratic party* has been very critical of nuclear power and of the fossil-based energy system. In contrast, it has been advocating energy efficiency and energy systems based on renewables (SP 2006).
- **Greens** The left *green party* has been particularly critical of nuclear power and fossil-based energy systems. They advocate that Switzerland's energy system be based completely on renewables. Therefore, they strongly advocate energy efficiency (Greens 2011).
- **CVP** The centrist *Christian peoples party* promotes energy efficiency, research into environmental technologies and the production of electricity from renewables. Historically, the party has accepted nuclear power. It sees it as a transitory technology to ensure energy security (CVP 2011).

- **FDP** The centrist *liberal party* argues that energy policy is of crucial impor-
  tance for the wealth of Switzerland, and therefore they stress the need to balance
  environmental considerations, energy security and economic considerations. They
  advocate energy efficiency, and research into innovative energy technologies. They
  support the current mix of nuclear, hydro and renewable generation. As they stress
  the importance of market forces, they are generally against subsidies for energy
  innovations (FDP 2010).
- **SVP** The right *Swiss peoples party* supports nuclear power plants. They argue that
  the conventional electricity mix leads to a secure, independent and cheap energy
  system. They argue that renewables will increasingly contribute to electricity pro-
  duction. Yet they demand that renewables succeed without subsidies on the market
  (SVP 2010).

In summary, the major Swiss parties can be positioned on an axis which runs
from conservative (support for a mostly nuclear and fossil-based energy systems)
to progressive (support for more energy efficiency and renewables). However, party
positions change in response to changes in their environment. The recent events
relating to the nuclear power station at Fukushima (Japan) can be read as an exam-
ple on how external shocks cause policy change. Now, with Switzerland seriously
deliberating the phasing-out of nuclear power plants, it seems that the balance has
shifted in favour of the progressives.

3.4.3 Public Policies in Response to Problematic Energy-Use Patterns

Since the year 2007, Swiss energy policy rests on four strategic principles. These are
energy efficiency, *renewable energy resources*, *replacement and new construction
of large electrical plants* and *energy-related foreign policy*. In order to substan-
tiate strategic principles, action plans for energy efficiency and renewables were
announced (BFE 2007a). These plans contain a series of specific measures which I
will further describe in Sect. 3.7.

Policies aiming at a higher *energy efficiency* seem to be very prominent, also
internationally (WEC 2008). This is because by increasing energy efficiency, the
utility drawn from energy services remains constant. Particularly, in cases where
energy efficiency is profitable, such policies may actually increase the welfare of
consumers. In contrast, *energy sufficiency* policies, which entail a reduction of the
utility drawn from energy services, are probably less accepted by the population as
they demand sacrifices and potentially reduce the welfare of consumers.

However, the view that an increased efficiency in the use of energy will actually
translate to a reduction in energy use has been challenged. Herring (2006, p. 10), for
example, argues that the "effect of improving the efficiency of a factor of production,
like energy, is to lower its implicit price and hence make its use more affordable, thus
leading to greater use." The existence of this phenomenon, called *rebound effect*, does

however not mean that energy-efficiency should not be promoted. Herring (2006) rather concludes that the growth of the demand for energy should be decoupled from carbon-based energy resources. One particularly interesting example of a rebound effect is reported by De Haan (2009, p. 16) who found that the average per capita floor space is 75 m^2 in buildings certified with the energy-efficient Minergie label. In contrast, the Swiss average per-capita floor space is 46 m^2. This illustrates how efficiency increases might be compensated for by expansions of the consumption level.[12]

Drawing on the experience of several OECD countries aiming to increase energy efficiency, Geller et al. (2006) conclude that well-designed policies can achieve substantial energy savings. Among the different types of energy policy approaches, the following concepts have been applied successfully.

- **Government-funded research and development** as well as demonstration projects contributed to the development and subsequent marketing of several energy efficiency technologies in several countries and sectors.
- **Minimum efficiency standards** can effectively stimulate energy efficiency improvements. Public policy however needs to ensure that energy efficiency standards are economically viable and technically feasible.
- **Voluntary agreements** between governments and the private sector—ideally complemented with financial incentives, technical assistance and the threat of regulations and taxes should private partners fail to deliver the outcome agreed upon—can be particularly effective when regulations are difficult to implement.
- **Financial incentives** can promote the adoption of energy efficiency measures. This is particularly useful for supporting newly commercialized technologies, particularly technologies with high first cost and a high probability of future cost reductions.
- **Increasing the cost of energy** by the abolishment of subsidies for fossil-fuels or by increasing energy or CO_2 taxes can help to foster greater energy efficiency, especially if the tax revenue is used to support energy efficiency programs.
- **Soft policies**, such as labeling, information dissemination and training can promote awareness of energy efficiency measures and increase energy management know-how, although such soft policies are more effective if combined with financial incentives, voluntary agreements or regulations.

Note that every of these approaches has been applied in one form or the other in the context of Switzerland's energy policy. However, a systematic review of all specific instruments would exceed the scope of this study. Hence, I must refer to the specialized literature, such as for example the energy policy review by OECD/IEA (2007).

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[12] However, some part of this may be explained by the fact that mostly new buildings implement the Minergie standard. New buildings in general provide larger floor space than old buildings. Further, some of this may also be explained by the fact that mostly tenants with high income live in new (and hence energy-efficient) buildings.

3.5 The Stock of Buildings

The objects which make up the built environment are the most valuable assets of advanced economies. In the year 1999, the value of Switzerland's built environment was estimated to be around 2 441 billion[13] Swiss Francs, of which the stock of buildings accounts for 1 788 billions (Steger et al. 2002, p. 91). Moreover, the stock of buildings (and the built environment in general) are crucial for the achievement of policies motivated by climate change and energy use patterns. This is because they account for a large share of Switzerland's energy demand and consequently also emit large amounts of greenhouse-gases.

3.5.1 Physical Aspects of Switzerland's Stock of Buildings

In the year 2000, Switzerland had a total of 1 462 167 buildings. Of these, 80.7 % were purely residential, 13.6 % were partially residential and the remaining 5.8 % were non-residential buildings. Of the purely residential buildings, about 69.6 % (821 719) were single family homes, about 11 % (129 760) were double family homes and about 19.4 % (227 799) were multifamily homes. 48.8 % of all buildings were built before 1961, 25.2 % of buildings were built between 1961 and 1980 and 26 % were built between 1981 and 2000 (BFS 2012a, n.d.c, T9.2.1.1). The situation in the European Union is somewhat similar. There, the stock of buildings is estimated to be about 150 million dwellings, with about 2 millions being added yearly. Roughly 70 % of the buildings are older than 30 years and about 35 % are older than 50 years (Balaras et al. 2005, p. 515).

Swiss buildings constructed before the year 1947 generally have a good structure and could easily be inhabited for several of the next decades. In many cases the structural condition of such buildings does not require urgent renovations. In contrast, buildings constructed between the 1950 until the 1970 are often of inferior quality. They are characterized by a lack of insulation and they implemented various other inferior construction technologies (Econcept and CEPE 2005, p. 88). At that time, demographic changes and economic growth lead to spectacular increases in the demand for housing (Van Wezemael 2005, p. 52). In consequence, between the years 1952 and 1972 the volume of all built structures in Switzerland was doubled (Koch, Somadin and Süsstrunk Koch, Somadin and Süsstrunk 1992, p. 197; cited in: Van Wezemael 2005, p. 52). In order to produce such enormous quantities of housing, construction work came to rely on rationalization, standardization and greater industrialization. It is particularly the large multifamily buildings that were constructed during the boom phase following world war II. All this means that about a quarter of buildings in Switzerland are due to be renovated in the next one or two decades. Among these buildings are the least energy-efficient buildings of the country (Van Wezemael 2005, p. 53).

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[13] I mean the american billion, which corresponds to 1 000 millions or 1 "Milliarde" in German.

3.5.2 Energy Use in Buildings

Its large share in energy use and CO_2 emissions make buildings all over the world an important object of climate and energy policy. Buildings are particularly important because they constitute a 'low-hanging fruit', as they have the largest share of negative- and low-cost mitigation opportunities (IPCC 2007b, p. 621). Hence, everything points towards the built environment being targeted for faster and more substantial reduction measures compared to most other sectors (Shipworth 2007, p. 483).

In Switzerland, half of per capita gross energy demand, around 2690 watt, can be attributed to the construction, use and maintenance of buildings. Roughly 60 % of this, around 1590 W per capita, can be attributed to residential housing. 30 % or 780 W per capita can be attributed to service buildings, while industrial buildings demand roughly 10 % or 320 W per capita (Koschenz and Pfeiffer 2005, p. 8). Most of this demand for energy is met based on fossil-fuels. Hence, the stock of buildings offers a large potential to reduce the demand for fossil energy sources as well as the emission of CO_2. Particularly residential buildings are relevant as they are the most widespread type of buildings. Due to the long life-cycles of buildings, the existing building stock will dominate the energy demand of buildings in the next decades. This aspect is important because old buildings generally are far less energy-efficient compared to recently constructed buildings. Hence, considerable savings can be achieved by refurbishing the existing stock of buildings (Jochem 2004; Regierungsrat des Kanton Zürich 2006).

Ürge-Vorsatz et al. (2007, p. 295) find that the implementation of carbon mitigation options in buildings is associated with several ancillary benefits, such as the creation of jobs and business opportunities, higher economic competitiveness and increased security of energy supplies. Further, social welfare benefits for households with low incomes, increased access to energy services, improved air quality indoors and outdoors as well as increased health, comfort and quality of life. However, "despite the significant potentials at negative costs and the substantial co-benefits identified (...) these potentials are difficult to unlock" (Ürge-Vorsatz et al. 2007, p. 295). The reason lies in the diverse and strong barriers that exist in the residential and commercial sectors.

In recent years, the call for increased energy efficiency in buildings has gained widespread support as an important part of a strategy to move Switzerland towards the vision of a 2000-watt society. A representative survey commissioned by the World Wildlife Fund for Nature Switzerland (LINK 2010) finds that a majority of respondents agrees mostly (21.1 %) or completely (53.3 %) with the statement that the Swiss should insulate their buildings better and implement other climate protection measures in order to create jobs and become more independent of oil.

Regarding the future development of the energy use in buildings, Harvey (2009) proposes the following reduction targets: "(...) an appropriate target would be to achieve a factor of 3–4 reduction in the energy intensity of new buildings by 2020 and
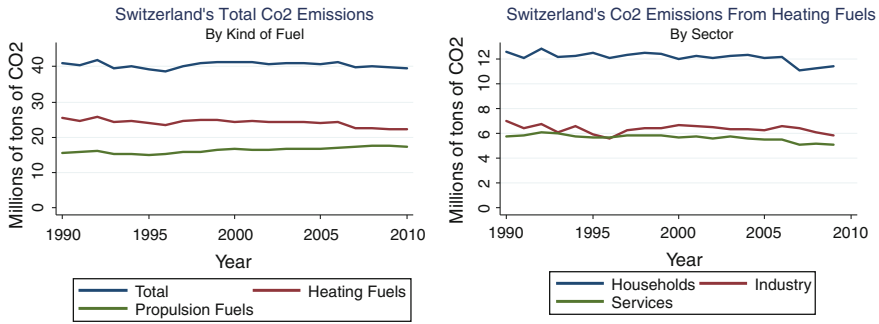
Fig. 3.3 Switzerland's CO_2-emissions (note that the scale of the y-axis does not correspond between the two exhibits). Data from BAFU (2011)

programs to achieve (on average) a factor of 2–3 reduction in the energy intensity of existing buildings whenever significant renovations are carried out" (Harvey 2009).

3.5.3 Emissions from Buildings

Worldwide, about one third of energy-related CO_2 emissions comes from the building sector (Ürge-Vorsatz et al. 2007). In Switzerland, the stock of buildings is of crucial importance for the achievement of climate and energy policy goals. Figure 3.3 shows Switzerland's CO_2 emissions. The exhibit on the left shows the development of Switzerland's total CO_2 emissions over the years 1990–2010. In addition, the emissions of propulsion fuels and heating fuels are shown. As can be seen, a slight reduction of the emissions from heating fuels is roughly offset by a slight rise of emissions from propulsion fuels. The exhibit on the right further differentiates the emissions from heating fuels according to the sectors. As can be seen, the households account for about half of the CO_2 emissions from heating fuels.

While CO_2 emissions from combustion play a large role, other, synthetic gases too contribute to the warming of the atmosphere. They amounted to 0.84 million tons of CO_2 equivalent in the year 2006. About half of this comes from cooling in buildings (airconditioning, refrigeration). The remainder comes from cooling in commerce and industry, cooling in vehicles and the production of industrial foams (BSS 2008, p. 10).

3.5.4 Housing and the Rental Market

In Switzerland, the majority of flats are rented to tenants. Schulz and Würmli (2004, 15) find that 60 % of flats were occupied by tenants and a further 3.7 % by members

of building associations, who typically also are tenants. In contrast, about 34.6 %
of total flats were occupied by owners of the whole building or the owners of a
condominium.

On a very high level, housings, and the buildings they are located in are multi-
faceted artifacts that provide several types of goods and services. Nicol and Knoepfel
(2008, p. 164) identified the following seven major categories: *Residential* goods and
services such as living space or indoor climate and technical services. Similarly, for
the *non-residential* sector functional or collective indoor space are provided by the
stock of housing. The housing stock functions as a *production factor* as it allows
for capital, land and labour investment, and it provides *utility services* such as waste
water disposal. It further has *urban*, *nonmaterial* and a range of *other* functions.

The market for rented flats can be segmented into simple, standard and luxurious
types of buildings. It can be seen that the newer a building is, the smaller the share
of simple flats is (25 % in flats built before 1981; 9 % in flats built between 1981 and
1990; 5 % in flats built after 1990). In contrast, the newer a building is, the higher the
share of luxurious flats is (8 % in flats built before 1981; 11 % in flats built between
1981 and 1990; 37 % in flats built after 1990) (POLIS 2007, p. 9).

Geiger (2006) argues that rental prices should be seen as *hedonic prices* for the
sum of pleasures the tenant draws from living in a specific housing. In particular,
each housing can be interpreted to be a bundle of material and immaterial attributes,
for which tenants have an (implicit) willingness to pay. In reality, rental prices are
paid for the whole bundle. Yet with statistical methods (discrete choice analysis)
the implicit prices for the attributes of a bundle can be estimated. According to this
logic, tenants are willing to pay more for those characteristics of a flat they enjoy
than the building owner's capital costs associated with that characteristics. The other
way around, for characteristics from which tenants do not derive a lot of pleasure
they may have a willingness to pay which is below the building owner's capital
costs. The same rationale holds for the location of a building and other exogenous
factors (Geiger 2006, p. 11). In conclusion, this means that building owners aiming
at maximizing their return on investment would invest primarily into characteristics
for which they perceive tenants to hold a high willingness to pay.

Without renovations, buildings move over time from a new condition to a good
condition, and later from a good condition to a bad condition. This is because their
physical substance ages and because the configuration of buildings often becomes
outdated. For example, the current trend towards large apartments puts small apart-
ments in older buildings at a competitive disadvantages. The process of buildings
becoming outdated and less attractive to the premium market segment is called
"filtering" (Eekhoff 1987, p. 19; Frey 1990, p. 144.). Consequently, buildings in
new and good condition are frequently inhabited by households with an income at or
above the average. Conversely, buildings in bad condition in average are frequently
inhabited by households with an income below average. Filtering processes can be
reversed by renovations: After remaining some time in a bad condition, buildings
are either renovated or reconstructed. Renovations change a buildings condition to a
good condition and reconstructions change a building to a new condition. However,

because older flats generally have smaller rooms than new flats, they increasingly do not conform to current housing trends (POLIS 2007, p. 7).

Referring to the construction of housings, Schüssler and Thalmann (2005, p. 5–6) find that the sector is highly fragmented. There are many different rationales for constructing housings. A surprisingly large share of the investment decisions are affected by coincidences and not the result of professional considerations of the market and investments possibilities. However, most of the construction of new housings is directed toward households with medium to high income.

There is a clear relation between the quality of social relations and the quality of the (built) environment. As the physical state of housing decreases, better-off tenants leave the place and the social problems in the remaining population increases (Kohler and Yang 2009, p. 355). The causes of such vicious cycles of social disintegration, high tenant turnover and flat vacancy rates above average can be found in architectural conditions (e.g. outdated and inadequate design of flats, peripheral location), socio-economical conditions (e.g., high share of persons with low income, high share of socially unintegrated persons, high share of immigrants) and psychological issues (e.g., poor image and reputation of the neighborhood, tenants without roots in the neighborhood) (Logis 2000). When such a process unfolds, it can lead to situations where the tenants in a neighborhood are predominantly from countries such as Ex-Yugoslavia, Turkey or Albania which are frequently marginalized on the Swiss housing market. Segregation in housing has several negative societal consequences, particularly for children and women who do not participate on the labour market. In a segregated environment they have fewer opportunities to encounter the Swiss culture, which means that children start school with a disadvantage.[14]

3.6 Elements of the Diffusion of Energy-Efficient Renovations

3.6.1 Theoretical Foundation: Explaining the Diffusion of Innovations

There is a large literature on the diffusion of innovations, reporting on theoretical advances and findings from a wide range of applications. In the following, I introduce key terms and concepts that are frequently used in the context of the diffusion of innovation. As the purpose of this section is to introduce rather than to review the literature, I mostly rely on Rogers (2003) and consciously omit contributions such as the Bass diffusion model (Bass 1969) or more network-focussed approaches (Valente 1995). The theory of the diffusion of innovations is important because it can provide concepts and generic explanations of diffusion processes to this study.

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[14] See BFM (2006) and the literature quoted therein for a survey of perceived integration problems of foreigners in Switzerland, including but not limited to housing issues.

Definitions

Generally, I find it useful to follow the classical definition by Rogers (2003, p. 12), according to which an innovation is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption". The same author defines diffusion to be "the process in which an innovation is communicated through certain channels over time among the members of a social system." (Rogers 2003, p. 5). Narrowing the focus specifically to innovations in the technological domain, Stoneman (2002) distinguishes between *process innovations* and *product innovations*: Process innovations refer to advances in the way production is organized. Product innovations refer to "technological advances in the nature and types of products produced" (Stoneman 2002, p. 4). However, technologies are very seldom stand-alone innovations, because the introduction of new equipment may lead to changes in the organization of the production process or new management forms. By introducing new technologies, spill-over effects might occur, such as increases of the productivity of old equipment (Stoneman 2002, p. 6).

Innovation-Decision Process

Rogers (2003, p. 169) proposes the following characterization of the innovation-decision process. It is an attempt at explaining how decisions on the level of individual decision making (the micro-level) cause the diffusion of an innovation (on the macro-level). Specifically, he proposes to differentiate the following five stages through with each potential adopter of an innovation moves:

- **The Knowledge Stage**: In the knowledge stage, a decision making unit learns of the existence of an innovation and how the innovation functions. Entering this stage can occur either "by accident" or as the result of an active searching process. Obviously, communication is a major aspect of the knowledge stage.
- **The Persuasion Stage**: If an actor finds that the information she has been exposed to is relevant, she enters the persuasion stage. There, she forms a favorable or unfavorable attitude towards the innovation (Rogers 2003, p. 174). In this stage, the perceived characteristics of the innovation are evaluated against the situation and the personal characteristics of the actor. Innovations are evaluated more favorable when they are advantageous in relation to alternatives, when they are compatible with the wider field of practice they are located in, when they exhibit little complexity and when they can be tried easily (Rogers 2003, p. 229).
- **The Decision Stage**: In the decision stage, the actor "engages in activities that lead to a choice to adopt or reject an innovation" (Rogers 2003, p. 177). Most individuals try the innovation or observe how the innovation works for a peer.
- **The Implementation Stage**: In the implementation stage, the innovation is put into practice. In order to overcome operational difficulties, individuals seek technical information. Frequently, implementation requires a change in behavior, as adopters are not passive recipients of innovations: The innovation and the behavior of the

actor co-evolve in order to adapt to the specifics of the individual's situation. Re-invention refers to "the degree to which an innovation is changed or modified by a user in the process of its adoption and implementation" (Rogers 2003, p. 180).

- **The Confirmation Stage**: The decision-maker keeps evaluating information and either continues the innovation or abandons it.

Adopter Categories

Rogers (2003, p. 282–299) classifies adopters according to the relative time of adoption of an innovation into five ideal-typical categories: *Innovators* are resourceful and competent individuals which can deal with high degrees of uncertainty when attempting to "launch the new idea in the system" (Rogers 2003, p. 283). *Early adopters* are well-integrated opinion leaders which serve as role models. Eventually, the *early majority* substantially increases the mass of adopters after a more lengthy evaluation-decision process. The *late majority* adopts innovations after the average member of the system and the *laggards* are the last to do so (Rogers 2003, p. 284).

3.6.2 Construction

The construction sector is of crucial importance for the transformation of the stock of buildings. It influences over what range of options building owners and architects can decide. In particular, it partially determines the costs and the technological quality of energy-efficient building designs in renovation projects.

In industrialized countries, the construction sector is a very important sector of the economy: In the OECD countries, for example, it accounts for about 5–15 % of GDP, provides about 5–10 % of total employment and around 45–55 % of gross fixed capital formation (OECD 2003, p. 20). In Switzerland, the construction industry contributes around 5.5 % of total value creation. In the year 2008 it employed almost every third person in the second sector which corresponds to 7.8 % of the total workforce (BFS 2010). Between the years 1980 and 2008 the total expenditures for construction amounted to some 10 to 13 % of Swiss Gross National Product. In prices of the year 2000, the expenditures for construction were between about 40 and 50 billion Swiss francs (BFS 2009). About a third of these expenditures came from various levels of the state (Wallbaum 2010, p. 3).

The construction sector is generally not a knowledge-intensive sector and generally not very dynamic concerning its innovativeness. Innovations originate mostly from suppliers and address new constructions first. Later, the solutions developed there diffuse to the renovation sector (Nill 2009, p. 295). The structure of the construction industry is often not favorable to the diffusion of energy-efficient renovations. Several barriers can be found in the industry. Examples for such barriers are the lack of transparency, principal-agent relationships or subcontracting by construction companies. There are some indications that there is a lack of competition in

energy-relevant markets. In addition, markets for energy-efficient technologies in the construction sector often still are in a very early stage of development (BFE 2004).

3.6.3 Renovation Practices

Terminology

Renovation can entail several modifications of a building. Econcept and CEPE (2005, p. 39) propose to differentiate practices related to buildings as follows: *Maintenance* ensures the functioning of the building by performing simple and regular repair and maintenance. Maintenance is included into the rent and consequently does not have any financial implications for tenants. *Repair* re-establishes the security and fitness for use of a construction element for a specific duration, generally until the service life of a construction element according to the SIA norm 469 is reached. Repair generally does not lead to increases of the tenant's rent. During *renovation*, the building respectively the building's elements are modernized such that they correspond to the current technological level. Normally, this includes energetic improvements of the building and leads to increases of the rent.

Motivations for Renovation

The physical condition of a building and economic reasons are seldom the reason for conducting thermal insulation of multifamily buildings given by building owners who conducted thermal insulation. Instead, Econcept and CEPE (2005, p. 75) find that environmental concerns and the motivation to save energy were the most frequent reasons given by owners of multifamily buildings for implementing energy-efficiency enhancing measures. The replacement of building elements that have exceeded their service life is not a typical reason for the implementation of energy-saving measures.

General Renovation Patterns

Between the years 1990 and 2000, about 23 % of all Swiss flats were renovated to some degree (Gerheuser 2004, p. 61). In contrast, only about 0.1 % of buildings were torn down per year in the period 1985-1999. This corresponds to an average service life of thousand (1000) years per building, a figure which is not realistic in the long run. Because the service life of buildings is expected to be much lower, an increase in reconstruction should be expected in the long term (CEPE and HBT 2002, p. 39).

Econcept and CEPE (2005, p. 51) argue that there is actually rather little empirical information for quantitative and qualitative aspects of renovation practices. In particular, the data collected by the federal office for statistics do not give insight

into which elements were renovated. However, in a dedicated research project (Jakob et al. 2003), retrospective information on renovation practices between the years 1986 and 2000 were gained. In that study, windows turned out to be the most frequently renovated building elements (59%). Nearly as frequently were façades (35–50%) and roofs (30–50%).[15]

Energy-Efficiency Enhancements During Renovations

The problem with the figures on renovations above is that they include both type of measures. Renovation measures that enhance the energy efficiency of buildings as well as measures that do not enhance it. In the case of façade renovation, Jakob and Jochem (2004, p. 3)[16] find that only about 10–15% of all buildings were insulated during the years 1986–2000. In the case of roofs, about 20–30% of buildings were insulated in the roof. The authors do not further discuss the energetic impact of window renovations. Yet in my opinion, as the capability of windows to insulate has improved substantially over the last decades, this should be interpreted as a substantial efficiency gain.

These findings roughly correspond to the findings of POLIS (2007)[17] who finds that slightly less than 1% of flats per year are retrofitted with thermal insulation on the façade. In a little more than 1% of flats per year work on the roof was conducted. In slightly less than 3% of flats the windows, the third major measure likely to increase the energy-efficiency of a building, were renovated or maintained (POLIS 2007, 11) Jakob and Jochem (2004, p. 5) conclude that energetically relevant renovations are generally not conducted during a complete overhaul of the building. Rather, the implementation of incremental measures seems to be the most widespread behavior.

Contributions to Sustainable Development

Power (2008), discussing the situation in the UK, finds that issues like the embodied energy of existing buildings and increased waste from demolition may reduce or even over-compensate the positive effects of reconstructions. Further, demolitions may create social problems as low-income housings are crowded out and gentrification processes are fueled. However, accelerated demolitions are probably neither cost-effective. For example, in a study of the residential building stock of the EU-27 countries, Uihlein and Eder (2010) find that an accelerated replacement of building elements such as roofs and walls, outside of normal renovation cycles, is not cost-

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[15] The percents given in brackets refer to the share of the corresponding elements renovated at least once during the years 1986–2000.

[16] Jakob and Jochem (2004) report on the same study as Econcept and CEPE (2005, p. 51).

[17] POLIS (2007) provides an analysis of rented and owner-occupied flats in Switzerland in the years 2001–2003, based on data from the Swiss Federal Office for Statistics. Specifically, renovation behavior was investigated based on a survey of rental prices, that was conducted in the year 2003 ("Mietpreis-Strukturerhebung 2003").

effective. Specifically for Switzerland, Ott et al. (2002) find that reconstructions can in the long run lead to reduced energy use. However, the general environmental impact of reconstructions substantially depends on the amount of recycling in the use of materials and the disposal of wastes.

In conclusion, it is probably not possible to find a generally applicable answer to the question whether reconstructions or renovations are better from an environmental perspective. Instead, answers must be provided for each building considering of the specific situation. However, for those buildings where demolition and reconstruction is preferable, recycling may help to reduce waste and environmental impact.

Variance Among Building Owner Types

POLIS (2007, p. 25) finds that building associations renovated their flats most frequently and with the highest intensity (in the years 2001–2003). Their renovation rate was 11 % per year. The other groups of building owners had a renovation rate somewhere between 8 and 9 % per year. This finding is confirmed by Econcept and CEPE (2005) who find that buildings owned and administrated by insurances and retirement funds get significantly more frequently refurbished with thermal insulation than buildings owned by private persons. Yet buildings owned by building associations are even more frequently refurbished with thermal insulation. Somewhat surprisingly, they find that buildings owned by the state are refurbished less frequently with thermal insulation than the average of buildings. Econcept and CEPE (2005) find that the renovation behavior of private persons is related to socio-demographic and socio-economic factors such as age, education, profession, importance of building ownership, and so on. In addition, the location and the condition of the building as well as legal and economical aspects influence the renovation behavior (Econcept and CEPE 2005, p. 89).

3.6.4 Energy-Efficient Building Designs

Buildings may be described as a combination of various technological components, including the building hull (walls, roof, floor), windows and various technical systems (heating, ventilation, etc.). I use the term *building designs* to refer to all the different ways of providing the functions required by a building. This term abstracts from specific technologies and the nearly infinite ways of combining the functional elements. Yet, for the purpose of this study, it is a useful simplification. Further, I define energy-efficient building designs as all the different ways of providing the functions required from a building such that the demand for space heating is much lower compared to conventional building designs with minimal insulation. Energy-efficient building designs may be seen as part of the wider field of "sustainable buildings".

Typically, energy-efficient building designs are built in a compact manner. Compact buildings have a small ratio of surface to volume which minimizes heat losses. That ration also decreases as buildings get bigger. Energy-efficient building designs frequently rely on natural processes. For example, trees may be used to provide shade in summer. In winter, when the leaves are gone, they let more light into the buildings. In addition to such conceptual elements, energy-efficient building designs typically rely on specific technologies, such as insulation, triple glazed windows and ventilation with heat recuperation.

Insulation

Insulation is usually applied to the exterior of buildings, between the wall and the façade, although buildings can also be insulated from the interior. Insulations of the roof and the ceiling of the basement are all important. A wide range of materials can be used to insulate buildings, including highly advanced materials based on vacuum components. While the application of external insulation is technically quite matured, it comes with some problems. For example, in Switzerland there are regulations that specify how close to the border of a lot a building may be built. If thick insulation material is applied, then the floor space within the building becomes smaller compared to what it could be if the walls were less thick. However, in recent years many have municipalities allowed buildings to be insulated beyond the construction line.

In earlier days, the application of external insulation was not standard practice when buildings were constructed. In fact, one of my interviewees (an architect at a construction company) observed that in the last decades the amount of insulation has increased substantially.

> (...) in the 1970s one began to apply external insulation. It is ridiculous. Two centimetres... one centimetre... and where are we now...? We talk about 15–18 cm.

Currently, insulation with a thickness of 30 cm and more can be routinely used. Unfortunately, however, thick insulation layers can lead to aesthetic problems. A representative of a tenant association expressed this in an interview as follows:

> When you insulate, then there are aesthetic problems, which I call the 'shooting hole' problem. You get this at about 20 cm of external insulation or more, if you leave the windows where they were before insulating. So, inside you have less light and from the outside the building looks like a bunker.

Windows

Highly insulating windows are a crucial element of energy-efficient building designs. Frequently, the south of energy-efficient buildings contains large windows to capture sunlight in the winter. Nowadays, windows are typically triple-glazed and the space between the glasses is filled with noble gases.

Ventilation Systems

In most buildings, ventilation occurs without technical ventilation system. There-fore, technical ventilation systems are not considered a key component of conven-tional buildings. However, ventilation systems are quite important in energy-efficient buildings. This is because energy-efficient buildings are built rather tightly in order to reduce heat losses. In consequence, natural ventilation is minimal. In addition to ensuring the continuous exchange of air, modern ventilation systems may also be used to recuperate waste heat. Ventilation systems can increase the comfort of hous-ings as they continuously improve air quality, reduce particles in the air and regulate humidity.

While ventilation systems play an important role in advanced energy-efficient building designs, they have historically suffered from rather poor acceptance. One reason for this is their initially poor performance record. For example, in a survey of 180 multifamily buildings that were renovated between 1998 and 2008, the authors found that in about a third of the buildings difficulties with the ventilation system arose (Rütter et al. 2008, p. 7). In fact, ventilation systems provide an instructive example how the premature application of a technology can lead to a negative, persistent image which results in low acceptance and even outright resistance by the inhabitants of buildings.

The fact that early installations of ventilation systems were performed by installers without experience probably contributed substantially to the negative image of ven-tilation systems. As one of my interviewees explained, ventilation systems would often be installed for a whole building rather than just for a flat. Such centralized systems need to be calibrated in order to ensure that each ventilation exit has an adequate air flow. In some instances tenants would block the ventilation exits, in order to reduce the air flow to the level they deemed comfortable. This would lead to over-ventilation of the flats below and beneath, whose tenants then would deposit complaints with the landlord. Another reason why ventilation technology has low acceptance may be that tenants are not systematically trained in the use and limita-tions of such technological systems. Finally, there is an influential myth according to which the windows cannot be opened in buildings with ventilation systems. This is of course not true.

Certified Energy-Efficient Building Designs

Basically, an energy-efficient building design is characterized by physical charac-teristics that can be implemented based on a wide range of technologies. However, due to the importance of considerations beyond physical aspects, well-designed stan-dards have been developed. Such standards offers architects and planners solutions for problems typically encountered in the development of energy-efficient building designs. Further, standards can signal building owners that energy-efficient build-ing designs are not a risky innovation but rather an established technology. Stan-dards can also empower building owners without technical know-how to demand

energy-efficient building designs from their architects. Finally, certification frequently is a pre-condition for the granting of a label. Nevertheless, probably only a minority of energy-efficient buildings actually get certified. In the following, I list the most frequently encountered certifications for energy-efficient building designs in Switzerland

- Minergie is the most important standard in Switzerland. From the initial Minergie standard several more ambitious standards have emerged. The Minergie-P standard is more ambitious compared to the conventional Minergie standard. The Minergie-Eco standard is certified if further criteria from domains such as sustainable sourcing and construction and health aspects are adhered to. The very recent 'Minergie-A' standard aims to achieve "nearly zero-energy buildings" (Minergie 2010a).
- The Passivhaus standard, which literaly means "passive house" standard, was developed in the year 1996 by Dr. Wolfgang Feist in Germany. In Switzerland, it was the basis for the Minergie-P standard. However, there are some minor differences between the two standards (IP Passivhaus 2011).
- LEED, which stands for 'leadership in energy and environmental design', is a standard which was developed by the United States Green Building Council (USGBC 2011). It is mostly irrelevant in Switzerland.
- In recent years, several countries have changed their requirements for buildings such that most of the buildings constructed in recent years can qualify as energy-efficient.

Currently there is a lot of activity in the construction domain related to sustainability issues. This includes passive houses, zero heating buildings, ultra-low energy houses, 3-litre houses and plus energy houses (Erhorn-Kluttig and Erhorn 2007). However, no standard definition of sustainable building has emerged yet. Instead, several models and evaluation criteria have been proposed in the literature (Siegl 2008). Recently, "zero energy buildings" have emerged as the new frontier in energy-efficient building designs. While substantial conceptual and methodological questions remain open (Marszal et al. 2010), significant technological progress should be expected in the domain of energy-efficient building designs in general and certified building designs in particular.

3.6.5 Technological and Economical Progress in Energy-Efficient Building Designs

Energy-efficient building designs and the technologies they rely on have been under development for a long time. Over the years, substantial progress in the technological and the economical dimensions have been achieved (Erhorn-Kluttig and Erhorn 2007). In fact, CEPE and HBT (2002, p. 314) recall that the rapid technological progress achieved over the last decades would have been called a super-efficient

development in the early 1980. Jakob and Madlener (2004, p. 175) sees the following drivers behind the impressive economic and technological progress in the years since 1975: "(a) the establishment of building codes and standards; (b) energy price signals; (c) environmental concerns; (d) the active promotion of labels and standards; and—as a consequence—(e) experience curve phenomena."

The notion of the experience curve originates from industrial economics (Porter 1989). It states that technological performance improvements and cost reductions are a function of cumulative production. As cumulative production doubles, the unit production costs fall by a certain value (Kahouli-Brahmi 2008, p. 139). Technological progress and unit cost reductions are specifically brought about by the accumulation of experience over time in the production process (McDonald and Schrattenholzer 2001). Such learning may come in a variety of different forms. For example, "learning-by-doing" occurs when new ways are discovered to make production more efficient. Learning may come from "learning-by-researching" when resources are invested in research and development. It may come from "Learning-by-using", when feedback provided by users helps firms to learn how they may adjust more to the users' needs. Further, it can come from "Learning-by-interacting" when interactions with a whole network allows to access knowledge of external sources (Kahouli-Brahmi 2008, p. 139).

For energy-efficient technologies in general, such as windows and thermal insulation, (CEPE and HBT 2002, p. 314) estimate the cost reduction coefficient to be between 0.8 and 0.9. This means that with each doubling of cumulative production volumes, the unit cost falls to about 80–90 % of what it was before. Specifically, the costs for a 20 or 30 cm thick façade insulation are expected to decrease by 0.7 % per year until the year 2020 (CEPE and HBT 2002, p. 251).

As a consequence of technological and economical progress, the application of energy-efficient technologies and energy-efficient building designs increased. CEPE and HBT (2002, p. 12) find that the thickness of insulation material used in roofs, basement ceilings and façades increased between the years 1960 and 2000. Since the period of 1971–1975, the increase in applied thickness of insulation material was accelerated due to the oil crises of 1973 and 1979–1980, and the increase continued despite falling prices for heating oil. CEPE and HBT (2002) argue that high oil prices not only affected building owners investment behavior. It also got business associations to adopt energy-efficiency enhancing practices as new standard, and it got public administration to institutionalize energy-efficiency aspects into legislation. Jakob and Madlener (2004, p. 166) found that the average U-values (in W/m^2K) of window glazings decreased from about $6\,W/m^2K$ in 1950 to well below $1\,W/m^2K$ in the year 2000 (based on data from two leading Swiss glazing companies). Regarding costs, Jakob and Madlener (2004, p. 167) found that "despite the impressive technical progress made over the last thirty years in terms of thermal conductivity, the price of coated double glazing has actually decreased by more than a factor of two (real 2001 prices)." This exemplarily shows how the performance-to-cost ratio of an energy-efficient technology can increase.

3.6.6 Economics of Energy-Efficient Building Designs

Energy-efficiency in buildings is best conceptualized as an investment where the cost of the investment must be offset by reduced costs for energy. Many authors use the "discounted cash-flow" (DCF) framework to evaluate the profitability of investments into energy-efficiency in buildings.[18] The DCF framework allows to calculate the present value of future income streams, under consideration of interest, investment cost, subsidies and income received at different moments in time. When the net present value is bigger than zero, then the investment is profitable. By calculating the net present value for several investment alternatives, the most profitable investment alternative can be identified.

However, before the DCF framework is discussed in greater detail, it is important to distinguish between the private profitability and the societal profitability of investments into energy efficiency. Most investment decisions are based on private profitability. This means that private building owners do not give any value to the positive externalities (such as cleaner air, mitigation of climate change, etc.) of their investment and potentially under-invest. From a societal perspective, the external effects of investments into energy efficiency are valuable. By promoting investments into energy efficiency, public policy can increase the welfare of Switzerland.

The net present value (**NPV**) of an investment into the energy efficiency of a building can be calculated according to the following example.[19] Let us consider the replacement of old windows by highly energy-efficient windows. The cost of the windows would be (**I**) but the building owner may receive subsidies and tax rebates with a value of **S**. Let us assume that the windows have a service life (**T**) of 25 years. Replacing the old windows would reduce the energy demand of the building by **R** megajoules for every year the windows are in service. In order to account for yearly variations in R, it is written with a time index (R_t). The cost of one megajoule in the year t is P_t. Hence, by investing into energy efficient windows, the building owners saves $R_t * P_t$ in each year the windows are in service. However, in order to calculate the net *present* value, future cost reductions need to be discounted. This is typically expressed by the interest rate **i**. Equation 3.1 shows how the NPV of an investment may be calculated.

$$\text{NPV} = \sum_{t=0}^{T}(1+i)^{-t}(R_t * P_t) - I + S \qquad (3.1)$$

When all variables are known, the DCF framework is a very reliable approach to find the most profitable investment. Typically, variables are known in ex-post

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[18] Amstalden et al. (2007, p. 1822) point out that the DCF framework is de facto the standard method for evaluating the profitability of investments. Details of its applications are described in SIA (2004).

[19] I derived this example inspired by the discussions of the DCF method in Amstalden et al. (2007, p. 1822) and in Clinch and Healy (2001).

evaluations of past investments, when actual empirical data can be used. However, at the moment of investing into energy efficiency, building owners do not know how several variables will develop in the future. When conducting an ex-ante analysis with uncertainty in one or more of the determinants of the NPV, the results of the DCF framework depend on expectations. In fact, all of the right-hand variables in Eq. 3.1 come with uncertainty:

- Service life (T): The actual service life of the investment is uncertain and depends on the specific technology used and the quality of the installation. Hence, building owners have to use the expected service life of their investment. While simple insulation materials carry little uncertainty regarding their service life, more technically complex investments (such as ventilation systems or automated building control) may exhibit large variance in service life.
- Interest rate (i): Depending on the origin of the funds invested, the interest rate may be uncertain or not. Mortgages can be obtained with both variable as well as fixed interest rates. If savings rather than mortgages are used, then it is not evident what interest rate building owners should use to discount future savings. Should building owners calculate with the interest rate of mortgages or with the interest rate they would get if their savings were invested in bonds, stocks or saving accounts? In such a case, the economic evaluation of investments into energy efficiency may partially depend on subjective choices.
- Energy reductions (R): When considering investment alternatives, the reductions in energy use brought about by the investment are uncertain. Further, they partially depend on user behavior. If increased energy efficiency leads to increased demand for energy services, the profitability of the investment may be reduced.
- Energy prices (P): The price of the energy used in a building depends primarily on the price of the fuel and to a smaller degree on the heating system employed. Except in the rare case of long-term contracts, the future price of energy is unknown because the price for fuels such as heating oil is volatile. A wide range of energy price expectations can be justified, entailing both rising and sinking energy price levels. Building owners may also extrapolate current price levels into the future. Consequently, the calculated present net value of an investment substantially depends on the choice of what future energy prices ought to be used.
- Cost of Investment (I): The costs of implementing elements of energy-efficient building designs are probably not very uncertain. However, it is conceivable that construction costs may deviate from the expected value due to discoveries during the construction process. Further, the cost of investment may be increased if sloppy work requires legal action against the construction company.
- Subsidies (S): The profitability of investments into energy efficiency is influenced by one-time transfer payments and tax reductions. Whereas transfer payment are quite foreseeable, the value of the tax deduction depends on the greater financial situation of the building owner. For example, building owners with very small incomes may gain hardly any benefit from deducting investment costs.

From this discussion it should become evident that the economics of energy-efficient building designs in renovations can actually only be evaluated ex-post.

Yet, ex-post evaluations are hardly useful for investment decisions of building owners. In consequence, the profitability assumed when deciding over investments into energy efficiency is mostly subjective and depends on expectations. In line with this Amstalden et al.(2007, p. 1819) find that "the most relevant factor for the investment analysis is the expected energy price."

Nevertheless, the DCF framework is useful. By taking the first partial derivative of Eq. 3.1, the impact of changes in any of the right-hand variables can be analyzed. As can be seen below, increases of the service life (T), the energy savings (R), the energy price (P) and the subsidy (S) increase the net present value of investments into energy efficiency. In contrast, increases in the interest rate (i) and the cost of the investment (I) reduce the net present value. These insights may explain how the expected profitability of investments into energy efficiency changes. As technologies become better and more cost-efficient, the expected profitability rises and more investments occur.

$$\frac{\partial \text{NPV}}{\partial \text{T}} > 0 \quad \frac{\partial \text{NPV}}{\partial \text{i}} < 0 \quad \frac{\partial \text{NPV}}{\partial \text{R}} > 0 \quad \frac{\partial \text{NPV}}{\partial \text{P}} > 0 \quad \frac{\partial \text{NPV}}{\partial \text{I}} < 0 \quad \frac{\partial \text{NPV}}{\partial \text{S}} > 0 \tag{3.2}$$

The discussion above assumed self-inhabited buildings where building owners pay for the investment and appropriate the resulting savings. When housings are renovated and then rented to tenants, then it is the tenant who receives the savings while the building owner still carries the investment cost. This situation is typically called the investor-user dilemma. It can be overcome if tenants are willing to pay higher rents such that the building owner may recover his investment.

In a next step, I report on several studies that analyzed the economics of energy efficiency in buildings empirically. First, I report on the construction costs of energy efficiency in buildings. AUE and AUE (2010) analyzed the construction costs of new Minergie-P buildings, and compared them to new buildings with a conventional design. They found that the markup generally is around 5–15 % of the whole construction cost, of which some can be recovered through reductions of energy use. In line with this, the Minergie association argues that the growing number of Minergie-certified buildings demonstrates that low-energy building designs are currently technologically feasible and economically viable in both construction and renovation (Minergie 2010b).

Based on extensive research (Jakob and Madlener 2004; Econcept and CEPE 2005; Jakob 2006, 2007a), Jakob (2007b, v) summarizes his position on the economics of energy efficiency as follows: "Many energy efficiency investments are economically viable also from a private perspective, particularly if best practice is applied and if long-term considerations are being made. The flat character of the curve of annualised capital and energy costs as a function of increasing energy efficiency levels implies that advanced energy efficiency levels are as cost-effective as low ones, having the advantage of a decreased energy price risk exposure." However, this seems to be somewhat relativized by the insight from Amstalden et al.(2007, p. 1819) according to which "present Swiss policy instruments push investments for energy-efficient retrofitting to profitability." Yet, Amstalden et al. (2007) calcu-

lated with rather low energy prices. At a cost of 0.7 CHF per liter of heating fuel, a retrofit package with 40 % becomes profitable. At a cost of 1 CHF, a reduction of 65 % becomes profitable. Yet with current policy instruments, a reduction of 65 % becomes profitable at a price of 0.5 CHF per liter of heating oil (Amstalden et al. 2007, p. 1828). What is more, Amstalden et al. (2007) do not consider the value of benefits of energy efficiency other than financial savings. If building occupants were to value such co-benefits, the profitability of energy efficiency might increase. Based on a survey and choice-experiments, Banfi et al. (2008) find that this is actually the case, as "the benefits of the energy-saving attributes are significantly valued by the consumers." Ultimately, however, it is uncertain to what degree building owners actually consider the economics of energy efficiency, as discussed above. Wallbaum (2010, p. 12) cautions that the "homo oeconomicus" is rarely found among private, non-professional building owners. In particular, a life-cycle perspective is not widely shared. Instead, the construction costs are much more relevant for a majority of investment decision.

In conclusion, the literature gives the impression that energy-efficient renovations can be profitable, certainly at heating oil prices above 1 CHF per litre. A brief glance at the literature shows that this may also be the case in other countries, as the following examples show. Clinch and Healy (2001) evaluated the retrofitting of Irish buildings with different energy efficient technologies. They find that effective programs provide "clear net benefits to society" (123). Further, Audenaerta et al. (2008, p. 54) conclude that "a low-energy house is the safest choice at this moment, because its profit is less dependent on future energy prices". Yet, Audenaerta et al. (2008) find that passive buildings might not be the most cost-effective option. Rather, low-energy building designs turned out to be more cost-effective, compared to both conventional and passive buildings. Referring to sustainable buildings, Van Hal (2007) finds that sustainable buildings can be profitable.

An extensive review of the literature beyond these examples would by far exceed the scope of this study, as it would require to carefully compare the scope and the assumptions underlying each study. Eventually, a strong political will is required to encourage more private sector involvement in the domains of residential energy-efficient investments (OECD/IEA and AFD 2008, p. 260).

3.6.7 Drivers of and Barriers to the Diffusion of Energy Efficient Renovations

Energy-efficient technology as well as energy-efficient building designs should be considered to be innovations which are at a specific step of the diffusion process, and hence are likely to follow the patterns described in the innovation literature (Rogers 2003; Stoneman 2002; Shove 1998). Individual decision making is at the core of the diffusion of energy-efficient renovations. The more individuals decide to implement

an energy-efficient renovation rather than a renovation without improving the energy efficiency, the faster the diffusion process is.

On a general level, there are four types of barriers in the built environment. These are *market failures*, the *economics of the various energy-efficiency opportunities*, the *cultural and behavioral characteristics of individuals* and *real or perceived costs or risks that are not captured directly in the financial flows* (Ürge-Vorsatz et al. 2007, p. 391). Also, the decentralized and fragmented decision making that characterizes construction and the real-estate sector accounts for many missed opportunities for sustainable construction in general, and energy-efficiency in particular (Van Bueren and Priemus 2002, p. 81).

More specifically, the following drivers of and barriers to energy-efficient renovations can be identified in Switzerland (Jakob 2007a)[20]:

- **Rising energy prices**: INFRAS (2008, p. 13) see rising energy prices, such as the exceptionally high energy prices since the year 2005, to drive energy-efficient renovations.
- **Economic viability of energy-efficiency**: Jakob (2007a, p. 6) argues that the "economic viability as such seems not to be a barrier to undertaking energy efficiency renovations if assumptions are based on long-term and forward-looking considerations and if competitive prices are being applied, but it is a barrier if this is not."
- **Capital requirements**: The costs of energy-efficient façades easily exceed hundred thousand (100 000) Swiss francs even for small multifamily buildings. Jakob (2007a , 5) argues that such expenditures are quite substantial, particularly because they have to be financed upfront, either by drawing on savings or by increasing the mortgage. In contrast, savings brought about by energy efficiency are spread over a long time period, perhaps 30–50 years. Jakob (2007a, p. 5) concludes that energy-efficient renovations are in "direct competition with other expenses (vacation, car) or needs (social security, health, living in the case of retired owners)."
- **Market transparency**: According to Jakob (2007a, p. 7), several microeconomic effects make the market for energy-efficient renovations intransparent. When building owners buy a building, they lack substantial information regarding the building's energy demand and the renovation costs required to make their building energy efficient. Hence, there is an information asymmetry between buyer and seller of buildings. Because renovations are only undertaken once in many years, building owners face high information and search costs. Further, building owners might not contact specialized architects and planners, but more traditional professions such as painters, window and façade companies or small construction companies. This may restrict the range of options offered and hence considered by building owners (also see BFE 2004).
- **Investor-user dilemma**: In residential buildings, the owner and the occupant of a flat are often different persons. The owner has an incentive to invest into the level of energy efficiency which has the lowest investment cost, regardless of the

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[20] Jakob (2007a) addresses single-family home owners. However, the barriers discussed here apply to multifamily buildings too.

actual profitability of that investment. Since he pays for the investment cost but does not benefit from the energy savings, the most cost-effective level of energy efficiency may be to do nothing at all. In contrast, tenants are interested in low energy costs and would value investments into the building's energy efficiency. When tenants do not compensate building owners for the higher investment costs of energy-efficient housings, the user-investor dilemma prevents even investments that would be profitable without these externalities. (OECD/IEA and AFD 2008, p. 36; Schleich 2009).

- **Cognitive biases**: A further barrier is the existence of cognitive biases during the planning phase of buildings, such as a bias towards the status quo (Klotz 2011).
- **Pioneer surcharges**: Because construction companies often operate on the margin of profitability they cannot invest into the development of advanced energy-efficient technologies and building designs. Therefore, costs need to be covered by the first clients, such as pioneers and early adopters (Jakob and Madlener 2004; Jakob 2007a).
- **Strategic delay**: Building owners may decide to renovate their building only once the implementation of energy-efficient building designs in renovations is technologically mature and highly cost-effective. The more building owners behave in such a way, the less chance there is for technological and economical progress.
- **Climate change and energy security concerns**: The emergence of a discourse on climate change is an important driver of energy-efficient renovations (INFRAS 2008, p. 13).
- **Social developments**: Long-term trends for Switzerland's population point to an increasingly old age structure. Changes in the way work is done may be associated with changing demands housings must fulfill. This may contribute an increased renovation rate which potentially could increase the energy-efficiency of the stock of buildings (Jakob 2007a, p. 8).
- **Tax incentives**: Regarding the current tax system, Jakob (2007a, p. 7) finds that it does provide some help for energy-efficient renovation. Yet, that effect is limited because the tax system encourages stepwise renovations. What is more, the tax law does not give particular incentives to ambitious levels of efficiency. Further, it is characterized by substantial free-riding when building owners realize that they can benefit from tax reductions only after having renovated.
- **Subsidies**: In Switzerland, subsidies contribute to pushing investments into energy efficiency to profitability (Amstalden et al. 2007) and hence should be considered a driver toward greater energy efficiency in renovations.

The literature has also clarified what factors do not really influence the diffusion of energy-efficient renovations. Jakob (2007a) finds that building conditions generally neither urgently demand renovations nor do they impede them. Further, building and planning regulations do not act as barriers in any significant way. INFRAS (2008, p. 15) find that international developments such as the European Union's introduction of regulations addressing the total energy-efficiency of buildings have no significant influence on the energy-efficiency of the stock of buildings in Switzerland. Further,

they evaluate the effects of the introduction of an incentive tax on CO_2 and the activities of the Stiftung Klimarappen as rather negligible.

3.7 The Institutional Context, Policies and Instruments

The diffusion of energy-efficient renovations is substantially influenced by the institutional context within which it takes place (see Sect. 3.7.1). In order to guide the subsequent review of policies and instruments, I introduce a typology of tools for sustainable development in Sect. 3.7.2. Then, I discuss policies and instruments affecting the diffusion of energy-efficient renovations (see Sects. 3.7.3– 3.7.6). Note that I also consider policies and instruments which are not yet implemented in Switzerland. However, a comprehensive review of policies and instruments in support of the diffusion of energy-efficient renovations can-not be undertaken here. For that, I must refer to the specialized literature.[21]

3.7.1 The Institutional Context

Following Van Bueren and Priemus (2002, p. 78), the institutional context may be seen to consist of "formal, planned institutions such as (state) organizations and regulations, and more informal, evolved institutions characterized by ground rules: institutions as interaction patterns that structure, but do not determine, behaviour, and define the space within which actors act, select problems and solutions and set priorities."

The institutional context within which actors in Switzerland's construction and real-estate sector act was described by Nicol and Knoepfel (2008, p. 157) to consist of "public policy, property rights and contracts." According to the Swiss constitution, the cantons are responsible for energy-related regulations in the building sector. The building code contains the regulations which building owners must adhere to when building, and it is an important policy instrument for promoting energy-efficient construction. It is mandatory public law, which means that the administrations have to enforce it ex officio. Therein, it contrasts with norms and labels. Norms are part of civil law, and they only apply when two parties agreed upon them. Nevertheless, the norms developed by the Swiss association of engineers and architects are important because they are perceived to represent the current state of technology. Labels certify that a building has fulfilled a specific trade-marked standard (Lenzlinger 2008).

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[21] See for example (Ürge-Vorsatz et al. 2007; Levine et al. 2007; Harmelink et al. 2008) or (WEC 2008).

As of January 2008, tenancy law[22] was adapted to acknowledge several energy-related investments as value-increasing rather than value-maintaining. This means that measures that reduce the loss of energy through the façade and energy efficiency measures now basically have to be paid for by tenants. However, maintenance that for example re-establishes the new condition of a façade has to be paid by the building owner, as maintenance is included in the rent. In cases where an aging façade is replaced by a new façade with much better insulation, tenants have to pay for the fraction of investment-costs that exceeds the cost of renovating the aging façade to it's original condition (Rohrbach 2009, p. 24).

Since the end of the 1970, the Swiss cantons increasingly made it possible to deduct energetic investments from taxes, particularly for privately owned buildings (Econcept and IPSO 1997, p. 1). Casual observation as well as information from my interviews suggest that tax deductions continue to play an important role. However, Jakob (2007a, p. 5) argues that these tax incentives for energy-efficient renovations are rather inefficient because many renovations would have been done anyway. Further, the current tax system encourages stepwise renovations spread over several years (Rütter et al. 2008, p. 6). Finally, because of progressive taxes, the effective tax reduction gets higher the higher the income of the investor is (Jakob 2007a, p. 6). This makes energy-efficient investments more attractive for persons with high income.

3.7.2 Theoretical Foundation: Typology of Tools for Sustainable Development

In order to guide the review of policies and instruments in support of the diffusion of energy-efficient renovations, I draw on a typology of tools for sustainable development (Kaufmann-Hayoz et al. 2001). It was developed by a group of authors in the context of the Swiss "Priority Program Environment." This typology was developed in response to the need for a "clearly arranged and comprehensive typology of instruments that would include all principal and politically acceptable possibilities known to influence human environmentally relevant behaviour" (Kaufmann-Hayoz et al. 2001, p. 35). The authors found it particularly important that policies and instruments are oriented towards actors, that too specific disciplinary theories and approaches are overcome, and that policies and instruments are evaluated regarding their effectiveness, costs and acceptance. The typology contains five types of instruments, each of which has its own rationale, implementing actors, target groups and implementation and enforcement:

- According to Kaufmann-Hayoz et al. (2001, p. 36) **Command and control instruments** are "legal prescriptions that have a direct impact on the range of options

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[22] Specifically the *Verordnung über die Miete und Pacht von Wohn- und Geschäftsräumen* (VMWG), SR 221.213.11, available online from http://www.admin.ch/ch/d/sr/221_213_11/index. html. Accessed 08 Oct 2009.

open to specified social actors". This means that they preclude some behaviors by way of mandatory orders. This kind of instruments is based on principles of command, control and possibly sanctions.

- **Economic instruments** are based on the idea that degradation of the environment is caused by externalities which may result from missing or misallocated property rights. Three principal approaches are conceivable: "Raising the costs of polluting behaviour. (...). Reducing the costs of environmentally sound behaviour. (...). Establishing markets for polluting rights" (Kaufmann-Hayoz et al. 2001, p. 37).
- **Service and infrastructure instruments** The availability of infrastructures and the possibility to obtain services are crucial preconditions to engage in behaviors with low environmental impact. For example, the availability of public transport is a crucial precondition to substitute personal motor-vehicles. These instruments aim to create the possibilities for environmentally responsible behaviors or to remove the possibilities for undesired behavior (Kaufmann-Hayoz et al. 2001, p. 40).
- **Collaborative agreements** are " legally binding or non-binding commitments by the private sector or parts of it (industrial sectors, their associations, or individual companies) made towards the government to enhance energy and resource efficiency or greenhouse-gas abatement in sectors that are traditionally not regulated by public policy" (Kaufmann-Hayoz et al. 2001, p. 48). A crucial element motivating private sector actors to participate in collaborative agreements is the threat that the government may develop more inconvenient, command-and-control-style instruments.
- **Communication and diffusion instruments** aim to influence actors such that they eventually change their behavior. In particular, these instruments aim to influence large groups rather than individuals. Hence, the spread of arguments and new behaviors promoting sustainability relies heavily on networks (Kaufmann-Hayoz et al. 2001, p. 50).

Kaufmann-Hayoz et al. (2001, p. 42.) further substantiated this typology as can be seen in Figs. 3.4 and 3.5. In the following sections, I will use the work of Kaufmann-Hayoz et al. (2001, p. 42.) to present policies and instruments in support of the diffusion of energy-efficient renovations. However, as is often the case with such typologies, a policy or an instrument may belong simultaneously to different types. For example, an energy label might be seen as a command and control type instrument, because it is mandatory for manufacturers to print it on a product. Yet, it may also be seen to be a type of communication and diffusion instrument, because it aims to inform and persuade consumers. Hence, it is not always possible to decide definitely to what type a policy or an instrument belongs. The following description of instruments and policies mostly ignores these finesses.

Command and Control Instruments	
Environmental quality standards (impact thresholds and standards) **Emission standards** - best available technology - prescriptive technology standard **Product standards and regulations for the use of pollutant substances** - restriction, rationing or prohibition - product standards	**Licensing** - licence to construct - licence to operate - licence to sell **Liability regulations** - strict liability - reversal of the burden of proof - compulsory third party liability insurance **Zoning** - Land use regulations - water protection areas - nature conversation zones
Economic Instruments	
Subsidies - grants - tax allowances - soft loans - guarantees - compensation for foregoing use of the resource **Incentive taxes** - taxes on energy/resources - taxes on emissions - taxes on products/processes **Charges** - one-time charge for connection to services - recurrent charges for use	- charges on advantages (value-added contribution) - prepaid disposal fees **Deposit-refund systems** **Market creation** - tradable allowances or permits - joint implementation **Incentives as parts of action campaigns** - rewards - lotteries - contests/benchmarking - discounts

Fig. 3.4 Typology of tools for sustainable development—Table 1. Reproduced and adapted in terms of graphics from Kaufmann-Hayoz et al. (2001, p. 42)

3.7.3 Command and Control Instruments

Van Bueren and de Jong (2007, p. 547), addressing the situation in industrialized countries, argue that the building sector has always preferred regulations as a means of government intervention. In earlier days, regulations specified "the exact means to be used to achieve specific ends" (Van Bueren and de Jong 2007, p. 547). However such regulations are too restrictive. They hinder innovations (Sexton and Barrett 2005, p. 144) and provide no incentive to tackle societal goals (Meacham et al. 2005, p. 92). Therefore, regulations now generally demand specific performance requirements (Van Bueren and de Jong 2007, p. 547).

Jakob (2008, p. 6) distinguishes between mandatory standards on the one hand and norms by the Swiss association of engineers and architects on the other hand.

Service and Infrastructure Instruments	
Service instruments - Offering or improving ecologically sound products - withdrawing environmentally undesirable products - offering or improving services that allow or facilitate ecologically sound action	**Infrastructure instruments** - offering or improving infrastructure that allows or facilitates ecologically sound action - dismantling or degrading infrastructure that hinders or inhibits ecologically sound action
Collaborative Agreements	
Public-private agreements - agreements on prepaid disposal fees on specific product groups - agreements on consumption goals or standards - formal agreements with individual companies	**Certifications and labels** - with legal compliance - without legal compliance
Communication and Diffusion Instruments	
Communication instruments without a direct request - presenting facts - presenting options - presenting appraisals, goals, and norms - providing experience of reality - presenting model behavior - giving feedback and enabling self-feedback **Communication instruments with a direct request** - persuading about facts - persuading about options	- persuading about goals, appraisals, and norms - sending appeals - presenting prompts and reminders - stimulating self-commitment **Diffusion instruments** - establishing direct personal contact - establishing contact via person-to-person media - establishing contact via mass media

Fig. 3.5 Typology of tools for sustainable development—Table 2. Reproduced and adapted in terms of graphics from Kaufmann-Hayoz et al. (2001, p. 43)

Mandatory standards are defined by laws and ordinances, whereas norms are part of civil law. This means that norms require contractual agreement between different parties. In addition, they are seen to represent good practices in the construction industry and may be used in court to argue for example that a construction company did not build according to the established standards.

The emergence of energy standards is related to the first oil shock in 1973. After the oil shock, most actors involved with Swiss energy policy agreed on the need for a constitutional basis for the regulation of energy in buildings on the federal level. However, considerable time passed until the constitutional basis was finally put to vote in 1983—where it was finally rejected (also see Sect. 3.4.2). A group of cantons did not want to wait until a constitutional basis for energy policies on the federal level

were implemented. Hence, in the year 1977, the first cantonal regulations governing the use of energy in buildings were put into place (Delley and Mader 1986; quoted in: BFE 2005a, p. 49).

Initially, energy regulations in the different cantons were quite heterogenous. Only in the 1990 did energy policies start to converge across the cantons (BFE 2005a, p. 114). However, the energy coefficient demanded by mandatory law decreased substantially over time (see Jakob 2008, p. 6.) for greater detail). Today, the MuKEn standard regulations[23] that were conjointly developed by all the cantons play an important role in this convergence. By the year 2008, 25 cantons have adopted the central regulations into their laws. About at the same time, the cantonal conference of energy directors decided to tighten the MuKEn regulations and include them into their energy laws (INFRAS 2008, p. 16). In doing so, the Swiss conference of energy directors argued as follows:

> (...) the strong diffusion of the MINERGIE brand, which was developed by the cantons, has shown that buildings that are significantly more efficient [than the present standard] can be constructed with only marginaly greater costs and with higher comfort. Because of the urgent action required by the energy and climate issues and because of the progress in construction technology, the Swiss conference of energy directors decided in March 2007 to revise the MuKEN 2000 energy standard and reduce the requirements for new buildings to about the level of MINERGIE, i.e. about 4.8 liters of heating oil equivalent per square meter heated floor space (EDK 2008, p. 13, translated by MM).

Compared to an autonomous development (brought about by technological progress or rising energy prices), the cantonal energy regulations saved about 1 % of the total energy demand of Switzerland for heating and warm water purposes (INFRAS 2008, p. 18), and they reduced the emission of CO_2 by about 0.6 % of Switzerland's total CO_2 emission (INFRAS 2008, p. 23). The implementation of cantonal energy regulations caused about 2.5 Billion (2 500 000 000) sFr. of investments in the year 2007 and created labour opportunities of about 10 000 personyears (INFRAS 2008, p. 21).

Parallel to the activities of the cantons and the federal government, the Swiss association of engineers and architects (SIA) presented various norms which are related to the energy-efficiency of buildings. Particularly important are the norms SIA 180 (heat and humidity), SIA 380-1 (thermal energy) and the norm SIA 380-4 (electrical energy)[24] (Jakob 2008, p. 6). In fact, the development of private law norms and the implementation of stricter mandatory energy regulations was mutually dependent. Without SIA norms, mandatory regulations would have been more difficult to implement. Yet, without mandatory regulations the SIA norms would not have spread as far as they now have (Jakob 2008, p. 7).

In the European Union, energy standards have been tightened substantially: In the year 2005, the countries of the European Union generally had stricter energy

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[23] The official name in German is: "Mustervorschriften der Kantone im Energiebereich (MuKEn)" (Lenzlinger 2008).

[24] Also see the website of the SIA section working on energy codes for the complete listing: http://www.energycodes.ch. Accessed 29 Mar 2011.

standards than Switzerland because of the strict "energy performance of buildings directive[25] (EPBD) (BFE 2005b)." Further, in the year 2010 the European Union adopted a directive that requires member states to "ensure that all newly constructed buildings consume 'nearly zero' energy" (Schimschar et al. 2011, p. 3346) in the next ten years.

3.7.4 Economic Instruments

Economic instruments play an important role in the building context. Particularly important are subsidies and incentive taxes.

Incentive Taxes

As discussed in Sect. 3.3.3, two incentive taxes are relevant in an energy and climate policy context. First, the climate penny ("Klimarappen") is a tax levied on propulsion fuels and does not work as an incentive tax for energy efficiency in buildings. Second, a tax is levied on fossil heating fuels based on the CO_2 law. Most of the proceeds from this tax are refunded to the population and the enterprises on a per-capita basis. This means that individuals which use a lot of carbon based fuels can reduce their tax burden by reducing their use of fuels. However, there are some reasons why energy price increases might not have a very strong impact. One is that the impact of the incentive tax is rather small compared to average incomes in Switzerland. Further, even if the incentive tax had a stronger effect, Sunikka (2006, p. 531) argues that "high-income households (...) do not have to react to price signals; and low-income households (...) cannot afford to respond to them (...)."

Subsidies

Since the year 2010, the federal government and the cantons run a large program in order to subsidize energy-efficiency enhancing measures and renewable energy systems in buildings. It is expected that this program will avoid the emission of about 35–52 million tons of CO_2. Until the year 2020, the program is expected to give about 280–300 million Swiss francs per year to qualifying building owners. The program is financed by the CO_2 tax[26] (about 200 million francs) and by the cantons (about 80–100 million francs) (EDK 2011). In addition, the proceeds from the "climate

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[25] See http://www.epbd-ca.org. Accessed 30 Mar 2011.

[26] Note that the CO_2 tax was initially conceived as a pure incentive tax. In a revision of the CO_2 law, the parliament decided to use a third of the proceeds from this tax for the building program. Some critics were strongly opposed to this change because the incentive tax now became partially a regular tax. See for example http://www.erdoel-vereinigung.ch/de/erdoelvereinigung/aktuelles/politfokus/TeilzweckbindungderCO2-Abgabe.aspx. Accessed 08 Oct 2011.

cent" (levied on propulsion fuels) are partially used by the climate cent foundation to support energy efficiency and renewables in buildings.

However, the situation regarding subsidies is complex and has been characterized by frequent changes. In fact, a leading Swiss newspaper called the whole situation a "subsidy-jungle" (NZZ Online 2010). To address this, there is a specialized website[27] enabling building owners to find all organizations and programs that support energy efficiency (and various technologies based on renewable energy systems) in buildings.

3.7.5 Service and Infrastructure Instruments

A wide range of different instruments can be positioned into this category. In particular, any policy or instrument that aims to provide enabling conditions such as technology should be positioned into this category.

Education and Training for Practitioners

In order to enable actors in the real-estate and construction industries to plan, implement and manage energy-efficient building designs, education and continuous training play an important role. In particular, sustainable construction needs to be integrated into the curricula of study programs in architecture, real-estate management and similar studies (Meier 2007; Wallbaum 2010). Recent years have seen increased efforts to introduce issues related to sustainable development into the education sector. Further, many organizations provide further training for practitioners (Brunner and Keiser 2009). Nevertheless, sustainability issues have probably not yet achieved the prominence they deserve in education related to the construction sector. This policy, as well as energy counseling described below, could also be described as communication and diffusion instruments.

Energy Counseling

Energy counseling is a service where an expert in energy-issues reviews a building and counsels the building owner regarding the state of his building and the options he or she has to improve the energy efficiency of the building. Counsel is typically given for a broad range of issues, such as insulation, renewables, heating systems, windows, lighting and so on. In Switzerland, energy counseling is a well established instrument and is typically co-funded by the state, the canton or the commune. The federal office for energy maintains a list of all the agencies providing energy counseling in Switzerland (BFE 2011).

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[27] See http://energiefranken.ch. Accessed 05 oct 2011.

Building Energy Performance Contracting

is a "business strategy to assist building owners overcome the financial barriers for improving the energy performance of their buildings" (Yik and Lee 2004, p. 235). The basic idea is that an independent energy service company provides investments that reduce the energy demand in a building and in return get a share of the savings. The result should be a win-win situation. In practice, however, several obstacles may impede the successful deployment of building energy performance contracting (Yik and Lee 2004, p. 236).

Commissioning of Buildings

This entails a "(...) review of a building's disposition to identify suboptimal situations or malfunctions and the associated opportunities for energy savings" (Mills 2011, p. 149). This can occur at any time during the planning phase or during the use phase of a building. During the process of commissioning, a team of external experts and representatives of the building owner and occupants identify weaknesses and propose measures to remove such weaknesses (Mills 2011). In a review of several studies in the United States, Mills (2011, p. 145) found that commissioning reduced energy use by a median of 13 % in new buildings and 16 % in existing buildings. That corresponds to negative costs of greenhouse-gas emissions. In dollars of the year 2009, the median benefit of conserving a ton of carbon was 110$ in existing buildings and 25$ in new buildings (Mills 2011, p. 159).

Promotion of Technology

With the energy crisis of the 1970s the promotion of various technologies in the energy sector became an important aspect of Swiss energy policy. The availability of the resulting technologies and energy-efficient building designs are an important infrastructure without which energy-efficient renovations would not be possible.

The development of technology is the result of private and government-sponsored research. The importance of state support for the development of energy technologies as a means to accomplish policy objectives is well recognized in the literature (see for example Banales-Lopez and Norberg-Bohm 2002). For example, SIA (2006, p. 51) calls for the political and administrative initiation and support for the development of energy-efficient building designs.

According to BFE (2009a, p. 25), the Swiss government spent a total of 67 million Swiss francs for researching energy efficiency in the year 2007. From that amount, 3 million Swiss francs were expended for pilot and demonstration projects. Applied research and development (R&D), combined with pilot and demonstration projects (P&D) were at the centre of federally funded energy research (BFE 2007b). In contrast, the private sector is estimated to have spent about 740 million CHF on energy efficiency research at the same time. From that amount, about 600 million CHF went

Fig. 3.6 Government expenditures for energy efficiency research and development 1975–2010 at current prices based on the classification of IEA (2010). Also see BFE (2009a, p. 7)
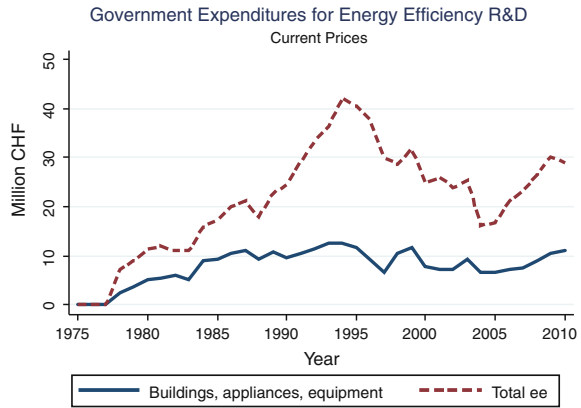
into pilot and demonstration projects (BFE 2009a, p. 25).[28] The finding that the private sector accounts for the overwhelming majority of energy efficiency research expenditures is consistent with Switzerland's innovation policy. Governmental support for technology should only be given subsidiary to the private sector (BFE 2008, p. 10). However, the private sector tends to focus its research activities on traditional areas of expertise and existing products (BFE 2009a, p. 25). Therefore, government support focuses on risky issues that the private sector neglects (BFE 2008, p. 10).

The upper line in Fig. 3.6 shows the historic development of the total expenditures of the Swiss government for R&D of energy efficiency technology between 1975 and 2010. The lower line in Fig. 3.6 shows the expenditures specifically for energy efficiency in buildings, appliances and equipment. The data is given in current prices, based on the classification of the International Energy Agency. Note that this classification exhibits substantial differences in the absolute value of governmental expenditures for energy efficiency.[29]

The data from the IEA is interesting because it provides the only time series data I could find. Several insights can be derived from Fig. 3.6. First, it shows that public funding for energy efficiency research has strongly fluctuated over the last 35 years. Second, government funding for energy efficiency R&D seems to have been caused by the energy crisis of the 1970. Third, governmental expenditures for energy efficiency research seems to have fallen substantially during the period of cheap oil in the 1990 (see Fig. 3.2 on page 6.2 for the energy price). Since the year 2004, governmental expenditures for energy efficiency exhibit a rising trend. This second increase in governmental R&D spending is probably driven by the emerging recognition of climate change as a policy issue. Finally, the government expenditures

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[28] The authors of this study caution that there are substantial uncertainties regarding the actual expenses in the private sector. Data on private sector energy research expenditures in other years can be found in BFE (2000, 2002, 2005c, 2007c, 2009a).

[29] Above, the government was said to have spent about 67 million Swiss francs for researching energy efficiency in the year 2007. According to the classification of the IEA discussed here, it was about 25 million Swiss francs.

for energy efficiency R&D in buildings, appliances and equipment seems to have been much more stable compared to the total governmental expenditures on energy efficiency.

3.7.6 Collaborative Agreements

In the typology introduced above, labels and certifications are conceptualized as collaborative agreements. Such instruments are highly relevant for energy-efficient renovations as they make the invisible characteristic energy efficiency visible in building designs. For example, Lindén et al. (2006) found that Swedish households actually often ask for further information. Although economic instruments, such as taxation and pricing are frequently used to promote energy-efficient individual behavior, Lindén et al. (2006) conclude that energy labeling may be a promising way to inform consumers. Van Hal (2007) points to the importance of tailoring labeling systems towards consumers and their needs. In particular, the language used in labeling systems must be adequate: "Instead of using environmental language—focused on topics such as energy, water, and waste—it should be couched in consumer language, including terminology such as money-saving, flexibility, and health" (Van Hal 2007, p. 401). According to Mlecnik et al. (2010), labels for highly energy-efficient buildings play an important role in reducing the technical complexity of such buildings and contribute to the communication of aspects which influence the decision making process of potential adopters. Indeed, labels may help to communicate aspects of energy-efficient housings that are relevant in the decision making process proposed in Rogers' theory of the diffusion of innovation (Rogers 2003). In particular, they contribute to the communication of the relative advantage and they make energy-efficient buildings more observable.

Minergie Label

The Minergie label, already introduced in Sect. 3.6.4, is a voluntary certification scheme. Building owners apply for the label and once the building is certified to adhere to the associations's standards, the label is given. Among the main reasons why building owners demand certification is that it is seen as a signifier of quality. Further, Minergie-certified buildings can obtain a higher market price. Single-family buildings yield a premium of 7 % and freehold apartments yield a premium of 3.5 % (Salvi et al. 2008; Meins et al. 2010).

Cantonal Energy Certificate for Buildings (GEAK)

Since August 2009, building owners in Switzerland can obtain an energy certificate for their building.[30] The certificate informs about the energetic quality of the building and it provides specific suggestions how the energetic quality of the building may be improved. The certificate is based on current European standards. Currently it is voluntary. However, some cantons are deliberating whether the certificate should become mandatory (BFE 2011).

3.7.7 Communication and Diffusion Instruments

Among the many policies and instruments which may be classified as communication and diffusion instruments, I find the following particularly relevant. While any of these instruments could be implemented by private actors, the state is the actor who uses them to the largest degree. Examples would be activities such as information campaigns, exhibitions or advertising directed at the general public.

Public Procurement

The state yields substantial market power in the construction sector, as it commissions and owns infrastructure and a broad selection of buildings. Because it does not need to obtain profits in a short time period, it is freer to act responsibly. Also, the state's time horizon is longer compared to private construction (Wallbaum 2010, p. 13). Jochem (2009) argues that public procurement may be an important strategy to promote the diffusion of energy-efficient buildings, such as passive houses. First, scale effects may be realized when public procurement increases demand. Second, a strict bidding process "may reduce the profits of passive house suppliers and suppliers of its components theoretically to an almost competitive level" Jochem (2009, p. 138).

Exemplary Role of the State

Beyond public procurement, the state can consciously choose a leading role. For example, the city of Zürich requires all its new buildings to implement the Minergie standard. Further, the state can induce technological developments in the construction sector. Exemplarily for this position, a former city council responsible for the city of Zürich's construction department, stated that "(...) regarding issues of sustainable construction, we often deal with issues where we do not have any experiences yet. The construction department likes to act as a pioneer because our achievements

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[30] In German the certificate is called *Gebäudeenergieausweis der Kantone* (GEAK). Also see http://www.geak.ch. Accessed 14 Oct 2011.

will benefit not only us, but also our children and grandchildren" (Martelli 2009, translated by MM).

Strengthening Professional Networks

Wallbaum (2010) finds that currently there is no broadly encompassing network for actors interested in sustainable construction. He proposes to implement a network (which he calls "Swiss Platform for Sustainable Construction").

3.7.8 Impacts and Implications

Ürge-Vorsatz et al. (2007) reviewed over 60 ex-post policy evaluations of best practice applications of 20 policy-instruments in 30 countries and country groups. These were assessed according to their effectiveness in reducing emissions, cost-effectiveness, applicability and special conditions for success. Ürge-Vorsatz et al. (2007) found that appliance standards, building codes, tax exemptions or reductions as well as labelling, demand-side management programs and energy-efficiency obligations were revealed as cost-effective and particularly effective. In general, regulatory instruments were most effective in reducing emissions and also more cost-effective than any other category of policies. However all policy instruments have limitations and are directed at specific barriers and hence must be combined into policy packages that account for local specifics. Ürge-Vorsatz et al.(2007, p. 474) conclude that a policy package combining regulatory, fiscal, market-based and information-related instruments "helps to capture the advantages of the single measures and in reducing the effects of their drawbacks."

3.8 Conclusions

In this final section, I provide a concluding description of the societal problem situation within which the diffusion of energy-efficient renovations becomes relevant. In doing so, I answer my first research question. There, I ask how the context within which the diffusion of energy-efficient renovations takes place should be described.

The stock of buildings provides a series of very important services to the Swiss population. These services, such as the provision of shelter, personal space or warmth, are what matters most for the general public. Energy use in buildings is mostly irrelevant as long as energy services are available at reasonable cost. This means that sustainability is probably just a minor issue in the design, use, management and maintenance of the built environment (Lovell 2005).

All over the world, the built environment faces two major challenges: First, it needs to adapt to increased temperatures, wind, flooding and sea level rise brought

about by climate change, such that the health, safety and quality of live of the people populating it is preserved. Second, in order to meet the emission targets required for mitigating climate change, the built environment will have to reduce emissions by a higher share than the average global or national reduction target. This is because the built environment offers a greater potential for emission-reductions compared to sectors such as transport. In the long term, this calls for nothing less than a radical transformation of the built environment (Barrett 2009). Two external drivers, i.e. climate change and energy security issues, are mostly responsible for the pressures on the stock of buildings. In the following I briefly elaborate on them.

The energy crisis of the 1970 took Switzerland by surprise. In order to reduce the vulnerability of its energy supply, the country began to implement a national energy policy. Among others, the country increasingly implemented ambitious efficiency-oriented energy policies, with the stock of buildings playing an important role. Over time, efficiency-oriented policies achieved spectacular results. For example, the energy intensity of production, which measures the amount of energy used to produce a standard unit of output, has steadily declined in Switzerland. However, energy policy was mostly characterized by a struggle between a "pro-growth" and a "pro-ecology" coalition (Kriesi and Jegen 2001; Jegen 2003).

Energy use patterns by themselves already constitute a serious policy challenge. However, they are currently and in the next few decades probably not yet drastic. On the one hand, fossil-fuels of lower quality (coal, shale gas, peat, etc.) are still quite abundant. On the other hand, Switzerland (together with some other industrialized countries) probably could maintain its ability to pay high prices for fossil energy resources long after most other countries. First, the doubling or perhaps tripling of prices for fossil energy resources could be offset by the abolishment of fuel taxes. While this is currently not seriously considered by the majority of policy makers, politicians from the right-conservative spectrum once in a while voice such demands in periods of high fuel prices. Second, rising world energy prices might even increase the competitiveness of the Swiss economy, as it already is comparatively efficient and hence less vulnerable as prices increase. I find it actually quite reasonable to speculate that Switzerland could maintain its ability to pay high energy prices even when most other countries could not.

In the building sector, the energy coefficient which has to be implemented in newly constructed buildings has been reduced to rather low levels.[31] Yet, at the same time, Switzerland's total demand for energy still exhibits a rising trend (see Fig. 3.1 on page 60). Decades of technological progress, economic growth and increases in the amount of floor space demanded per capita in conjunction with rising populations have more or less compensated the efficiency gains by expanding the level of consumption, thus indicating the existence of a substantial macro-economic rebound effect.

While scientists recognized anthropogenic climate change as a dangerous possibility as early as in 1977, the general public was much slower in recognizing it. Only over the last decade has climate change emerged as a very influential environmental discourse. As this discourse became ubiquitous, it profoundly re-shaped the way

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[31] See Fig. 4.3 on page 120 for details.

energy policy was debated. In fact, the emergence of climate change issues led to a radical problematization of the current energy use patterns. As a consequence the mitigation of greenhouse-gases became an important element of both, environmental and energy politics.

Scientific studies have established with a very high degree of certainty that higher CO_2 concentrations in the atmosphere were mostly caused by anthropogenic activities and that higher concentrations lead to an increase of the average surface temperature. This should be considered to be a fact. However, there are actors which perceive this not to be true and argue that higher CO_2 concentrations are actually caused by global warming.

I propose to see the issue of climate change policy on the national and subnational level as a field of contest among different societal actors conflicting over the interpretation of positive knowledges produced by the sciences. In such a contest, the perception and interpretation of scientific information is not independent of actors' interests. In addition to material interests (cheap fuel for consumers and industry), the contest about climate change policy is basically also a contest over symbolic values, such as the place of humans in the universe and the role of science.

Energy use patterns and the emergence of a discourse on climate change increasingly caused societal actors from various backgrounds to demand the transformation of the stock of buildings. These claims were generally meant as a contribution to the public good, particularly in domains of security and environmental conservation. Yet this discourse and the prospects of strong interventions cause other societal actors to voice opposed views. Indeed, valid and reasonable arguments can be voiced against strong interventions. Technology, for example, was not generally available in the 1980s and early 1990s, and it might have been expensive and inconvenient. Several other reasons motivated actors to oppose strong energy and climate policy, such as a preference for affordable housing, expectations of further discovery of oil fields, scepticism regarding climate change, the desire to postpone problems, and many more.

Over the last decades, the stock of building has substantially increased. This is mostly due because of socio-economic developments. With economic growth, the average floor space and the level of comfort demanded per person have risen. All this happened against the backdrop of a rising population. Particularly in the years between about 1950 and 1980, a lot of floor space with low energy efficiency was built. In conjunction with low prices for fossil-fuels, this has led to a rapid expansion of the demand for fossil heating fuels. Consequently, the emission of greenhouse-gases increased.

Given that buildings account for about half of Switzerland's energy demand, the building sector became a crucial element of environmental and energy politics. Further, the renovation of existing buildings is one of the most cost-effective way to reduce CO_2 emissions in industrialized countries (Galvin 2010). In fact, the building sector has substantial potential to achieve CO_2 reductions at a *negative* cost (Ürge-Vorsatz and Metz 2009).

There are three major ways how greenhouse-gas emissions from buildings can be cut: by reducing energy consumption in buildings, by switching to low-carbon

fuels with a higher share of renewable energy carriers and by managing the emission of non-CO_2 greenhouse-gases. Improving the energy efficiency of new and existing buildings is the most interesting approach because it provides the most diverse, largest and most cost-effective mitigation opportunity (Ürge-Vorsatz et al. 2007, p. 394).

The problematization of energy use patterns and the emergence of a climate change discourse are the main drivers causing the emergence of the societal problem situation. It is within this context that calls for the transformation of Switzerland's stock of buildings towards low emission and high energy efficiency are situated.

However, in contrast to contested issues such as nuclear power or restrictions on mobility, many Swiss support or at least accept that the stock of buildings needs to reduce its energy demand. A representative survey (LINK 2010) commissioned by the World Wide Fund for Nature Switzerland finds that a majority agrees mostly (21.1 %) or completely (53.3 %) with the statement that the Swiss should insulate their buildings better and implement other climate protection measures in order to create jobs and become more independent from oil.

Figure 3.7 visualizes the relationship between heated floor space (horizontal axis) and the average energy coefficient of floor space (vertical axis) for the canton of Zürich.[32] The floor space is shown according to its year of construction. For example, from Fig. 3.7 it can be seen that the canton's stock of buildings had slightly more than 10 million m^2 of floor space before about 1920. It can be further seen that it had an average energy coefficient of 700 MJ/m^2a for heating and warm water. It can further be seen that since about the year 1970 the average energy coefficient of constructions has been significantly reduced. Further, it is expected that the average energy coefficient of constructions will continue to decrease.

Due to the low energy coefficient of the future floor space, the old, inefficient stock of buildings continues to dominate the energy use and CO_2 emission patterns of the stock of buildings. In order to reduce Switzerland's stock of building's demand for energy the rate of energy-efficient renovations has to increase. Both actors in the public sector as well as state actors need to promote ambitious energy-efficient renovations or reconstructions as well as low-emission heating systems.

Unfortunately, a rapid alleviation of this situation is unlikely, for two major reasons. First, the stock of building is highly inert. The various components of buildings have a service life that ranges between about 30 and 60 years, depending on what component is discussed. This means that major renovations of a building occur only about two times per century. Current renovation rates point to rather slow transformation processes. Energy-efficiency enhancing renovations are implemented only in about 1–2 % of the building stock per year. Further, only about 0.1 % of buildings are yearly torn down and replaced by new, more energy-efficient constructions.

The second major reason why the Switzerland's stock of buildings will continue to emit substantial CO_2 emissions is that building owners implement energy-efficient renovations only if and only when they want to. There are no regulations forcing them to increase the energy efficiency of their building if they do not want to. Building

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[32] There was no figure for the whole of Switzerland. However, the relationships shown for the canton of Zürich also hold for Switzerland as a whole.
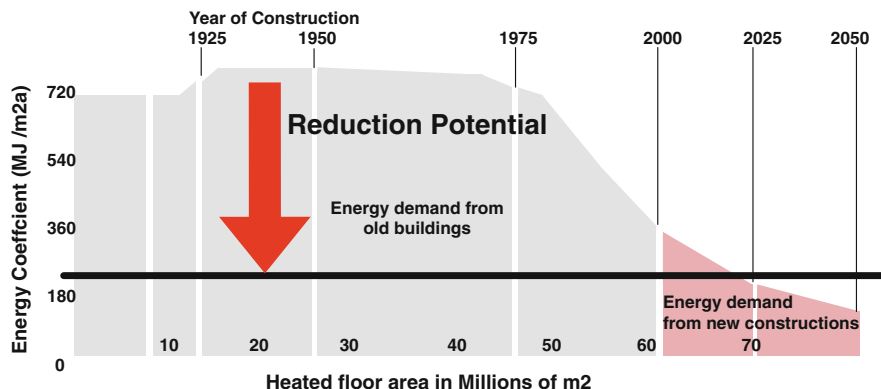
Fig. 3.7 Heated floorspace of housings in the canton of Zürich, in millions of square meters, arranged according to its year of construction. Reproduced and extended from Regierungsrat des Kanton Zürich (2003, p. 18)

owners, for example, may choose to do nothing at all or simply paint their façade instead of insulating it. If this situation prevails, we should expect the transformation of the stock of building to unfold in a sluggish manner over several decades, with a gradual rise in energy-efficient buildings.

Technically, it would probably be possible to implement energy-efficient building designs in most of Switzerland's stock of buildings within one or two decades. With some sacrifices and strong determination, the up-front financing of widespread energy-efficient renovations probably also could be organized. Based on rigorous command and control instruments, such a plan probably also could be enforced. However, in Switzerland's liberal, democratic society, where market mechanisms play an important role it is unlikely that the voting majority would support such ambitious plans. Hence, such a 'grand-plan' solution is not a viable option for policy makers. Instead, public policy will continue to be characterized by gradual, incremental progress toward stricter policies.

The energy crisis and later the emergence of a discourse on climate change led to the development of technological innovations. Particularly relevant were advanced insulation materials, highly efficient windows and ventilation systems. Further, specific ways of implementing such technologies (what I call "building designs") may also be considered as innovations. Initially, technological innovations usually come at a high cost and they usually have a rather low performance. Further research activities, sponsored either by the state or the private sector, can lead to improvements of the performance and cost reductions. Improvements and cost reductions can also be an effect of learning and of economies of scale and scope in the industrial manufacturing process. In Switzerland, state support for energy-efficiency technologies and building designs has been substantial. Yet the private sector probably bore the largest share of research and development related to energy-efficient building designs. In the future, the potential for technological and economical breakthroughs

is limited. Instead, incremental cost reductions, further improved performance and the integration of various technologies should be expected (IEA 2008, p. 183).

Eventually, energy-efficiency technologies and energy-efficient building designs have to penetrate the market and eventually achieve a high market share in renovations. Without diffusion, technologies cannot contribute effectively to the alleviation of the societal problem situation. Diffusion processes can be influenced by various actors (Steger et al. 2002). On the one hand actors can try to strengthen the effect of drivers, on the other hand they can try to weaken the effect of various barriers. With marketing activities, for example, actors in the construction and housing industry can make potential customers aware of a product, influence them to form a more favorable evaluation of a product or reduce various transaction costs of potential customer. Further, the state can use instruments to shape drivers and barriers such that the diffusion process is accelerated.

In Switzerland, state interventions have had a profound impact on the diffusion of energy-efficient renovations. On the one hand, the tightening of energy standards supported the development and the subsequent diffusion of energy-efficient renovations. On the other hand, strong technological progress in energy-efficient technology in buildings has led to tightened standards for new buildings and energy-efficiency enhancing renovation practices (CEPE and HBT 2002, p. 314).

Eventually, however, the primary goal of public policy addressing energy in the built environment should be to reduce carbon emissions rather than the use of energy. This is because of the rebound effect and people's continual desire for more comfort and convenience (Herring 2009). This entails that the sustainable provision of services of buildings should be the objective of policies, not buildings per se (Barrett 2009).

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Chapter 4
A Small Model for the Analysis of the Transformation of the Stock of Buildings

4.1 Introduction

In this chapter, I address my second block of research questions. They read: *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?* It is not the purpose of this study to provide a detailed, highly accurate model of the stock of buildings. The model I develop here shall serve as my "dependent subsystem". I use it to quantitatively estimate the impact of socio-economic processes on the stock of buildings (see the subsequent chapters). I strive for reasonably good empirical founding, but I am not interested in obtaining point estimates. I therefore propose to develop a "small model" of the transformation of Switzerland's stock of buildings to high levels of energy-efficiency (see also Coffey et al. (2009) for an other example of a small top-down model).

Small models can be seen as one of three approaches to communicate complex models and issues to decision-makers who are generally seen as lacking the time and perhaps the training to indulge into the details of a large model: *Group model building* (Vennix 1996; Andersen and Richardson 1997a,b) is currently the most prominent example. It was developed as a way of involving decision-makers (and clients in general) into the process of model development. Among the benefits of group model building is that it helps to elicit and integrate different client perspectives. Further, it fosters the clients' understanding of and trust in the model. *Model simplification* (Saysel and Barlas 2006) is a second approach to the challenge of communicating

large models. It is the practice of reducing large, complex models to small models, while retaining their most important behavioral characteristics. As they are derived from larger models, they can be evaluated against the performance of the big model. The development of *small models* consitutes a third approach. There, the intention is to build only a small model, without having a large model in the background. This is because "for many public policy problems a small model is sufficient to explain problem behavior and build intuition regarding appropriate policy responses" (Ghaffarzadegan et al. 2009, p. 3). In line with this argument, I aim to also use this model to communicate fundamental insights into the transformation of Switzerland's stock of buildings to policy makers and the interested public in general. The added value of my small model is that it is a useful complement to the large and detailed models generally used to describe Switzerland's stock of buildings (see Sect. 4.2).

Now, the two contributions this chapter makes become evident: On the one hand, I give myself a solid foundation upon which I can build my large System Dynamics model (see Chap. 7). On the other hand, I provide a model which can be used to communicate fundamental insights to persons beyond the narrow specialist domain models usually are used.

The remainder of this chapter is organized as follows: In Sect. 4.2 I review the mostly model-based literature on the transformation of Switzerland's stock of multifamily buildings. In Sect. 4.3 I give a brief overview of the setup of the simulation model, and in Sect. 4.4 I provide a detailed account of the Appendix C three sectors which make up the model. In Sect. 4.5 I simulate three different scenarios and present the simulations results. Section 4.6 contains a discussion of the results obtained by simulation. Based on that discussion I elaborate implications for policy-making and propose two regulations which I think should complement Switzerland's current policies in support of the transformation of the stock of buildings (see Sect. 4.7). In Sect. 4.8 I present the conclusions to this chapter. Appendix C provides a brief report on model testing and validation.

4.2 Review of Current Knowledge in the Dynamic Behavior of the Stock of Buildings

There is a stream of publications on the dynamic behavior of Switzerland's stock of buildings and its long-term management, many of which focus on energy issues. Only a fraction of that literature appears in peer-reviewed journals or other academic publications. A lot of work is grey literature and appears in the form of research reports to government agencies. In the following, I briefly review data sources and the major contributions I deem relevant for the development of my small model.

Government energy perspectives

Every few years since the mid-1970s, the Swiss Federal Office of Energy has prepared a series of reports called *energy perspectives*, in order to provide a long-term view on Switzerland's energy policy. In the year 2004, work was begun to produce the newest perspectives which look as far as to the year 2035 (BFE 2010). Among the work conducted, Hofer (2007) addresses a large number of variables which directly relate to the stock of buildings. For example, it contains data and projections for the heated floor area over the period from 1990 to 2035, diffusion patterns for various heating systems, temporal data on average energy coefficients of new and existing buildings. Frequently, the work presented in the energy perspectives draws on previous work (Wüest and Gabathuler 1991; Wüest and Partner 1994).

Models

Kost (2006) developed a highly disaggregated simulation model of Switzerland's stock of residential buildings which includes changes in floor space over time, and which tracks a series of energy-related metrics. The purpose of that model was to conduct scenario analyses and compare simulation results with the vision of the 2000 W society. Based on that model, it was found that a reduction of final energy by the factor of 3 and a reduction of CO_2 emissions by the factor of 5 is possible until the year 2050 (Kost 2006; Siller et al. 2007). The authors argue that the implementation of stricter energy standards and low-emission technology for water and space heating are the most effective options to achieve this. The refurbishment of existing buildings was deemed to be of higher importance than new constructions.

Schulz (2007) investigates intermediate steps towards the 2000 W society in the year 2050. As a part of his work he includes the residential building sector in his model. Considering Switzerland's energy system as a whole, he finds that during the first half of the 21st century "only intermediate steps towards the 2000 W society can be achieved" (113). Related to buildings he finds that heating systems based on oil and gas fuels could be largely avoided, even if the heated floor area would rise by an estimated 4 % until the year 2050. This could be achieved by relying on heat pumps and district heating based on combined heat-power generation (CHP) from natural gas and biomass. That would lower the CO_2 emissions of residential buildings by about 10 million tones, which corresponds about to 20 % of Switzerland's current emissions (118).

TEP and ETH (2009) provide a further model of the stock of residential buildings in Switzerland (their model includes the single- and two-familiy homes which I excluded in my model). TEP and ETH (2009) partially build on the work of Hofer (2007) and follow a similar approach as Kost (2006) and Schulz (2007) by modeling consecutive cohorts of buildings, with specific parameters for each cohort. Investigating different scenarios they find that the final demand for energy rises by either 1 % or falls by 17 % until the year 2050. In their most efficient scenario they assume a strong substitution of oil with heat pumps. They further assume that the role of

gas will increase (40). The energy demanded for heating is estimated to be roughly 50–60 % of a building's energy demand (44). TEP & ETH (2009, p. 46) find that the stock of buildings' emission of greenhouse-gases (estimated at about 20 million tons of CO_2-equivalent) can be reduced by 28–65 %, depending on what assumptions are made.

Similarly as I did in this chapter, Filchakova et al. (2009) used the concept of the ageing-chain to model the dynamics of the city of Basel's stock of buildings. By differentiating between embodied energy and energy consumption they treated energy use by the stock of buildings in a more detailed manner than I do here. Filchakova et al. (2009, p. 1074) call for further modeling work in which "the stimuli for decisions to renovate were modeled" such that strategies for increasing renovation frequency could be tested.

In a contribution dedicated to the improvement of techno-economic models, Catenazzi (2009, p. 81) presents a model (named RESIDENT) which forecasts the demand for heat for buildings in the residential sector. He presents simulation results for the city of Zürich. For a "business as usual" scenario he finds that the energy demand of the residential sector decreases from roughly 10,000 TJ in the year 2005 to 9850 TJ in the year 2035, even though heated floor space increases. He attributes these efficiency gains to the efficiency policies induced by the oil shock of the 1970ies (Catenazzi 2009, p. 105). In a second scenario, Catenazzi (2009, p. 107) investigates a very efficient development, characterized by the application of the Minergie and Minergie-P standard in new and retrofitted buildings. There, "results show a substantial reduction of 32 % relative to the reference scenario in 2035 and even a 35 % reduction relative to the energy demand in 2005" (107). He finds that in this scenario the use of energy decreases by about 1.2 % per year as compared to the business as usual scenario.

Further, not explicitly model-based contributions are to be found in the literature: The Swiss association of engineers and architects (SIA) provides a planning tool addressed to politicians, building owners and planners to achieve a "reduction path" towards the vision of a 2000 W society by the year 2050 (SIA 2006). It includes several assumptions by experts concerning the future development and the target values for the stock of buildings. In a contribution by Novatlantis (Jochem 2004), the authors ask what technologies need to be developed to achieve the goal of a 2000 W society in various sectors. Regarding the building sector they find that technically a "one liter" (heating fuel per m^2 per year) building is possible (20). They conclude that the energy demand from the stock of buildings will be dominated by the stock of existing buildings.[1]

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[1] This only holds for the energy demand. For energy-efficient renovations, the construction sector is of major importance because it is in the construction of new buildings where innovations in the field of energy technology are first implemented before they are employed in the renovation of buildings. See the research conducted by Susanne Bruppacher, Stefan Grösser, Lisa Lauper and Silvia Ulli-Beer in the context of the DeeB study.

International perspective

The dynamic behavior of the stock of buildings is also an important issue in other countries and on the international level. For example, Uihlein and Eder (2010) provide a building-stock model for the EU-27 countries. They find that the recent IPCC report on mitigation provides a full chapter on residential and commercial buildings (Levine et al. 2007). Kavgic et al. (2010) provide a review of bottom-up building-stock models for energy consumption in the residential sector. Ürge-Vorsatz et al. (2007, p. 387) find that in developed countries there is a technical efficiency potential of 21–54 % compared to the national baseline for buildings by the year 2020. Many more publications could be found. However, it is far beyond the scope of my study to provide a representative review.

4.3 Setup of the Small Simulation Model

The simulation model rests on a number of assumptions which need to be made explicit before the different sectors are discussed.

Reference mode

The reference mode of this model is the CO_2-emission rate, which should be reduced.

Temporal and spatial dimension

The model runs over a time of 125 years, from the year 1975 to the year 2100. The period spanning the years 1975–2008 is based on empirical data where available. The model covers the whole of Switzerland without making any further geographical differentiation.

Level of aggregation

The simulation model has a high level of aggregation. The aim is to include a small number of key characteristics and look at their interrelations. For example, buildings are treated as identical objects differentiated only over the attributes *quality state* and *level of energy-efficiency*. Differences which in the real world account for a substantial degree of variance in rental prices, such as the floor space, the number of rooms or the amount of sunlight received, are not explicitly included in the model. Instead, such attributes can be assumed to be implicitly included at their mean value and uniformly distributed across all reference buildings.

Model boundaries

The model provides no endogenous explanation why the shares of the three differ-
ent renovation strategies change. It does however simulate the effect of the shares
of renovation strategies changing over time. Further, the model does not explain
by which combination of technologies (heating systems, ventilation or insulation)
energy-efficient housing designs are implemented. In the model, only the energy use
for heating purposes is addressed. Energy use for warm water and appliances in the
building are not addressed, because only the energy used for heating is substantially
affected by energy-efficient building designs.

Model purpose and target audience

In line with the purpose of the study in general, the purpose of the small model
described in this chapter is to aid in the understanding of the most basic dynamic
patterns of Switzerland's stock of multifamily buildings regarding CO_2 emissions.
The target audience are primarily scientists. However, I think that basic insights into
the model could also be communicated to politicians, practitioners and interested
members of the population in general.

Model sectors and basic feedback structure

The model has three sectors. In the main sector, the behavior of the stock of buildings
over time is modeled (see Sect. 4.4.1). In the second sector, non-energy-efficient
and energy-efficient floor spaces and their energy coefficients are calculated (see
Sect. 4.4.2). In the third sector, the CO_2 emissions are calculated (see Sect. 4.4.3).
Figure 4.1 shows the three model sectors and conceptually represents the way the
three sectors interact in order to calculate CO_2 emissions.

4.4 Modeling the Stock of Buildings and its CO_2-Emissions

4.4.1 The Building Sector

4.4.1.1 Definition of the Standard Building

In the real world, each building is unique. Statistically oriented scientific studies, for
example Geiger (2006), try to account for the wide diversity of buildings by conceptu-
alizing buildings as a cluster of many attributes of the building and its neighborhood.
For the purpose of this study, a highly aggregated perspective is sufficient as high
level analyses will be conducted.

Building sector
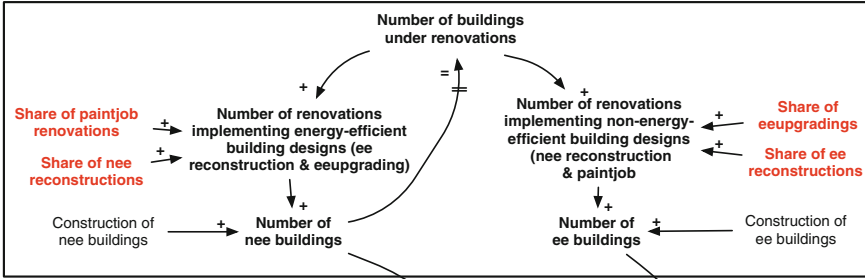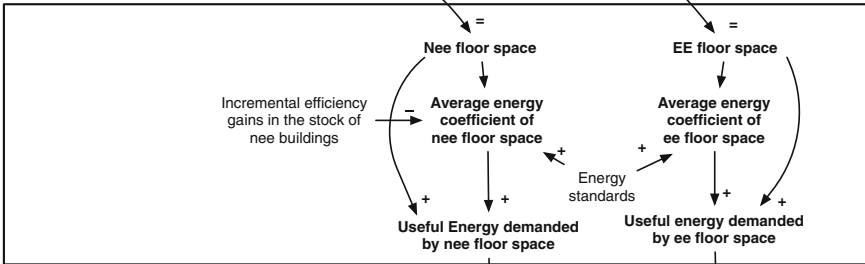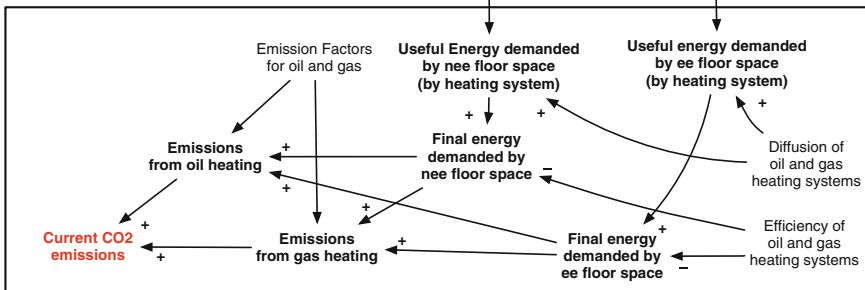
Fig. 4.1 Sector diagram of the small model. Variables set in *bold* refer to central variables used to calculate CO_2 emission. Note that although this figure is not a causal loop diagram, it represents the structure of causality used to calculate CURRENT CO_2 EMISSIONS (set in *red*) from exogenous inputs such as SHARE OF PAINTJOB RENOVATIONS (also set in *red*). The abbreviation "ee" refers to "energy-efficient" and "nee" refers to "non-energy-efficient"

This aggregated perspective is implemented by defining a standard building with a very small number of attributes. Of those attributes, variation only takes place in two attributes, specifically in the *energetic* and *quality* state of buildings (see below). Over all six possible combinations of energetic and quality state, all the other attributes are implicitly defined to be invariant and normally distributed around their mean value.

For example, attributes such as "number of housings per buildings", "number of rooms per housing" or "surface area per housing" are either defined to be constant or are not even explicitly defined because they are not relevant in the aggregate perspective. The following attributes are relevant for my model:

Quality states of buildings:

In the model, buildings have one of the following three different quality states:

- **New condition:** These are buildings that were recently built. They correspond to the recent demands of the market and all the construction elements are in new or nearly new condition.
- **Good condition:** These are buildings that are in a good, but no longer new condition. While the construction elements of the building generally are in good shape, first traces of wear and tear show.
- **Bad condition:** Buildings in a bad condition are characterized by the fact that the life-cycle of construction elements in several aspects is either reached or already has been exceeded.

Typology of energetic states of standard buildings:

In the model, a fundamental differentiation is made between non-energy-efficient buildings and energy-efficient buildings. The energetic state of a building is expressed by its energy coefficient.

- **Non energy-efficient** (nee) buildings are defined as having an energy coefficient of 193 MJ per m^2 and year or higher.
- **Energy-efficient** (ee) buildings are defined as having an energy coefficient below 193 MJ per m^2 and year. This value corresponds to the Minergie label after 2003 and the mandatory level after 2008 as defined by the Swiss conference of the cantonal energy directors (EDK 2008, p. 13).

4.4.1.2 Renovation Strategies

The following three renovation strategies are relevant in order to understand the transformation of the stock of buildings to a higher level of energy-efficiency. It is assumed that for each renovation strategy the energetic level either remains constant or is improved:

- **Paintjob renovation:** The energetic state of the building is slightly improved, but it remains non-energy-efficient as defined above. However, its level of quality is increased from bad to good.
- **Energy-efficient upgrading:** The energetic state of the building is substantially improved, so that it now is considered to be energy-efficient according to my definition. In line with Fig. 4.4, most implementations of energy-efficient building designs occur after the year 2000.
- **Reconstruction:** When a building gets torn down and replaced with a new building, then that is called reconstruction. By definition, a newly constructed building is of new quality. Over time, the share of nee buildings that are reconstructed as nee
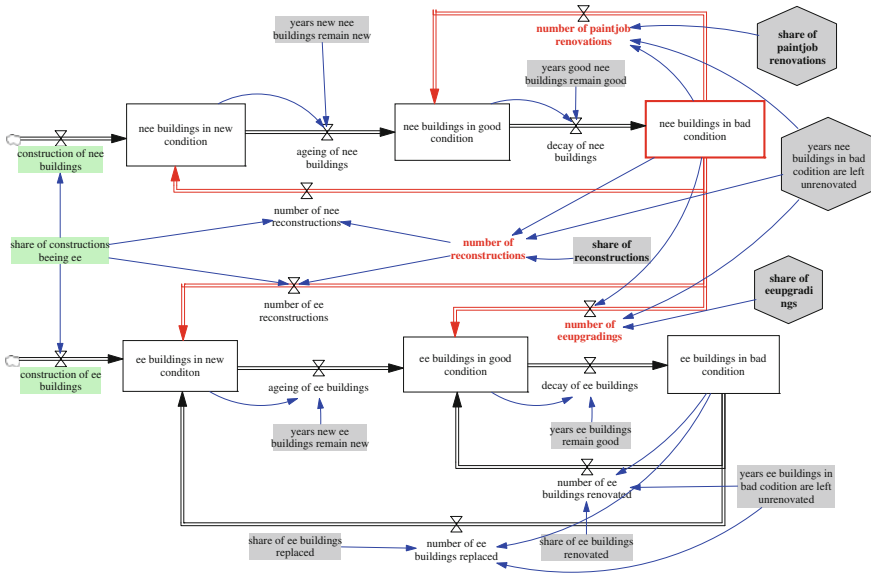
Fig. 4.2 Stock-and-flow diagram of the building sector. The flows (*double arrows*) going out of the stock of nee buildings in bad condition are buildings under renovation. The variables represented by *grey hexagons* control these flows and will be used to conduct scenario analysis

buildings declines, and an increasing share is reconstructed as a new ee building (also see Fig. 4.4) For the sake of simplicity, the share of reconstructions (of nee buildings in bad condition) is modelled as constant.

4.4.1.3 Stock and Flow Diagram

Figure 4.2 shows how the two levels of energy-efficiency, the three levels of quality and the three renovation strategies can be meaningfully combined into a stock-and-flow diagram of the stock of residential, multifamily buildings. By underlying this diagram with the appropriate equations and parameters it is possible to simulate the evolution of the built environment over time.

In addition to the three renovation strategies described in Sect. 4.4.1.2, two further renovation strategies are included for the sake of conceptual consistency. Those are the renovation of energy-efficient buildings in bad conditions (analogous to the paintjob renovation strategy) and the replacement of energy-efficient buildings by energy-efficient buildings in new condition (analogous to the reconstruction strategy). However, as these two flow variables do not affect the energy-efficiency of the stock of buildings, they are held constant over time.

Equations

For each year, the values for the stocks at the end of the year are calculated by adding the inflows to and subtracting the outflows from the stock of buildings. For example, the number of NEE BUILDINGS IN BAD CONDITION is given by calculating Eq. 4.1. The values for the other five stocks are calculated in analogy.

$$N_t = N_{t-1} + DEC_{t-1} - neeREN_{t-1} - eeREN_{t-1} - neeREC_{t-1} - eeREC_{t-1} \quad (4.1)$$

with:

N	nee buildings in bad condition
DEC	decay of nee buildings
neeREN	number of paintjob renovations
eeREN	number of energy-efficient renovations
neeREC	number of nee reconstructions
eeREC	number of ee reconstructions

For each timestep the NUMBER OF PAINTJOB RENOVATIONS, the NUMBER OF EEUPGRADINGS and the NUMBER OF RECONSTRUCTIONS is calculated. Equation 4.2 shows the formula for the NUMBER OF PAINTJOB RENOVATIONS. The other two renovation strategies are calculated in analogy.

$$neeREN = \frac{s * N}{Y} \quad (4.2)$$

with:

neeREN	number of paintjob renovations
s	share of paintjob renovations
N	nee buildings in bad condition
Y	years buildings in bad condition are left unrenovated

Of special importance is the specification of the number of buildings that are renovated $\left(\frac{N}{Y}\right)$ as a first-order material delay rather than a pipeline delay (Sterman 2000, p. 415). Using a pipeline delay would correspond to assuming that all buildings are renovated after the specified time (Y). This does not make sense because there is a lot of variation in the specific situation of each building, which may cause any individual building to be renovated after a different number of years than the average.[2] It makes much more sense to assume an average number of years (Y) that buildings in bad condition are left unaltered and assume a one-peaked, symmetric distribution around the average value. The disadvantage of using a first-order material delay is that it may take relatively long to approximate zero. The higher the value of Y is, the slower the rate of convergence becomes.

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[2] See the appendix C for some comments on the problems with fixed time delay operationalization of aging processes.

Table 4.1 Various parameters used for the calibration of the building sector

Parameter	Value
YEARS NEW NEE BUILDINGS REMAIN NEW	10
YEARS GOOD NEE BUILDINGS REMAIN GOOD	30
YEARS NEE BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED	15
YEARS NEW EE BUILDINGS REMAIN NEW	10
YEARS GOOD EE BUILDINGS REMAIN GOOD	30
YEARS EE BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED	15
SHARE OF EE BUILDINGS RENOVATED	0.75
SHARE OF EE BUILDINGS RECONSTRUCTED	0.25

Parameters

Parameters of critical importance concern the aging behavior of the stock of buildings: Table 4.1 shows how long buildings in average are assumed to remain in any given state. Note that in the model, the SHARE OF PAINTJOB RENOVATIONS, the SHARE OF EEUPGRADINGS and the SHARE OF RECONSTRUCTIONS are set exogenously rather than endogenously. By definition, the shares of the three renovation strategies must add to unity.

Data

In the literature, historical data and projections for the heated floor area of Switzerland's stock of buildings can be found. Figure 4.3 gives the projections of the heated floor area used in this model. In order to obtain the number of buildings, I assume the average multifamily building to have $1000\,m^2$ of heated floor area. Dividing the floor area through 1000 then gives the number of buildings at any time (see the Appendix C for further detail).

In Switzerland, a permit must be obtained before a building can be constructed. The permit is given only if the building conforms to the relevant energy regulations. Since 1975, the legal energy coefficient has become more and more strict (Jakob 2008, p. 8). Figure 4.4 shows the historical and projected energy coefficient that newly constructed buildings must adhere to.

Initial values

Initially, in the year 1975, all buildings are classified as non-energy-efficient. The available data does not allow to differentiate the buildings into buildings of a *new*,
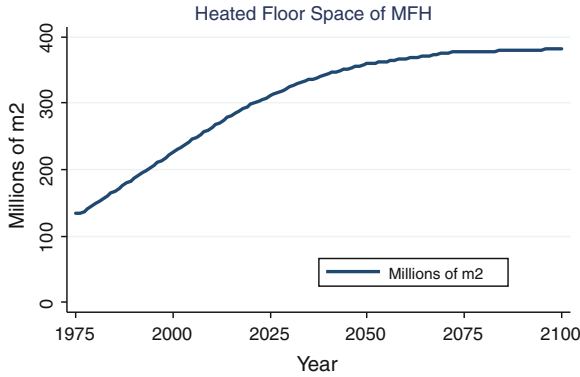
Fig. 4.3 Heated floor area of residential multifamily buildings 1975–2100. Datapoints for the years 2005 until 2050 are available in five-year intervals from TEP & ETH (2009, p. 26). Theoretically, datapoints for the years 1990 until 2003 are available from BFE (2004). However, the floor space for multifamily buildings reported here is measured differently and hence lower than the numbers given in TEP & ETH (2009, p. 26). Therefore, own assumptions based on the other datapoints are used instead
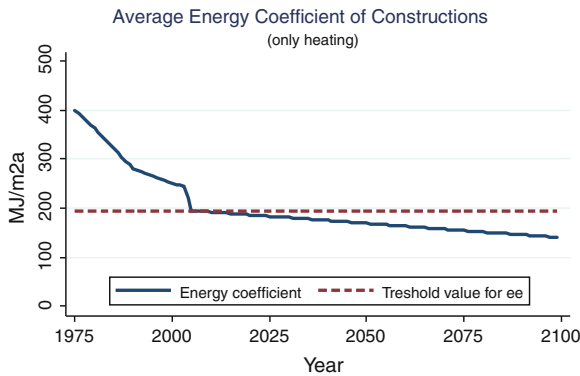
Fig. 4.4 Past empirical and projected average energy coefficient of new constructions as used in the model. Datapoints for the years 1991, 2000 and 2003 were taken from Hofer (2007, p. 26). Datapoints for the years 2005, 2035 and 2050 were taken from TEP & ETH (2009, p. 29). Datapoints for the year 1980 were taken from Jakob (2008, p. 34). Datapoints for the years 1975 and 2100 are own assumptions based on the other datapoints

good or *bad* condition.[3] Therefore, the total initial number of buildings was distributed across the three states based on plausibility considerations (also see the sensitivity analysis in the appendix C). Table 4.2 gives the values used.

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[3] Initially, I tried to approximate the distribution of the number of buildings over the three conditions based on data from Switzerland's population census. However, due to the lack of concise data on energetic aspects of renovations, this approach proved unfruitful.

Table 4.2 Distribution of the total number of buildings over the three building quality states

Building condition	Share of total buildings (%)
NEE BUILDINGS IN NEW CONDITION	20
NEE BUILDINGS IN GOOD CONDITION	40
NEE BUILDINGS IN BAD CONDITION	40

Note that in the year 1975 only non-energy-efficient buildings existed

Due to the uncertainty concerning the classification of the stock of buildings into the three categories new, good and bad, the share for new buildings was set relatively high. However, because between model initialization (1975) and the start of policy analysis (in 2010) a period of 35 years has passed, any deviation of five or even 10 percent away from this assumption will be balanced out by the model, as buildings move down the aging chain.

4.4.2 Energy Coefficients of EE and NEE Floor Space

Total nee and ee floor spaces

Figure 4.5 shows the model structure used to track the total of nee and ee floor space. It basically reproduces the logic underlying the building sector described above. For
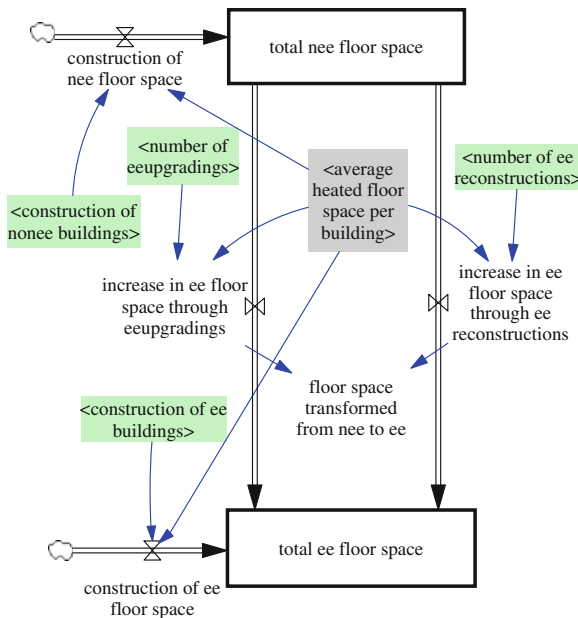
Fig. 4.5 Model structure used to track floor spaces and their energy coefficient

example, the total nee floor space is given by the floor space in new, good and bad condition in the nee ageing chain. The building sector described above gives the number of buildings renovated by different renovation strategies. In order to obtain surfaces rather than numbers of buildings, several variables need to be multiplied with the AVERAGE HEATED FLOOR SPACE PER BUILDING (see Fig. 4.5). The stock of TOTAL NEE FLOOR SPACE is increased by the construction of nee floor space. It is depleted as floor space is either upgraded or reconstructed to energy-efficient floor space. Floor space upgraded or reconstructed increases the stock of TOTAL EE FLOOR SPACE together with the construction of ee floor space.

The initial value of the stock TOTAL NEE FLOOR SPACE is set to be the initial value of the total floor space put into the model in the year 1975. The initial value of the stock TOTAL EE FLOOR SPACE is also set to 1 rather than zero, in order to avoid any divisions by zero.

Nee floor space: energy demand and energy coefficient

Knowing the total floor space of nee floor space is a prerequisite for the calculation of the corresponding energy demand and energy coefficients. Figure 4.6 shows the structure used to calculate the energy demanded by nee floor space. The ENERGY DEMAND OF NEE FLOOR SPACE is modeled as a stock. Initially, it contains the product of total nee floor space with the initial average energy coefficient of the stock of buildings in the year 1975. Over time, the product of CONSTRUCTION OF NEE FLOOR SPACE with the AVERAGE ENERGY COEFFICIENT OF CONSTRUCTIONS flows into the stock. By dividing the ENERGY DEMAND OF NEE FLOOR SPACE through the TOTAL NEE FLOOR SPACE, the AVERAGE ENERGY COEFFICIENT OF THE STOCK OF NEE BUILDINGS is derived.
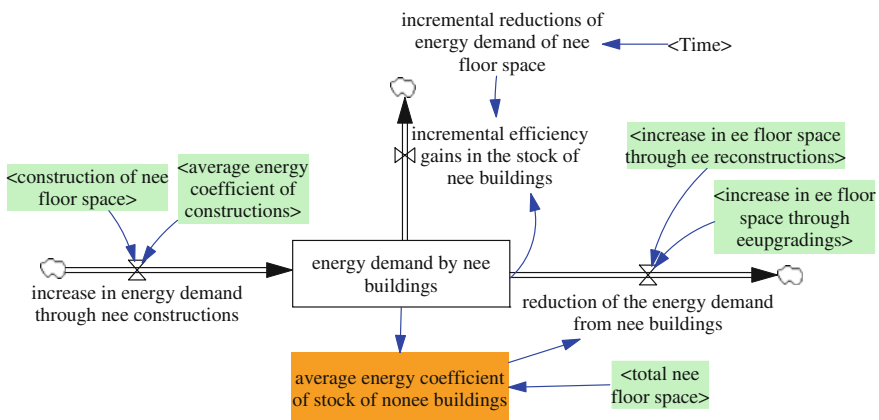
Fig. 4.6 Model structure used to calculate the energy demanded by nee floor space

Two processes deplete the stock ENERGY DEMAND OF NEE FLOOR SPACE. First, floor space which is undergoing eeupgrading or ee reconstruction must no longer be counted as part of the nee energy demand. Therefore, the product of the AVERAGE ENERGY COEFFICIENT OF THE STOCK OF NEE BUILDINGS and the corresponding floor spaces is subtracted from the stock. This operationalization ensures that the energy demand from the stock of nee buildings changes only with energy-efficient renovations. It also ensures that the AVERAGE ENERGY COEFFICIENT OF THE STOCK OF NEE BUILDINGS is not affected.

Second, I included INCREMENTAL EFFICIENCY GAINS IN THE STOCK OF NEE BUILDINGS. This is to account for the fact that the stock of nee buildings did not remain at a constant efficiency level. This variable is specifically used to calibrate the CO_2 emissions of the model to the empirical data (see the appendix on p. 309 for further details).

EE floor space: energy demand and energy coefficient

Following the same logic as above, Fig. 4.7 shows the model structure used to calculate the energy demanded by ee floor space and its energy coefficient. The floor space added to the stock of ee floor space is multiplied with the relevant AVERAGE ENERGY COEFFICIENT OF CONSTRUCTIONS and added to the stock of ENERGY DEMAND OF EE FLOOR SPACE. The average energy coefficient of ee floor space is then calculated by dividing the stock through the floor space.

As can be seen in Fig. 4.7, the energy demand from eeupgradings is calculated with a different energy coefficient compared to ee construction and ee reconstruction energy demand added. This is because eeupgradings are assumed to implement an energy standard which is one quarter less strict than the AVERAGE ENERGY COEFFICIENT OF CONSTRUCTIONS (AECC). Therefore, the AVERAGE ENERGY COEFFICIENT OF EEUPGRADINGS (AECeeup) is calculated according to Eq. 4.3 (initialAECC refers to the initial value of the average energy coefficient of construction, AECC).

$$\text{AECeeup} = MIN(\text{initialAECC}, 1.25 * \text{AECC}) \qquad (4.3)$$

Calculation of absolute energy coefficients

Based on the average energy coefficients of nee and ee floor spaces, the absolute energy coefficient of the total stock of buildings (AECtotal) can be calculated as a weighted average of nee and ee floor space (An, Ae) and the corresponding energy coefficient (Cn, Ce) (see Eq. 4.4):

$$\text{AECtotal} = \frac{\text{An} * \text{Cn} + \text{Ae} * \text{Ce}}{(\text{An} + \text{Ae})} \qquad (4.4)$$
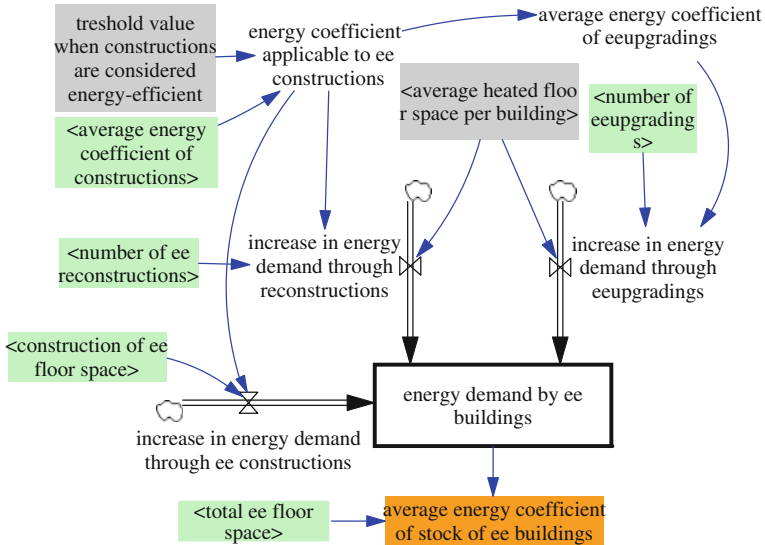
Fig. 4.7 Model structure used to calculate the energy demanded by ee floor space and the corresponding energy coefficient

4.4.3 CO_2 Emission Sector

In order to calculate the stock of buildings CO_2 emissions from energy coefficients and floor spaces, further assumptions need to be made. Specifically, the prevalence of different heating systems and their efficiency needs to be considered. Physical aspects such as useful energy, final energy, and emission factors from oil and gas heating also need to be considered.

Diffusion rates

Figure 4.8 shows past and projected diffusion rates of oil and gas heating systems for nee and ee floor space. In exhibit 1, the diffusion rates for the stock of non-energy-efficient buildings is shown. Here, a substitution process from oil to gas is visible.[4] In exhibit 2, the diffusion rates of oil and gas heating systems in the stock of energy-efficient buildings is shown. This contains buildings that were constructed, reconstructed or eeupgraded to be energy-efficient.

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[4] Note that other heating systems, such as heat pumps or wood heatings are excluded, and the shares of oil and gas heating hence do not add up to unity. This is because most other heating technologies are considered to be low- or nearly free of greenhouse-gas emissions (BAFU 2010).
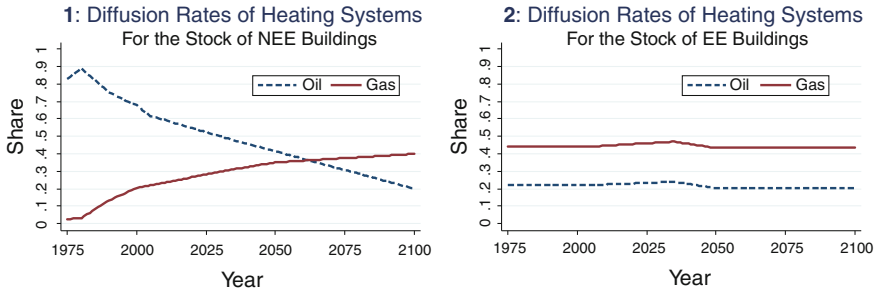
Fig. 4.8 Diffusion rates of heating systems. *Source* TEP and ETH (2009)
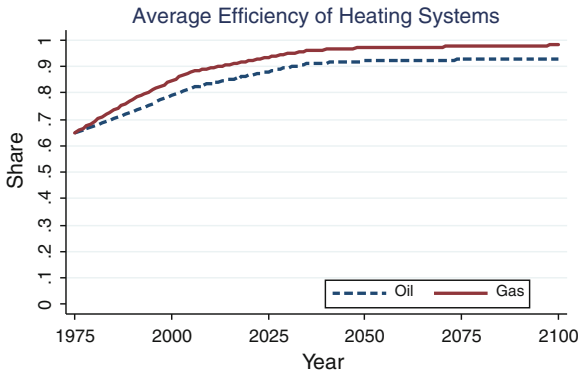
Fig. 4.9 Efficiency of heating systems. *Source* TEP and ETH (2009)

Efficiency of heating systems

Figure 4.9 shows the increasing average efficiency of oil and gas heating systems over time. As the efficiency increases, the amount of energy input (oil or gas as a fuel) used to provide the desired energy output (heat) decreases.

Emission factors

In order to calculate the emissions of CO_2 for floor space heated with fossil-fuels, emission factors need to be known. According to BAFU (2009), 73.7 tons of CO_2 are emitted per Terajoule when using light heating oil. When gas is used for heating 55 tons of CO_2 are emitted per Terajoule.

Calculating CO_2 emissions

The CO_2 emissions of the stock of buildings are calculated by applying the factors introduced above (diffusion rate and the efficiency of heating systems, emission factors). As a first step, the nee and ee floor spaces heated with oil and gas need to be calculated by applying the diffusion rates (the example given in Eq. 4.5 is for nee floor space heated with oil. The other three are calculated in analogy):

$$\text{Nee space}_{oil} = \text{NEE floor space} * \text{diffusion rate of oil heating in nee} \qquad (4.5)$$

As a second step, the demand for useful energy (UE) is calculated for each of the four types of floor space. As shown in Eq. 4.6, this is done by multiplying the four types of floor space obtained above with the corresponding average energy coefficient (AEC) (the example given in Eq. 4.6 is for nee floor space heated with oil, the other three are calculated in analogy).

$$\text{UE Nee space}_{oil} = \text{NEE floor space}_{oil} * \text{AEC}_{Nee} \qquad (4.6)$$

As a third step, the efficiency of the heating systems needs to be considered in order to obtain the demand for final energy (FE). This is done by dividing the useful energy obtained above through the average efficiency of the heating system used (the example given in Eq. 4.7 is for nee floor space heated with oil, the other three are calculated in analogy).

$$\text{FE Nee space}_{oil} = \text{UE Nee space}_{oil}/\text{Efficiency}_{oil} \qquad (4.7)$$

Once final energy for each type of floor space is obtained it can be multiplied with the corresponding emission factor. By adding the emissions from all four types of floor space together, the total emissions for each year are obtained.

4.5 Scenario Analysis

4.5.1 Scenarios

In the following, I use the simulation model to analyze the transformation of Switzerland's stock of multifamily buildings under different scenarios. Specifically, I simulate the following scenarios:

- **Baserun:** In this first scenario, the share of energy-efficient renovations rises from 0 prior to the year 1995 to 0.5 in the year 2010 and remains constant at 0.5 until the year 2100. This scenario is closest to the current situation in Switzerland where a substantial share of renovations currently do not reach an energy-efficient level.

- **Efficiency:** In this scenario, the share of energy-efficient renovations rises from 0 prior to the year 1995 to 0.95 in the year 2010 and remains constant at 0.95 until the year 2100. Such a scenario corresponds to the (unlikely) situation in which every building owner whose building has exceeded the service life of its hull implements an energy-efficient building design.
- **Mandatory:** Just as in the previous scenario, the share of energy-efficient renovations rises from 0 prior to the year 1995 to 0.95 in the year 2010 and remains constant at 0.95 until the year 2100. In addition, nee buildings in a bad condition now must be renovated within an average period of five years, rather than within an average period of 15 years.

These scenarios are simulated by adapting the values for two to three variables, while all other parameters as well as the model structure remain identical across the scenarios. For the scenario *efficiency*, the variables SHARE OF PAINTJOB RENOVA-TIONS and SHARE OF EEUPGRADES are used to simulate what would happen if all the paintjob renovations were replaced by eeupgradings. For the scenario *mandatory* the variable YEARS NEE BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED is reduced to 5 years in order to model the effect of making the (energy-efficient) renovation of nee buildings in bad condition mandatory.

Figure 4.10 shows the share of buildings renovated by a specific renovation strategy. Exhibit a) gives the values for the *baserun* scenario. Over the time period 1975–1995, only paintjob renovations are carried out. This is because neither the technology for energy-efficient renovations was readily available, nor was there a widespread realization that climate and energy constitute an urgent problem that needs rapid action. Over the period 1995–2010, energy-efficient upgrading gradually emerges as a technically feasible and financially viable renovation strategy. After a diffusion process of 15 years, eeupgrading is modeled here as achieving a market share of 50 % by the year 2010 which is maintained through to the year 2100. In correspondence
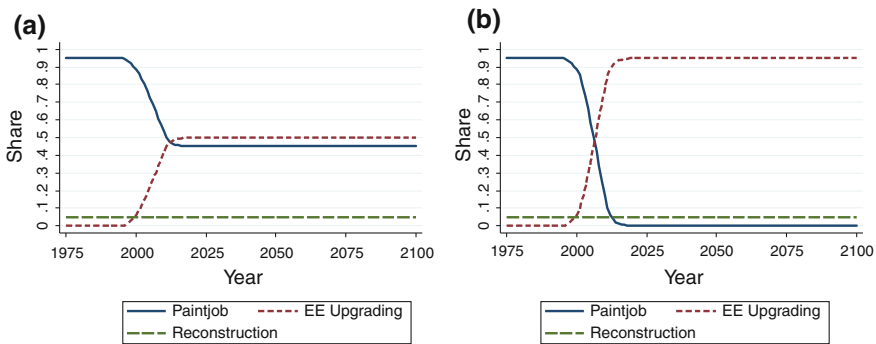
Fig. 4.10 Shares of the three renovation strategies over time. Values for the scenario *baserun* are given in graph a. The shares of the three renovation strategies are the same in the scenarios *efficiency* and *mandatory* (see graph b). (In the mandatory scenario, the YEARS BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED are reduced from 15 to 5 years.)

with the literature on the diffusion of innovations (Rogers 2003; Stoneman 2002), the diffusion process is modeled as a logistic s-curve. In exhibit b), the diffusion process of the eeupgrading renovation strategy is modeled as achieving a market share of 95 % by the year 2010, which is maintained through to the year 2100. As explained above, this is due to the effective prohibition of paintjob renovations, which occurs in both the *efficiency* and the *mandatory scenario*.

4.5.2 Simulation Results

For each scenario, Fig. 4.11 shows the behavior of the six stocks of buildings obtained by simulation. In the *baserun scenario*, where I assumed that half of the non-energy-efficient buildings in bad condition are upgraded to a higher state of energy-efficiency, the transformation process takes very long. This is mostly due to the fact that in the baserun scenario, buildings can move upstream in the inefficient aging chain by way of the paintjob renovation strategy. Consequently, a substantial number of non-energy-efficient buildings cycle between a good and a bad state. However, this number diminishes because 50 % of all renovations are carried out by the eeupgrading strategy which drains the number of buildings for which paintjob renovations could be considered. However, by the year 2100 still about 83,000 buildings are in the non-energy-efficient stream. Therefore, the realization of the baserun scenario would constitute a substantial setback for energy and climate policy. Because of the long time a paintjob-renovated building stays in service before the next renovation is necessary, in the baserun scenario the transformation of the stock of buildings is sluggish at best.

In the *efficiency scenario*, the reduction of the stock of nee buildings in bad condition is initially rather small compared to the baserun scenario. Over time, however, the gap widens gradually as the stock of nee buildings in good condition is depleted without being replenished by paintjob renovations. In the long run (until the year 2100), an almost complete transition to energy-efficiency is achieved. In this scenario there are about 26 500 buildings in the non-energy-efficient stream by the year 2100.

The success of the *mandatory scenario* in achieving a quick reduction of the nee buildings in bad shape is apparent in Fig. 4.11. Following the introduction of mandatory renovations, a sharp decline in the number of nee buildings in bad condition can be seen. However, the depletion speed of the stock of nee buildings in good condition is the same as with the efficiency scenario, thus limiting the higher effectiveness of the mandatory scenario compared to the efficiency scenario. The success of the mandatory scenario lies in the fact that the number of nee buildings in good condition is substantially reduced before the year 2050. In the long run (until the year 2100), the mandatory scenario converges toward the efficiency scenario (about 18,100 nee buildings by 2100).

Over all, the built environment's speed of transformation to energy efficiency is fastest in the mandatory scenario. However, this speed may come at a price: By man-
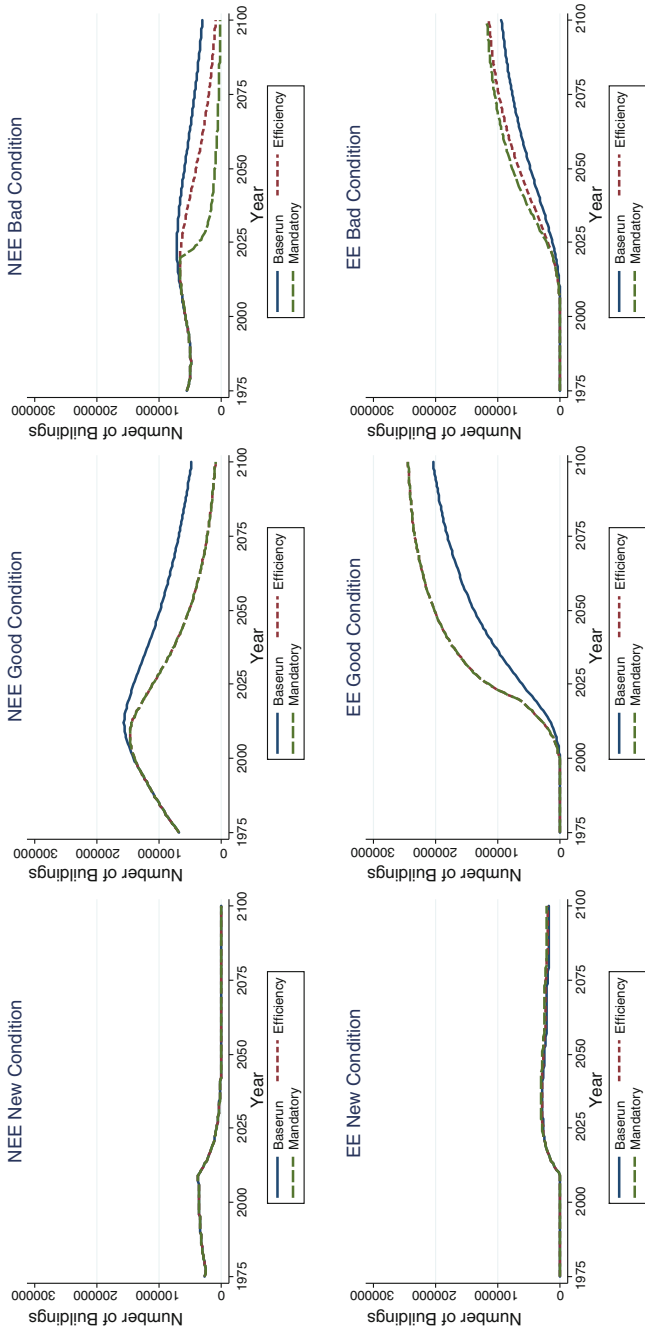
Fig. 4.11 Behavior of the six stocks of buildings for the three scenarios
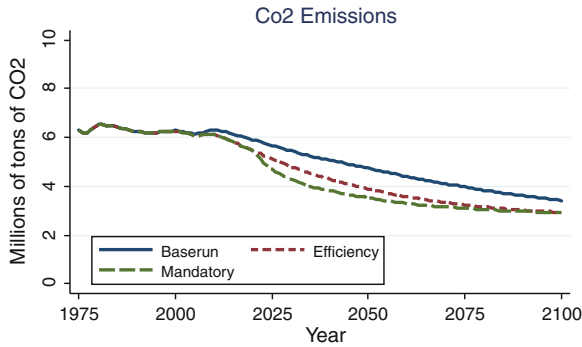
Fig. 4.12 Yearly emissions of CO_2 by the stock of buildings in the three scenarios

dating the renovation of nee buildings in bad condition, the demand for construction services could drive up prices for construction services and materials, thus undermining the cost-effectiveness of investments into energy-efficiency in buildings. Further research also needs to investigate whether the share of buildings in bad condition, which declines sharply in the mandatory scenario, reduces the availability of housing for low income households. This would be an undesirable effect and could threaten the social sustainability of the mandatory policy package.

Figure 4.12 shows the current emission rate of CO_2 for each of the three policy scenarios.[5] Emissions peaked at around 6.5 million tons of CO_2 in the year 1980 and then slowly start to decline. The dynamic behavior until about the year 2010 might seem very unspectacular. Yet in light of increasing numbers of buildings a stabilization is still a mild policy success. In the *baserun* scenario, emissions are reduced to about 4.7 million tons of CO_2 per year in the year 2050. In the *efficiency* scenario emissions in 2050 amount to 4.1 million tons per year. In the most ambitious *mandatory scenario* emissions are cut to an emission rate of 3.6 million tons CO_2 per year. By the year 2100 further reductions are achieved (baserun: 3.4; efficiency: 2.9; mandatory: 2.9 million tons CO_2 per year).

4.6 Discussion

It is evident that the occurrence of paintjob renovations delays the transformation process. This is because in the *baserun* scenario, paintjob renovations replenish the stock of nee buildings in good condition. In the *efficiency* scenario, a substantial transformation of the stock of buildings is achieved. This is because the aging chain with nee buildings is drained consequently and no replenishing occurs. However, in the

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[5] See appendix C for a discussion of how the model fits the available data. There, I conclude that the dynamic behavior of the model and the magnitude of the emission rate has been established with sufficient certainty.

short to medium run, the stock of buildings is transformed slower to energy-efficiency and the CO_2-emission-reduction speed is slower compared to the mandatory scenario. But in the long run (towards the year 2100), the efficiency scenario converges towards roughly the same state as the *mandatory* scenario. Mandatory renovations were the most effective policy package to achieve a quick and determined transformation of the stock of buildings to a high state of energy-efficiency. However, determined policy efforts aimed at implementing mandatory renovations probably would come at the expense of a part of the population that relies on low-cost housing.

I find that the reduction of CO_2-emissions proceeds more slowly than the transformation of the stock of buildings. This is because a part of the efficiency gains made by making buildings and heating systems energy-efficient is compensated by the expansion of the total number of buildings. This particularly holds because increases in the efficiency of heating systems are limited to a maximum efficiency of 100 %. Yet even with the unrealistically ambitious parameter settings of the mandatory scenario, efficiency measures in the building hull could achieve only a 50 % reduction of emissions. This finding clearly shows the importance of considering low-emission heating systems together with efficiency improvements of the building hull (see below).

What do the model results imply on a per capita basis? In the year 2008, Switzerland had about 7.7 million permanent residents (BFS 2010a). Switzerland's federal statistical office estimates in its medium scenario that by 2050 the Swiss population will consist of about 8.3 million permanent residents (BFS 2010b). For the *baserun scenario*, dividing the CO_2-emissions from all residential multifamily buildings (4.711 million tons) by the expected population (8.3 million persons) yields an annual per capita emission of about 0.57 tons CO_2. The corresponding figure for the *efficiency scenario* is roughly 0.49 tons CO_2 per capita, and for the mandatory scenario it is about 0.43 tons CO_2 per capita in the year 2050.

Next, how do these per capita emission rates compare to the vision of a one ton CO_2 society? According to Novatlantis (2007), Switzerland should reach an emission rate of 2 tons CO_2 per capita in the year 2050 and an emission rate of 1 ton CO_2 per capita in the year 2100. Even in the rather optimistic *efficiency* scenario, 0.49 tons of the total allowance of 2 tons CO_2 per capita in the year 2050 would account for the heating of Switzerland's residential multifamily buildings. Said differently, a quarter of a person's yearly emission quota is being spent for the heating of residential multifamily buildings. Consider that the 0.49 per-capita tons of CO_2 only contain the emissions used for the heating of multifamily buildings. Those emissions do not include the per-capita emissions from single- or two-family buildings or commercial buildings. Warm water and appliances are also not included in the per-capita emissions given above.

Eventually, I think that the emission rates even in the optimistic *efficiency* scenario are not compatible with the goal of a two ton CO_2 per capita society by the year 2050. Further, such per-capita emission rates are not consistent with the vision of a one-ton-CO_2 society by the year 2100. While these results should be considered rough quantifications rather than precise results, it seems clear that Switzerland's emission need to be reduced further. The construction, use and maintenance of buildings with residential purposes (single- and multifamiliy buildings) accounts for about

31 % of Switzerland's demand for gross energy (Koschenz and Pfeiffer 2005, p.8). Conservatively subtracting the energy used for single family buildings and the energy used for construction and maintenance, one should expect that the stock of multi-family buildings' demand for energy should be somewhere around 15–25 % of the Swiss total. Assuming that this roughly corresponds to the share of CO_2-emissions, the stock of multifamily buildings should emit in the range of about 0.15–0.25 tons of CO_2 per capita per year in a one-ton-CO_2-society.

These results prompt the question what could be done to further reduce the CO_2 emissions from Switzerland's stock of multifamily buildings. As the energy-efficient renovation of buildings in good or even new condition does not make sense from a financial perspective, the heating systems become the most important policy lever.

In oder to investigate the effect of a gradual substitution away from fossil-based energy systems, I simulated a fourth scenario. Specifically, I assumed that the diffusion rates of heating systems were gradually reduced. This was simulated by multiplying the diffusion rates of heating systems as described in Fig. 4.8 with a variable which moves from 1 to 0. The exhibit on the left of Fig. 4.13 shows the specific substitution rate used. I set is such, that the substitution begins from a share of 1 in the year 2010 and gradually declines to a share of 0.1 in the year 2050. Between the year 2050 and 2100, the substitution rate further declines towards zero. As can be see on the exhibit on the right of Fig. 4.13, the CO_2 emission rate from the stock of residential, multifamily buildings is substantially reduced between 2010 and 2050. The reduction speed closely follows the assumed substitution rate. In conclusion, this fourth policy scenario has shown that spectacular emission-reductions can be achieved if fossil-based heating systems are gradually phased out.

The next question would be to ask what technologies could be used in order to replace fossil-based heating systems. A profound discussion of technological aspects of carbon-free or carbon-reduced heating systems is not possible here. However, such an ambitious policy may bee less utopian than apparent. Shinnar and Citro (2008), for example, argue that the United States could replace around 98 % of fossil-fuel
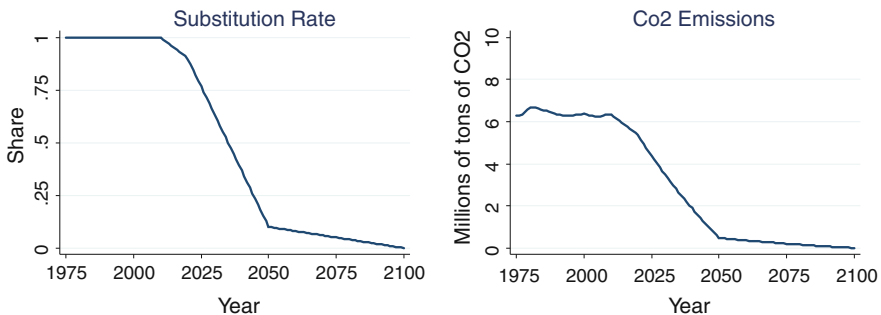
Fig. 4.13 Scenario 4: Gradual substitution of fossil heating systems until 2050. The exhibit on the *left* shows the assumed substitution rate. The exhibit on the *right* shows the resulting emission trajectory

needs and reduce the present US emissions by 97 % over the next 30–50 years. They argue that this could be achieved with currently available and affordable technologies. On the other hand, climate change mitigation efforts as well as fossil-fuel depletion should be expected to anyway require incredibly ambitious reductions. Shafiee and Topal (2009) argue that coal will be the only fossil-fuel left after 2042. The emission-reductions required to constrain global warming to somewhere near the 2 or 3 degree goal are in line with such ambitious policies.

4.7 Implications for Policy-Making

What implications do the findings discussed above have for policy-making? First, I think that the inertia of the stock of buildings needs to be fully acknowledged. Ambitious climate and energy policy interventions into the stock of buildings are long term policy challenges (Sprinz 2008) and need to be thought about in decades rather than years. Second, potential policy levers need to be identified and evaluated. Table 4.3 summarizes the major levers that public policy can address in this model. As can be seen, substantial success has been achieved in the prevention of new non-energy-efficient constructions. Related to this, the energy coefficient demanded in the energy code has also been successfully reduced. In contrast, limiting the construction of new buildings is not a realistic policy option, and reducing the time a building remains in bad condition also is of questionable importance. Accelerated renovations of nee buildings in bad condition might create pressures for low-income households and thus undermine the necessary political momentum to implement ambitious policies. In contrast, it is an important challenge to ensure that any renovation that is made leads to a highly energy-efficient building. Finally, the most important challenge is to achieve the decarbonization of heating systems.

Table 4.3 Evaluation of the implementation of major policy levers

Lever	Evaluation
Limit the construction of new buildings	Unrealistic
Make new constructions energy-efficient	Substantial success achieved
Prevent paintjob renovations	Crucial challenge
Speed up renovations	Of questionable importance
Decarbonize heating systems	Crucial challenge
Increase efficiency of heating systems	Substantial success achieved
Reduce the energy coefficient in the energy code	Substantial success achieved

4.8 Conclusions

In this chapter, I set out to address my second research question: *How should the transformation of the stock of buildings to higher levels of energy-efficiency be conceptualized, so that basic insights into the dynamics of the process, its causes and possible policy scenarios can be analyzed?* I argued that for the purpose of my study, it is sufficient to produce a small model, which only captures the basic, most fundamental issues. In line with the general focus of my study, I concentrated on the role of energy efficiency of the building hull. Heating systems were only briefly addressed, although they eventually emerged as the main lever for substantial emissions reduction. While I think that I have indeed succeeded in modeling the stock of buildings sufficiently well, I obviously do not provide the same level of precision that is found in engineering models of the stock of buildings. Nevertheless, the model should be considered fairly robust regarding its dynamic behavior patterns. As the model testing procedures applied have shown, the model reproduces empirical values within reasonable limits (see appendix C for a report on model testing).

In the next two chapters I investigate actors in the societal problem situation (Chap. 5), provide a dynamic explanation of the causal factors causing the diffusion of energy-efficient renovations (Chap. 6) and eventually provide a substantially extended simulation model, which provides an endogenous explanation of the causes and effects of the diffusion of energy-efficient renovations.

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Chapter 5
Actors in the Societal Problem Situation

5.1 Introduction

In the previous chapters, the actors in the problem situation have not yet been systematically addressed. I do this in this chapter, as I address my third research question. It reads: *What groups of actors are involved in the societal problem situation and which ones are particularly relevant? Further, how should the behavioral characteristics of the most important actors be represented for System Dynamics modeling?* I define actors to be individuals or collective entities that carry out actions in the real world.

In order to address this research question, I first describe how the renovation process for a building typically unfolds (see Sect. 5.2). As a second step, a list of actors that potentially influence the diffusion of energy-efficient renovations on the macro level is compiled (see Sect. 5.3). In order to identify the actors with the highest impact on the diffusion process, I evaluate for each actor, how strong his interest in energy-efficient renovations is. And I further assess whether they have the power to significantly affect the diffusion process. The actors which will be modelled explicitly in the simulation model are then selected from that list and described in greater detail (see Sect. 5.4). For each important actor, sub-types with different behavioral traits are identified. This approach allows to represent the diversity among actors. Finally, in Sect. 5.5, the effects the different actors have on the diffusion process are analyzed.

Throughout this chapter, I draw on the expert interviews I conducted with actors involved in the construction sector. Based on a small number of exploratory interviews (N = 6), I developed a questionnaire and used it to conduct semi-structured expert interviews (N = 14). The interviews were conducted in Swiss German and transcribed into standard German. The transcripts were coded and analyzed with the MaxQDA software, in order to develop a system of categories. I translated all the quotations used in this chapter into English. See Sect. 2.3 for a discussion of methods. See the electronic supplement for further documentation of the interviews.

5.2 The Renovation Process

In this section, a detailed description of a typical renovation process is provided. Doing so shows the interactions of several actors, which will be further introduced below. It gives an empirical basis to the renovation strategies described in Sect. 4.4.1.2.

I define the *renovation process* to include all actions that are undertaken in order to improve the condition of a specific building. It includes a wide variance of construction activities, ranging from minor painting of the interior and the façade to replacements of all but the most important structures of a building.

The following description is a result of the interviews. Specifically, I asked those interviewees that were involved in the renovation of a building:

> First, I am interested why the building was renovated in the first place and what strategic goals were pursued with the renovation. After that, could you explain me how the renovation process unfolded and which actors were involved?

From the interviews I learned that the process, according to which renovations are made, generally follows a similar pattern. Of course, each building is individual. In consequence, not every element of the renovation process is found in each of the renovations described by my interviewees. Therefore, the following description is to be seen as an ideal-typical account of the renovation process. It particularly illustrates the eeupgrading renovation strategy. The process according to which paintjob renovations are implemented basically follows the same general logic. Yet in paintjob renovations, several elements of the ideal-typical renovation process might be omitted.

Table 5.1 shows the elements of the renovation process found in the interviews. Following this overview, each element is further described.

Initiation of the Renovation Process

Buildings are generally renovated for three reasons: First, significant parts of the building have deteriorated so far that they are no longer able to provide the services demanded. Second, the requirements for the performance of the buildings have changed. Third, the use of the building has changed. It is slow processes rather than discrete single events that lead to deterioration and changing requirements. As long as the building is not at risk of collapsing, there is generally no immediate need to renovate a building (Aikivuori 1996; Hillebrandt 2000).

Professional building owners generally have procedures and a database that they use in order to decide whether to renovate a building or postpone construction to later years. In order to maintain the actuality of the data in such databases, buildings are systematically reviewed every few years. Based on the building's condition according to the database, the decision to analyze the building in greater detail is made. Non-professional building owners generally do not follow such a systematic approach. Rather, they seem to proceed step by step, renewing selected parts as capital becomes

Table 5.1 Elements of the renovation process

1.	Initiation of the renovation process
2.	Contacting an architect
3.	Detailed analysis
4.	Development and evaluation of renovation strategies
5.	Organization of finance
6.	Planning
7.	Application for a construction permit
8.	Informing tenants
9.	Obtaining offers from construction companies
10.	Selection of construction companies
11.	Construction phase
12.	Quality control
13.	Offering apartments on the market
14.	Handing over the apartments to tenants
15.	Dealing with complaints from tenants
16.	Demanding rework from construction companies

available. Often, major renovations take place after a building has been sold and the new owner wants to reposition the building in a better market segment.

Contacting an Architect

Once the building owner has decided to renovate his or her building, an architect may be contacted. Professional building owners generally have architects with whom they collaborate regularly or they might have architects within their organization. And they almost always rely on the expertise of an architect. Sometimes, a competition may be held where architects are asked to submit proposals that then are reviewed by a board. In contrast, non-professional building owners are often reluctant to involve an architect. Due to the extra expense of involving an architect, they prefer to get advice directly from artisans and construction companies. I therefore assume that the bigger the renovation project is, the higher the probability is that an architect will be contacted. If non-professional building owners involve an architect, they often select an architect based on recommendations from peers. Once an architect is involved, exploratory discussions are held so that architect and building owners both clarify what has to be done.

Detailed Analysis

In order to prepare for the decision whether to renovate the building and if so, with what strategy, a detailed analysis of the building and its context are often performed, either by the building owner, by the architect or by specialized companies. As part of

the analysis, the building is inspected together with the care-taker who has detailed knowledge of crucial issues. All these analyses lead to reports on the exact physical condition of the interior and the exterior of the building. Reports are obtained regarding the local rental market and the future potential at the location of the building.

Development and Evaluation of Renovation Strategies

Based on the information learned from detailed analysis, a range of principally applicable renovation strategies needs to be developed and evaluated. Ultimately, a decision must be made as to which renovation strategy will be used to achieve the goals of the renovation. Since buildings in need of renovation generally are a unique case, the conceptualization of different renovation strategies must consider the individuality of each case. By developing options it becomes easier to see trade-offs between issues and ultimately develop a renovation strategy that balances all important issues. Such issues, for example, are whether one big apartment should be made by conjoining two small apartments. Or what level of energy-efficiency should be implemented. Or how much the rents may rise so that the apartment remains competitive on the local market.

The environmental impact of a building is strongly influenced in the early planning phase and in the use phase (Lalive d'Epinay 2000, p. 23). Similarly, Van Hal (2007) finds that the early planning phase also significantly impacts the profitability of sustainable housing.[1] Professional building owners generally are guided by their organization's standards when developing and evaluating different renovation strategies. This way, considerations from the normative and strategic level influence the organization's actions on the operative level. Non-professional building owners generally do not have the skills required for effectively developing, evaluating and adapting renovation strategies for their building. Therefore, I think that they probably consider less options when developing and evaluating renovation strategies. However, collaboration with an architect may overcome this deficit.

Organization of Finance

In order to pay for the cost of renovation, finance needs to be organized. Building owners who hold buildings as a form of investment generally can organize finance from their own assets. Other building owners frequently need to obtain a mortgage from a bank if they cannot invest from their own assets. Banks only give mortgages if the value of the property (building and land) exceeds the total debt on the property. In addition, banks often review construction plans in order to ensure that the expenses covered by their loan lead to the construction of a valuable asset, which could be sold on the housing market.

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[1] Van Hal (2007) addresses the situation in the Netherlands. However, it seems very likely that the situation in similar in Switzerland.

Planning

In order to specify how the renovation strategy should be implemented, detailed plans must be made. Obtaining precise measurements of the building is a crucial prerequisite to planning. This is because there is no guarantee that a building was constructed precisely according to the original plans or that the available plans are still up to date. Unfortunately, obtaining measurements is a tedious undertaking. In addition to architects measuring, construction companies and artisans too might have to go measuring in order to obtain the specific measures they need.

Application for a Construction Permit

Basically, any construction work that implements or changes permanent structures needs a construction permit. Minor construction work is typically exempt from having to apply for a construction permits. In particular, the painting of a façade generally does not require a construction permit—and hence it also does not require an energy certificate. Major renovations always need a construction permit. This means that major renovations have to comply with energy-related regulations (AWEL 2010). If, and only if, a building owner plans to conduct renovations considered to be non-minor, a full energy verification document must be provided to the authorities as part of the application of the construction permit. The authorities review the plans and documents that are typically submitted by the architect. Once the authorities find that the plans correspond to the legal requirements, the construction permit is given and construction work may proceed.

Informing Tenants

The time on which tenants are informed about impending construction work differs according to building owner. It probably also depends on whether the building will be renovated with the tenants living in it, or whether it will be renovated with tenants absent. Renovations that are conducted with the tenants occupying the apartment are often inefficient. However, building owners may continue to earn rent, although tenants can demand a reduction of their rental fee of about 20–50 %, due to the inconveniences involved with renovations. In contrast, renovations without the presence of tenants generally are more efficient, although it also means that building owners lose income from rental payments. In addition, it may prove costly and lengthy to evict all tenants.

Obtaining Offers from Construction Companies

The building owner (either personally or through an architect) has to take care of many details and take many complex decisions. While new construction work can

be given to a total contractor for a price previously agreed upon, in the renovation case total contractors are not common. In consequence, the building owner has to organize all the different specialists. This quickly means having to deal with dozens of different companies because the degree of specialization is high, and because many companies may be interested to offer their services.

Selection of Construction Companies

Based on the offers submitted by construction companies, building owners have to select the ones they actually want to use. Frequently, the lowest or nearly lowest price determines which company gets the contract. Thus, price competition is usually intense in the construction industry. Because of the inconveniences involved for construction companies and because of the rather small volume of renovation contracts compared to new building contracts, building managers usually cannot negotiate any discounts. And in fact, some companies are reluctant to take renovation contracts.

Construction Phase

Construction work in existing buildings is much more demanding than construction work for new buildings. In new constructions, a more efficient approach to construction can be followed. In contrast, in renovations unforeseen situations are very common. If buildings are renovated without a long-term plan, renovation work carried out in present can impede renovation work carried out in the future. Because precise measurements may be difficult or impossible to obtain a long time ahead, a lot of adjustments have to take place on the construction site rather than in the workshop of the company. While the final results may look just as fine as in the case of new constructions, the process of fitting prefabricated elements to an existing building is inefficient and error prone. Working conditions on construction sites, such as exposure to the weather, distance to supplies and the lack of spare-parts for something unexpectedly broken, favor a sloppy style of work.

Often, old buildings have installations now considered to be substandard, such as too few electrical or telecommunication sockets. Similarly, the installation of solar systems or ventilation systems is hampered by the absence of channels within the building. Refurbishing existing houses with ventilation channels, pipes or electrical wires is not only costly, it is also a quite complex task for planners as it tends to involve many different construction specialists.

Quality Control

Between the various steps of the construction process, quality control takes place. This means that a representative of the building owner (generally the architect) checks if the quality of the work corresponds to the planned specifications. Should

it not correspond to the plans made, then the building owner can demand that the construction company fix it.

Offering Apartments on the Market

If the tenants left before the renovation, new tenants have to be found. Therefore, towards the end of the construction phase, the apartments are advertised in local papers or on websites. When letting an apartment to a new tenant, building owners can set the rent as they see fit. Even when the tenants did not change due to renovation, the rent can be increased. This is because renovations generally include a value-enhancing component that the building owner may charge to the tenant. However, if the new rent is set too high, it might prove difficult to find tenants at all.

Handing over the Apartments to Tenants

Once construction has been completed, tenants can move into the apartment. Generally, caretakers, the building owner or a representative from the real-estate administration hand the keys to the tenants, show them the various installations and perhaps introduce neighbors.

During the process of handing over apartments to tenants, they sign a standard form which specifies what is included in the apartment and in what condition various elements are, such as walls, sanitary installations and appliances.

Dealing with Complaints from Tenants

Almost every construction project has some imperfections which are only realized by the tenants after they moved in. Upon discovery, they are obliged to inform the building owner about any deficiency. The building owner then has to make sure that the issue is resolved, either by initiating adjustments, or by demanding rework from construction companies if they are liable.

5.3 List of Actors

In the following, I provide a list of all the actors that are somehow involved with the problem situation. The list is divided into *actors in the market*, *actors in civil society* and *actors in the state*. I used results from my interviews and selected contributions in the literature to develop this list. In the systematic interviews I asked interviewees the following questions (translated from German, see electronic supplement):

> Of the actors that were involved with the renovation process, which ones had big influence on the energy efficiency of the renovation? How did they take influence? And what interests did they follow?

Several contributions in the literature analyze actors in the problem situation. I draw mostly on the following two: BFE (2004, p. 48–51) provide an analysis of the construction market that follows the value creation chain approach. They also provide an analysis of the interactions of actors representing the supply and the demand side of the market for energy-efficient constructions (BFE 2004, p. 62–65). Steger et al. (2002, p. 195–202) discuss the chances of a sustainable energy innovation strategy in the political process. Therefore, they focus mostly on what I call actors in the public sphere, such as voters, politicians and political parties, the administration, NGOs, interest groups, consumers, corporations, workers, labor unions, and scientists. I think that most of these groups are also relevant for the diffusion of energy-efficient renovations.

For each group of actors, I briefly state the interest it has in energy-efficiency and what kind of power it has to influence the energy-efficiency of a construction project or the stock of buildings as a whole.

5.3.1 Actors in the Market

Building Owners

Building owners hold a building as property and assume the costs, risks and benefits of owning a building. Ultimately, building owners are the ones who have the right to make final decisions related to their building. I therefore see them to have by far the most power to decide on the renovation process. An interviewee put it as follows: "The building owner is the one with the money and hence he is in charge." This basically also applies to the whole stock of buildings. Within the limits of the legal framework, building owners decide whether and how their building is made energy-efficient. Building owners' interest in energy efficiency depends on the rental price they get, construction costs and the evaluation of the technological quality of energy-efficient building designs. (See Sect. 5.4.1 for a detailed discussion of building owners.)

Tenants

Tenants pay a rent in order to use an apartment within a building for housing. Tenants' interest in energy-efficient housing space depends on the price for energy services, the rental price of energy-efficient housing relative to non-energy-efficient housing and their evaluation of the co-benefits of energy-efficient housing. On the level of the individual building, tenants generally have no influence on the renovation strategy chosen by the building owner. On the aggregate level, however, tenants heavily influence the configuration of the built environment. This is because building owners generally consider what tenants demand from buildings and hence aim to implement renovations according to the demands of the housing market. (See Sect. 5.4.2 for a detailed discussion of tenants.)

Architects

Architects are providers of professional know-how and planning competence in the domain of construction. Organizationally, they can be independent or affiliated with a construction company. They are responsible for the integration of various functional and aesthetic aspects, technical systems and economical considerations into a building design and a construction process. Generally, architects have no strong interest in energy-efficient building designs. While they might earn slightly more, energy-efficient construction is also more complex, which again increases their costs. However, specialization on energy-efficient building designs may provide some architects with the chance to strategically position themselves and earn reputation and other early-mover advantages (Groesser 2013). The power architects have to influence specific renovation projects varies with how much know-how the building owner has. The more know-how building owners have, the less influence architects have. (See Sect. 5.4.3 for a detailed discussion of architects.)

Engineers and Planners

Specialized engineers and planners plan specific aspects where architects lack detailed know-how. The larger and the more complex a renovation project is, the more important such specialists become. They usually plan domains such as statics, heating, water and ventilation installations. Because they have specific tasks and generally act within the limits set by building owners or architects, they have very little interest in and influence on the decision wether an energy-efficient building design is implemented or not. The notable exceptions are energy planners who can propose efficiency-enhancing measures. However, they too are usually only contacted after basic decisions were made and hence have only limited influence, should building owners not want energy-efficient renovations. In an indirect manner, engineers and planners however do have influence, as their know-how in domains relevant for the implementation of energy-efficient renovations is of crucial importance.

Construction Companies

The construction industry consists of a broad range of companies. There are companies with several thousand employees as well as companies with less then 10 employees. There is a big variance in what kind of services the different construction companies provide. Sometimes, construction companies implement specific structures, for example the walls and the floor, as agreed upon in a contract with the building owners. Sometimes construction companies take on the full responsibility for the execution of the architect's plans and bid specific tasks to subcontractors. In such a case, they are referred to as general contractors and essentially provide project management as a core service. Building owners generally only enter into contracts with construction companies that can demonstrate that they have the resources to fulfill the

contract. Construction companies generally have no or only very little influence on the planned energy-efficiency of a renovation project. They however have a (weak) interest in the diffusion of energy-efficient renovations, because energy-efficiency leads to slightly larger investments and hence larger revenues for construction companies.

Suppliers and Technology Developers

Building materials and the different components needed for energy-efficient building designs are developed and supplied to construction companies and installers by various manufacturers. Suppliers manufacturing materials that are directly related to energy-efficient building designs have a strong interest in the diffusion of energy-efficient renovations, as they directly profit from expanding market volumes. However, their power to affect the transformation of the stock of buildings is weak.

Installers

Installers are specialized construction companies that implement specific technologies such as heating or ventilation systems according to the plans provided by architects or planners. They have no power in influencing the building design chosen by building owners because they are contacted after decisions are made and planned. However, the broad diffusion of energy-efficient building designs is beneficial for those installers who install key technologies of energy-efficient building designs such as ventilation, because this increases the size of the market they are active in.

Banks

Banks give mortgages to building owners who do not have the means to finance construction or renovations themselves. Banks generally play an important role in financing the construction activities of non-professional building owners. In contrast, professional building owners who hold buildings as a form of investment generally need no finance from banks. Until some time ago, banks had no particular interest in energy-efficient building designs. However, banks have show recently interest in energy-efficient building designs. Some banks even started to give preferential mortgages to energy-efficient constructions. However, one of my interviewees put it as follows: "There are models where banks give a little cheaper credits… but to be frank… that is peanuts." As a very important provider of finance, banks potentially have a very big influence on renovation projects. However, as long as the economic viability and resale value of a renovation project remains intact, and as long as all the legal requirements are met, banks generally do not interfere with the specifics of the building designs.

Agencies Providing Subsidies

Between 2005 and 2009 a trust with the name 'climate cent' provided subsidies for renovations that enhance energy efficiency. Since 2010, a similar building program is run by the federal and cantonal governments. On the local level, communities and utilities may provide further subsidies for a wide range of measures (Stiftung Klimarappen 2009; EDK n.d.). Obviously, such agencies or programs have a high interest in the transformation of the stock of buildings. Although they have some influence, they are not nearly as influential as other actors.

Real-Estate Administrations

Real-estate administrations are typically responsible for routine administrative tasks, such as letting the flat, collecting the rent and dealing with minor maintenance issues, such as broken ovens. Usually, these companies are small, with less than 10 employees, although a few bigger administrations exist. They are under constant market pressure to reduce costs because building owners and tenants want to spend as little as possible for administration, and they will gladly move to an other company should that be significantly less expensive. Because they pass on the costs for maintenance to building owners and the costs for heating to tenants, they have no particular interest in energy-efficiency in buildings. Due to competitive pressures, they generally cannot afford in-house expertise beyond the administrative domain. Hence, they usually have no influence on what kind of renovations get implemented. As tenants and building owners are responsible for all costs, real-estate administrations are rather indifferent to energy-efficiency.

Caretakers of Buildings

Caretakers of residential multifamily buildings usually do this as a side-job and often have no vocational training for this job. The caretaker of a building may live in it as a tenant. Frequently this role is given to a retired person who receives a reduction on the rent in exchange for these services. In the case of privately owned multifamily buildings, the owner might live in his building and act as care-taker. In the initial stages of a renovation project, the caretaker usually is consulted and might show the building to the person charged with proposing a renovation project. However, regarding the planned energy-efficiency of major renovation projects, care takers usually have neither a specific interest in energy-efficiency nor do they have the power to substantially influence the building owner's decision.[2]

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[2] Care takers however have a substantial influence on the building's actual demand for energy resources, as their actions account for a substantial share of user behavior. As technology in buildings can be expected to become increasingly complex and sophisticated, it is unclear what this means for the effect user behavior has on the energy demand from energy-efficient buildings.

Suppliers of Heating Oil and Oil-Based Heating Systems

Suppliers of heating oil import and distribute heating fuels. They have very similar interests as the suppliers of oil-based heating systems. Both have no direct influence on whether an energy-efficient building design is implemented in a renovation or not. In an indirect manner, their public communications might influence the expectations of building owners and architects. Regarding their interest in energy-efficiency, they are in an ambivalent situation: On the operational level, they have no interest in anything that reduces the demand for heating oil, as this reduces their earnings. On a strategic level, however, they must adjust to increasing concerns about the environmental impact of oil-based fuels. Therefore, they promote the use of more efficient burners and energy-efficient building designs as contributions to the environment (see Erdölvereinigung 2010a). They label heating oil with a low content of sulfur and nitrogen as "eco-heating oil" and state that alternatives to fossil-based heating systems are not worthwhile (Erdölvereinigung 2010b). However, I conclude that suppliers of heating oil and oil-based heating systems do not directly affect the diffusion of energy-efficient building designs. However, by providing increasingly efficient systems[3] and by contributing to a positive image of heating oil, they indirectly contribute to the status quo.

Suppliers of Gas and Gas-Based Heating Systems

Suppliers of gas import and distribute gas. They have very similar interests as the suppliers of gas-based heating systems. As in the case of the oil interests (see above), they have no direct influence on the energy-efficiency implemented in a renovation. However, gas interests currently have a strong interest in energy-efficiency and the decarbonization of the heating system. Because gas emits less CO_2 per energy unit compared to heating oil, it is being promoted as a more environmentally friendly alternative.

Suppliers of Non-Fossil Heating Systems

Like the two actor groups discussed above, suppliers of alternative heating fuels have no direct influence on the diffusion of energy-efficient building designs in renovations. However, by providing heating systems with no or little greenhouse-gas emissions, they substantially contribute to the decarbonization of Switzerland's stock of buildings. Heating systems based on heat pumps, solar panels, wood combustion, and other systems complement energy-efficient buildings designs, as they too are

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[3] The provision of increasingly efficient heating systems is ambivalent from an environmental perspective. While more efficient oil-based heating systems promise to reduce the demand for primary energy, a rising efficiency rises the attractiveness of oil-based heating systems, thus supporting the widespread diffusion of such heating systems.

a solution to the problem situation. Therefore, the suppliers of non-fossil heating systems have a strong interest in the diffusion of energy-efficient building designs.

Energy Consultants

Energy consultants are specialists who can help building owners and architects to plan and evaluate measures that increase the energy efficiency of an existing building. However, it is not mandatory that building owners consult with an energy consultant before renovation. Yet the energy consultant, or an other specialist with similar qualifications, evaluates the energy-related aspects of the application for a construction permit. Energy consultants generally have a strong interest in energy-efficiency. However, beyond checking the building permit for compliance with energy regulations, they can only attempt to convince building owners. On a more general level, the installation of state-funded energy consultants is a policy instrument.

5.3.2 Civil Society Actors

Environmental Non Government Organizations (NGOs)

Environmental NGOs are associations that promote the vision of a sustainable development. As they participate in the public discourse and the political process, they educate the general public and create awareness. And they attempt to influence legislation. In order to do so, they mobilize citizens, use the media to put pressure on the political system, and use their often profound expertise to influence policy initiatives. Some of the big environmental NGOs in Switzerland contribute their own energy strategy to the political process. Specifically, Greenpeace Switzerland, the Swiss Energy Foundation (SES), the Swiss Association for Transport and the Environment (VCS) and the World Wide Fund For Nature Switzerland (WWF) collaboratively commissioned a report (Elipson AG 2006) which provides solutions and strategies how to achieve an energy system compatible with their goals. As energy-efficient renovations are nested within the wider political agenda of environmental NGOs, they have a high interest in the diffusion of energy-efficient renovations (WWF 2010; Greenpeace 2010; SES 2010). However, environmental NGOs generally have no direct influence on the renovation of specific buildings. Yet through their activities, they contribute to the accelerated diffusion of energy-efficient buildings in an indirect manner.

Professional Associations and Interest Groups

A wide range of professional associations and interest groups can be found in Switzerland. The association of tenants or the two associations of building owners (Hauseigentümerverein, Hausverein) are examples of interest groups with a wide

base. The Swiss Real-Estate Association (SVIT) or the building services association (suissetec) are examples of industry associations. Generally, such organizations charge membership fees and in exchange provide services to their members. They provide information and training, represent their members' collective interests in the political process and establish industry-wide norms and definitions of good practice. Regarding the diffusion of energy-efficient renovations, associations generally have an important role to play, as they are gatekeepers for their members. When they promote innovations, they can substantially contribute to diffusion of energy-efficient building designs, either by informing and advocating innovations, or by supporting members to adopt innovative technologies. They therefore have a moderate influence on the diffusion of energy-efficient buildings in renovations. The interest an association or interest group has in energy-efficient renovations depends on the specifics of the organization.

Association of Engineers and Architects (SIA)

The Swiss Association of Engineers and Architects (SIA) represents about 2,500 organizations with about 11,500 experts in the domains of construction, technology and environment (SIA n.d.). It is a professional association that has both a high influence and a strong interest in promoting the diffusion of energy-efficient buildings. As one of my interviewees told me: "The SIA certainly has an influence… it is basically [responsible for] the norms we have here in Switzerland… and therefore it obviously has an influence."

The Media

The media select and disseminate information to the greater public and in doing so provide a forum for public opinion. Several of my interviewees stated that the media create substantial pressure in support for energy-efficient renovations. The pressure arises from the communication of climate and energy as societal problem situations, and the communication of energy efficiency as a mitigation strategy to the problem. By giving voice to these issues, they substantially influence public opinion. To my observation, the media generally do not question the importance of energy-efficiency in buildings. Therefore, I think the media have a strong interest in energy efficiency. As the media are a crucial transmission mechanism between the realms of science, public opinion and politics, I think that they have a strong indirect influence. To claim that the media have a direct influence on the decision making processes of building owners seems exaggerated. However, information and awareness are an important aspect of building owners' decision making.

Political Parties

In Switzerland, political parties are private associations. Membership in one of Switzerland's major political parties is the most frequent road to becoming a member of parliament or a member of government on either the federal, cantonal or communal level. Political parties are the main link between Switzerland's pluralistic civil society and its institutional politics. Parties, respectively their members, can influence the diffusion of energy-efficient renovations by influencing public opinion and shaping legislation. Generally, Switzerland's parties agree on the importance of energy-efficient renovations, yet there might be differences as to how to support the diffusion process.

Scientists

Scientists in the fields of climate and energy research are the driving force behind the emergence of energy and climate as a societal problem situation. As they developed their research over the last three decades, the problematic nature of anthropogenic climate change became increasingly evident. Scientists generally have a high interest in energy-efficiency, which is perceived to provide a solution to the climate and energy crisis. Scientists calling for sufficiency strategies too find efficiency important. Scientists generally cannot directly influence the diffusion of energy-efficient renovations. However, as scientist develop strategy scenarios and recommendations, they set the boundaries of the (political) discourse on climate and energy policy. Therefore, I find that they have a lot of power to indirectly contribute to the diffusion of energy-efficient renovations.

5.3.3 Actors in the State

Voters

In Switzerland, the people are the sovereign of the state. Citizens express themselves generally through voting. Voters elect politicians and judges into office, decide on ballots and propose legislation. Trechsel and Sciarini (1998, 120) argue that popular opposition could intervene at any given moment into Switzerland's direct democratic system. In general, however, the voters do not constantly attempt to block the elites they voted for with direct legislation. Trechsel and Sciarini (1998) conclude that elites matter in Swiss politics as they exercise power in the decision making process.

Members of Parliaments

Members of parliament were elected by voters to represent their interests, as well as the interests of their parties and interest groups. They are generally informally expected to pursue policies that are roughly in line with the interests of the groups

they represent. Members of parliaments on the cantonal and the federal level appear to have some interests in energy-efficient renovations as a policy lever in the domain of energy and climate. At least, as long as it is done voluntarily and does not require the state to implement further instruments. Members of parliaments have substantial power to promote or impede the diffusion of energy-efficient renovations by way of legislation. However, they are not independent but must consider the interests of their constituencies in order to secure re-elections.

Public Administration

The public administration is the executive branch of the state. It contains both, the elected politician and the professional staff of the bureaucracy. Depending on the political orientation of its leadership, the public administration can play a very important role. Usually, it is the administration that proposes first drafts to legislation, as it has detailed know-how in its field. Sometimes, the public administration initiates and finances studies in the subject matter they are specialized with. And by implementing state-of-the-art renovations they may set an example that radiates into the whole construction industry. Dedicated and competent administrators can promote innovations and policy change which public administrations in other agencies or cantons may adopt. In the domain of energy-efficient buildings, the administrations of Zürich, Basel and Bern have often given decisive impulses towards energy-efficient construction. I therefore conclude that public administrations can significantly influence the diffusion of energy-efficient renovations. As the public administration's offices and agencies negotiate the implications of energy-efficient construction and build consensus, they have shown an increasing interest.

Construction Administration

Communal construction administrations are responsible for applying regulations and helping building owners comply with the law. They operate within a legal framework, which specifies the minimal requirements for specific cases. Beyond that, they basically do not have a particular interest in energy-efficiency. They also cannot influence the planned energy efficiency of a renovation project beyond the legal minimum requirements. Other than what is specified in the legal regulations, they basically do not have any particular interest in energy-efficiency in renovations. However, they can contribute by providing building owners and architects with information and by making them aware of the importance of energy issues.

Heritage Protection Agencies

Heritage protection agencies are charged with the task of protecting built structures of cultural significance. They can classify buildings as protected and prevent the owners

of such buildings from substantially changing such buildings. Energy-efficiency is not part of their task and hence they have no particular interest in it. For buildings under protection, these agencies have substantial power to prevent (but not encourage) energy-efficient building designs. For example, they can prohibit the application of a thick layer of thermal insulation to the façade of a protected building if it would change the appearance of the building.

5.4 Actors in the Simulation Model

Including all the groups of actors described above into the simulation model would yield a very complex model. And it is questionable, whether a lot of additional insight would be gained. Therefore, I will only include the most important actors explicitly into the model. From the domain of the market, these are *building owners*, *tenants* and *architects*. From the domain of civil society, I explicitly include two *advocacy coalitions*. The actions of several actors will be only implicitly included into the model. For example, construction companies, planners, technology developers and suppliers are the actors actually driving improvements in the technological quality of eeupgrading designs. However, I will only include the consequences of their actions.

Detailing all the actors in the public sphere who are involved in the policy fields of energy, climate and the built environment would be too complex. Hence, civil society actors are conceptualized as belonging to a coalition that either supports or rejects public policy interventions in support of energy-efficient renovations. In contrast, I will not model actors or advocacy coalitions in the state. Here too, I will restrict the model to include reactions of the state.

In the remainder of this section, I will briefly explain in what situation a specific actor is. I will then propose a typology to distinguish different subtypes of each actor group. And I will then model qualitatively how actors, respectively their decision making, change in response to changes in their environment. I use selected passages from my interviews to illustrate my analysis and ground it in the views of my interviewees.

5.4.1 Building Owners

5.4.1.1 The Situation Building Owners Are In

Motivations for Owning Buildings

There are several motivations for owning and renting multifamily buildings. In my opinion the most important one is that ownership of a rented building provides a stream of income. Owning and renting buildings is a way of making capital productive. One interviewee (responsible for investments into buildings at an insurance company) explained this as follows:

The reasons we exist is principally that we obtain a return on investment. We have a bench-mark which we must meet, because otherwise the funds are invested into other asset-classes. (…) The overarching goal is always finances, because we are evaluated against this.

An other interviewee (from a construction company) mirrored this view and provided further detail:

(…) a strategy of a pension fund, they of course say, we have to invest our money with a profit margin of 6 percent. And if we now say… we demand an energy target… and then there is only 5.5 percent profit… then we do not conform [to the strategy] with what we do with your money.... of course that is also an excuse… But there are few building owners who say I now only build Minergie or Minergie-P… also in renovations… (…) there are a few who say I only renovate with Minergie standard… but those are not necessarily the big ones.

In addition to the stream of income provided by monthly rent payments, gains in property values can be an important benefit of building ownership. An interviewee (project manager at a large construction company) points to real-estate speculation as an important aspect of building ownership and a potential barrier to energy efficiency in renovations:

What is also going on in the background, that are speculation objects… we are talking about buildings, about real-estate, and that is only speculation… and then we buy something, where we say keep it for two years, do a little cosmetics … make it fresh with some new painting and in two years it has to go for 15 % profit… and later, there is somebody in the chain who buys it and says 'great, now I have to do energetic renovations'.

However, while the financial aspects of building ownership are important to nearly all building owners, there are differences in the importance of profits. While the attainment of a given (high) profit-margin is a *conditio sine qua non* for some building owners, others are satisfied with rental payments which allow them to roughly break even. Such building owners are not strongly interested in profits beyond the costs of operating, maintaining and depreciating the building. Their motivation to own buildings lies more in the act of providing a service. Typically, these are building associations and agencies of various levels of the state who assume the responsibilities of ownership. One interviewee (a representative of the building associations in the City of Zürich) told me:

Building associations are oriented towards humans and society, rather than towards profits. The buildings are ours, we are not allowed to sell them… Therefore we have a long-term orientation. And then you act very differently. (…) Of course, we are also in a market, we provide products that are compatible with the market needs. But we are guided by societal considerations.

According to the same interviewee, these considerations materialize into clearly quantifiable outcomes:

The share of Minergie-certified buildings of building associations is at least double compared to the others. (…) Or, regarding solar panels, building associations own about 20 % [of apartments in the city of Zürich, MM], but they have about 60 % of solar panels.

Based on this, I propose to differentiate building owners into two general types: On the one hand, there are building owners who are primarily motivated by finances

and profits, and on the other hand there are building owners who are influenced by multiple criteria. Building owners oriented towards multiple criteria are not free from economic restrictions, yet they also consider issues beyond costs and profits in their decision making. These two categories account for behavioral differences, as I will argue below.

Levels of Professionalism

A second dimension by which building owners can be differentiated concerns the level of professional know-how a building owner has: On one end of the scale we find building owners who have professional know-how to manage buildings and construction projects. Typically these are organizations such as insurances, trust funds, larger building associations and governmental building owners who hold a large amount of buildings that allows them to support a professional infrastructure. They usually have a long-term strategy for their buildings, in which they detail the standard they offer, where they want to own buildings and what kind of buildings they want to own. The following statement is from an interviewee who is responsible for investments into buildings at an insurance company. It nicely illustrates how many steps and issues are considered by professional building owners when they evaluate whether they should renovate a building or rather not.

> In a first step (…) we make a discounted cash flow calculation, based on the costs generated by our tool [a software tool for evaluating buildings, MM]. And when we go into the meeting, then there are also all the market data. (…) So when we sit the first time together, then we know what our average rent is, what the average rent in the near surrounding is… we know… because the real-estate administration is present at this meeting… we also know what happens in the near surrounding, there are a lot of factors which need to be considered. (…) there is a lot of additional knowledge and know-how, that one can only have when one has the corresponding people in-house. Because you can also not easily source that externally, that is all too complicated… and it takes too long… and at that meeting we decide what scenarios we want to develop.

Another indicator of professionalism is the way how building owners deal with trade-offs and what the same interviewee quoted above called "soft factors":

> We have a building on a very good location. (…) We could probably without problems install a loft in the attic, for which we can ask 7000 Swiss Francs [monthly rent, MM], it has views of the lake and all. And then the discussions started… well… do we really want to have a building within which we basically have a two-class-society....? Or do we not want that…? (…) We have such discussions … and these are all … soft factors … Beyond a certain level, one cannot argue anymore with figures, discounted cash-flow … and we hold such discussions.

On the other hand, there are building owners who lack professional know-how, and in consequence experience various difficulties. An interviewee, who is an architect, provided the following example of the inefficiencies created when different construction steps are not coordinated over time:

> There was the case of a small building association that had a few buildings… about 30 buildings. And they constantly… I would not say without a concept, that might be a bit hard, but… without long-term plan they always did a little bit of renovation… once the windows… once the kitchens… wow, new kitchens… but that the pipings behind the kitchen were rusting… that one would have to tear out the kitchens and replace the pipings… and they are now in a situation where they had to go to one of the big building associations and say, hey, take us over or else we are ruined.

Due to the lack of long-term planning, a series of non-aligned dependencies arises. These are costly, as for example a recently installed new kitchen needs to be de-installed in order to access the rusty pipings.

Importance of Energy-Efficiency

Due to the fact that the tenants pay for heating costs, the building owner has no direct financial incentive to improve the energy-efficiency of his or her building. However, on a more indirect level, several incentives exist also for building owners. One interviewee (responsible for investments into buildings at an insurance company) gave attention to the fact that energy-efficiency acts as an insurance against higher energy prices in the future:

> Well, if one does not want to have unrented apartments … because in the future buildings which have bad energy-efficiency will be… in the extreme case very cheap… because the rent with the side costs will be more expensive, the more energy costs become expensive or apartments will be unrented. And if one doesn't want this… then there is no way around… exactly because the lifecycle is not 10 years but 80 or 100 years… It is actually quite evident that one does this already today, so that this does not happen in the future.

According to the following statement from an interviewee at an architecture company, a potentially higher resale value of a building with certified energy efficiency may be a further reason for implementing energy-efficient renovations:

> The building owner has other interests… [other than energy-efficiency, MM] for him it is an added value when he sells the buildings if he has Minergie standard… a building simply has more value.. On the other hand when renting it is… I say there are tenants.... you can count them on one hand.... who are willing to pay five or 10 percent more rent for the Minergie standard… that's how much this costs…

In the perspective of that interviewee, generally only a small share of tenants have a willingness to pay for the comforts associated with energy-efficient building designs. Beyond financial issues, some building owners see energy-efficient building designs as an aspect of their business strategy. One interviewee (responsible for investments into buildings at an insurance company) explicitly mentions that they perceive energy-efficient housing to constitute a market advantage:

> In the short term, we offer something that others do not have.. market advantage. And in the long run, the building keeps its value, because it will continue to have acceptable rental prices.

However, the use of cost-benefit analysis to decide on the best renovation strategy may not be the most widespread approach. As the following statement from an interviewee (responsible for investments into buildings at an insurance company) illustrates, building owners often seem to focus on the cost side of their investments and perhaps give less weight to the fact that in renovations they implement attributes from which tenants derive utility and hence have a willingness to pay for.

> I find this very dangerous, but most discussions go in this direction, that one always only looks at the one side, the costs. But it is always both… the product and what the market is willing to pay for the product… that is decisive.

Attitudes Towards Technology

At the most basic level, building owners provide a service and expect financial compensation. As the following statement of an architect managing the buildings at an insurance company illustrates, they generally aim to do this with as little inconveniences as possible.

> We provide a service, we rent apartments. And our tenants do not want to have problems with their apartment. If it is cold and the floor heating starts only four hours later, then you have the phone calls…

The statement explains why building owners are rather risk-averse regarding technological innovations. If technological innovations are not yet completely mature, there is the risk of unsatisfactory performance. Tenants who are confronted with unsatisfactory performance of technologies, such as noise and drafts from the ventilation systems or mold due to humidity problems, may file complaints. This may lead to inconveniences and expenses, and tenants may demand reductions of their rent as long as the problematic situation prevails. Such costs and hassles ultimately reduce the building owner's profits. Such partially non-material costs and an aversion towards risk could explain why building owners are reluctant to adopt innovations and prefer well-proven technology.

5.4.1.2 Typology of Building Owners

In the literature, there are several categorizations of building owners. Van Wazemael (2005, 89) differentiates between commercial building owners (insurances, real-estate trusts, private persons, etc.) and those who are oriented to the greater good (housing associations, governments). POLIS (2007, 25) identifies four categories of building owners: private persons, public administrations, building associations and institutional building owners. Finally, Switzerland's federal office for statistics provides ownership data based on the more fine-grained categorization scheme seen in Table 5.2.

Four Types of Building Owners

I use a typology that is different from the categorization schemes found in the literature. It is based on differentiations over motivation and competence, and it captures behavioral differences rather than differences in legal status. The drawback of developing an own typology is that there is no statistical data readily available. Therefore, the share of buildings managed by each ownership type needs to be estimated based on the available information. Specifically, I obtain my categorization scheme by intersecting the two dimensions (professional versus non-professional and profit-oriented versus multicriteria-oriented) identified above. This yields a typology consisting of four types of building owners who can be further described as follows:

- **P-BO-K** are the profit-oriented building owners with professional know-how. They are motivated by the goal of obtaining a high return on investment. Due to their professionalism, they are not influenced by the opinions of architects and planners and they perceive the state of technology with a delay of only 2 years.
- **P-BO-N** are the profit-oriented building owners without professional know-how. They are motivated by the goal of obtaining a high return on investment. Due to their lack of professionalism, they are strongly influenced by architects and planners and they perceive the state of technology with a delay of 5 years.
- **MC-BO-K** are the multi-criteria oriented owners with professional know-how. They are motivated by the goal of providing housing at moderate rent. Due to their professionalism, they are not influenced by the opinions of architects and planners and they perceive the state of technology with a delay of only 2 years.
- **MC-BO-N** are the multi-criteria oriented owners with no professional know-how. They are motivated by the goal of providing housing at moderate rent. Due to their lack of professionalism, they are strongly influenced by architects and planners and they perceive the state of technology with a delay of 5 years.

In order to estimate the share of buildings owned by each building owner type, I first provide an assumption for the shares of building managed by building owners with and without professional know-how. Thereafter, I provide an assumption regarding the share of buildings owned by profit- and multicriteria-oriented building owners. Based on that, the share of buildings managed by each building owner type can be calculated.

Approximating the Share of Buildings Owned by Building Owners with
Professional Know-How

Econcept and CEPE (2005) find that about 25 % of building owners have professional training in the construction sector (architects, planners, artisans, etc.). More than a third of building owners have a professional background in administration, frequently with a direct link to housing (building administrators, certificate in real-estate SVIT). On the other hand, more than 50 % of building owners do not have any professional or work-related links to the building sector. Econcept and CEPE (2005) conclude

Table 5.2 Number of residential multifamily buildings owned by type of ownership

Ownership category	Buildings	Percent
Private persons	162,042	71.13
Building associations (members)	12,122	5.32
Other building associations	3,706	1.63
Real-estate fund	2,686	1.18
Other real-estate companies	7,159	3.14
Construction company	1,769	0.78
Insurance company	7,011	3.08
Pension fund	13,606	5.97
Other trust	2,726	1.20
Club	614	0.27
Other society/association	9,449	4.15
Community, canton, federal government	4,583	2.01
Other types of owner	326	0.14

Source BFS (n.d.) based on data from the federal census of the year 2000 and own calculations
(percent)

that the situation regarding construction and renovation can be best characterized
as a semi-professional market environment. Since professional building owners are
likely to manage more buildings than non-professional building owners, the share of
buildings managed by professionals must be somewhat higher than 25 % (Econcept
and CEPE 2005, 74p.).

Table 5.2 shows the number of residential, multifamily buildings owned by dif-
ferent types of owners in the year 2000.

The fact that private persons own about 71 % of buildings is a strong indicator that
a substantial majority of building owners must be considered to be non-professional
building owners. While there certainly are private building owners with professional
know-how, there also certainly are non-professional building owners among the hous-
ing associations and the minor categories of building owners. Hence, I propose the
following distribution: 30 % of buildings are assumed to be owned by building own-
ers with professional know-how; 70 % of buildings are assumed to be owned by
building owners without professional know-how.

Share of Buildings Owned by Profit-Oriented Building Owners

Estimating the distribution of buildings across the second dimension of the typology,
ownership motivation, is less straightforward. While the persons I interviewed all
were professionals in the real-estate and construction sector, the picture they painted
regarding private building owners was rather clear: Private building owners in general
are primarily motivated by financial aspects. A representative from an association of
tenants formulated it as follows:

Private owners, in contrast to institutional building owners, look at buildings like at bonds or stock shares. They extract as much as possible and they do not say 'I have to set a fund aside for later reinvestments' … It's like a company that gives all the profits to its stockholders. (…) Actually we often observe that revenues from a building were maximized, with relatively little renovation and maintenance. After 40 years the building is thrown away like an empty shell and brought to the market. The new owner than has to catch up with all the delayed maintenance… And the new building owner wants to recover his investment… This then often leads to a change of the tenants.

An other interviewee (architect in an architecture company) made a similar statement regarding the lack of reserves private building owners generally have:

(…) There is a big difference how one deals with reserves between private and professional building owners… respectively between professional and non-professional building owners… those who do this well are often building associations, who are financially very intact. Then there are the public building owners who can… skim it from somewhere [This refers to taxes, MM]. And then there are the private building owners who neither have reserves nor anything else… or who are burdened with mortgages.

The previous two statements support the conclusion that private building owners in general should rather be considered to be profit-oriented. It also illustrates that they may have difficulties financing renovations due to a lack of reserves. And as no or little reserves for investment into renovations are available, it can be speculated that building owners may be inclined to make decisions on the basis of investment costs rather than on the basis of a cost-benefit analysis. Regarding institutional building owners, an other interviewee from an architecture company finds that the public building owners give a little less importance to economic aspects. I perceive this as an indication that public building owners in general should be considered to be multi-criteria oriented.

There is a difference between the different types of institutional building owners. Public building owners act as a positive example… it plays that role better. The economic aspects are a little less important

Another interviewee from an architecture company remarks that building associations, due to the long time horizons over which they own their buildings, are financially very well intact:

(…) there are the public building owners… And the building associations… who have a longterm interest to maintain such a building but nevertheless are privately financed. They have to ensure that the money they spend is recuperated. (…) I would say that for private building owners the costs are the central issue… (…) and with public building owners costs are an issue among others.

This, together with the statement on the building associations' societal orientation provided on page 8, leads me to conclude that also building associations should generally be considered to be oriented towards multiple criteria.

Based on the insights from the interviews and the data provided in Table 5.2, I conclude that a majority of building owners, in particular the private building owners and the non-public institutional building owners should be considered to be profit-oriented. I propose to set the share of buildings managed by profit-oriented building

owners to 85 %, with the remaining 15 % being managed by multicriteria-oriented building owners.

Share of Buildings Owned by Building Owner Type

Based on the assumed distributions of buildings over the two dimensions (motivation, professionalism), the share of buildings owned by a specific type of building owner can be calculated by multiplying the corresponding share for each dimension (see Table 5.3 for the resulting distribution).

Summary

Table 5.4 summarizes the important characteristics of the four building owner types. These characteristics will have to be represented in the large simulation model.

5.4.1.3 Explaining Changes in the Attractiveness of Renovation Strategies for Building Owners

Including all the variables that influence building owners decision making would be unnecessarily extensive. I rather assume that the majority of influences that could be found in survey research can be treated as constant over time. This assumption allows to include only those variables into building owners' decision-functions which change over time. Figure 5.1 qualitatively shows how changes in the attractiveness of each renovation strategy are explained.

Table 5.3 Share of buildings owned by each type of building owners

	Professional	Non-professional	(Total)
Profit-oriented	0.255	0.595	(0.85)
Multicriteria-oriented	0.045	0.105	(0.15)
(Total)	(0.3)	(0.7)	

Table 5.4 Summary of characteristics of building owners

Issue	Actor			
	P-BO-K	P-BO-N	MC-BO-K	MC-BO-N
Financial considerations	Very important	Very important	Important	Important
Influence of architect	Low	Medium	Low	Medium
Perception delay	1 year	5 years	1 year	5 years
Preference for EE	Weak	Weak	Medium	Medium
Share of buildings owned	0.255	0.595	0.045	0.105
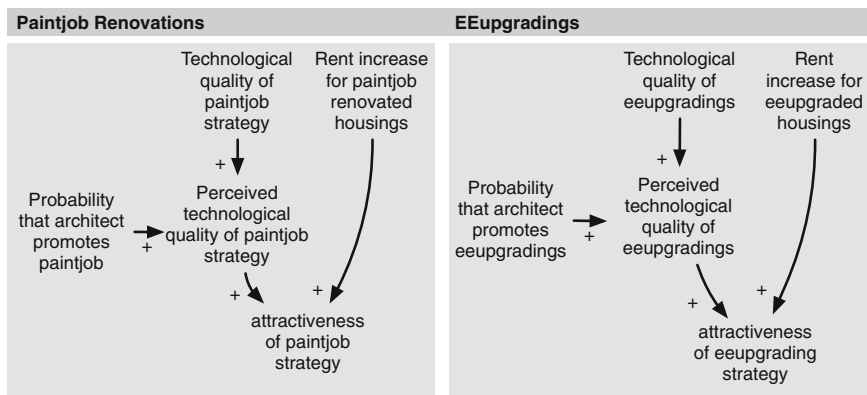
Fig. 5.1 Influences on the attractiveness of renovation strategies for building owners

The attractiveness of both renovation strategies is affected by technology, finances and the opinion of the architect. As the TECHNOLOGICAL QUALITY […] rises, the PERCEIVED TECHNOLOGICAL QUALITY […] also rises, although with a delay. This in turn increases the ATTRACTIVENESS OF […] STRATEGY. However, the PERCEIVED TECHNOLOGICAL QUALITY […] is also positively affected by a rising PROBABILITY THAT ARCHITECT PROMOTES […] the corresponding renovation strategy. The bigger the RENT INCREASE FOR […] HOUSINGS AFTER RENOVATION is, the more attractive the corresponding strategy is.

5.4.2 Tenants

5.4.2.1 The Situation Tenants Are In

Function of the Home

For tenants, rented apartments are first of all their home. As such, their function is much more than just the provision of shelter. Thiemann (2006) lists several functions the home has: First, it provides spatial order, because it differentiates space into a center from which action emanates and an environment from which one returns to the center. Second, the home provides temporal order, because it provides a continuity of things and because it allows for cyclical, every-day routines. Third, it provides social and ideal order. The temporal and spatial layout of the home structures action and habit, such as conversation, eating or sleeping. For children the home is the first place of learning and hence a place of enculturation. Finally, the home is an expression as well as a provider of identity.

Importance of Energy Efficiency

From the perspective of tenants, housings should be seen primarily as the center of their life-worlds rather than an object of climate and energy policy. Energy issues are of minor importance as long as energy services, such as heating or lighting, are provided at an affordable cost. In the interviews, it became clear that the energy-efficiency of rented housing is a non-issue for tenants—at least in the perception of my interviewees. (Although I did not interview tenants, observational evidence leads me to support this perception). The following statements illustrate this (the first quote is from an architect managing the buildings at an insurance company, the second quote is from a representative of a communal real-estate administration and the third quote is from an architect).

> Tenants have no big demand [for energy-efficiency, MM], as I find. Perhaps there is a demand that we renovate in a normal rhythm… (…) Tenants are more interested what kitchen they get, or what bath room.

> Many tenants don't think about what energy-efficiency means. They just want to live as cheap and fast as possible… actually all other criteria are not important.

> The average tenant… has one target and that is a low rental price. And if a family with five children, two grown-ups plus grandmother and about 10 relatives live in a three-room apartment… they have very different issues other than energy saving… ok? When you get there, than you have to clear the fog … a large share of the population only wants to spend the minimum for living space. And then there is an upper segment, where this becomes an issue… but for the tenants this is a luxury in my opinion… saying it a bit exaggerating, it is a luxury for those that can afford to live in an energy-saving building…

These statements support the perception that energy use is of minor relevance for tenants and that energy-efficiency mostly is relevant for the upper tier or luxury housing. However, while energy-efficiency might not be perceived to be an important element of lower-tier housing, building owners do have room to maneuver. The following quote from a member of a housing association's construction commission indicates that there might be a discrepancy between tenant's verbally stated preferences and their actual behavior on the housing market:

> Perhaps if we had asked the people 'do you want energy-efficient renovations, it costs a bit more…' they would not have said yes… But I think there it needs a … because who is willing to pay more, just like this…? But once the apartments are on the market, they are willing to pay more.

In this statement, the omission after 'there it needs a' is intriguing. I interpret this to mean that the interviewee implies that building owners need to lead tenants towards accepting energy efficiency. When given a choice, tenants might object to paying more for something which they do not know and value yet. However, when the attribute energy-efficiency is presented as part of an otherwise attractive bundle, which can only be accepted or rejected as a whole, then tenants might be willing to accept a mark-up for energy-efficiency.

Financial Aspects of Energy-Efficient Housing

It is not entirely clear how tenants perceive financial aspects of energy-efficient housings. A representative of real-estate administrations is convinced that energy-efficient housing yield a financial benefit:

> Energy-efficiency is clearly value-enhancing. … Eventually the tenant feels this in his pocket, in the reduced side costs… (…).

Yet an other interviewee, who is an architect, argued that energy-efficiency does not yield any substantial financial yield:

> The curse is that the tenants… to be honest, the tenant has no interest … the tenant is basically… when he has an apartment where he feels comfortable… where he has a fair rental price… to be honest I have to say he does not care at all if there are 60 or 120 millimeters of insulation… he feels well… (…) The corresponding reduction of the side costs is in the realm of peanuts… isn't it? In addition, other side costs increase because of all the technical installations… (…) the energy savings are often consumed by technical maintenance and such… and it even might get more expensive… (…) We used to argue that the side costs would be reduced… we really did save 30 or 40 percent… but today where everything gets more expensive…

According to this statement, it is questionable whether energy-efficient building designs really lead to substantially reduced side costs for tenants. The main argument against this is that while the energy component of heating costs indeed is reduced, the total side costs remain largely unaltered. After all, side costs also include the cost for installation and maintenance. As technology gets more complex, these costs rise. However, an other architect sees the effect of energy-efficiency on the rental cost somewhat more skeptical:

> When you have a low income, then you can afford only cheap living space… The one who offers cheap living space cannot invest, because then he has no tenants anymore… because the affluent tenants… you do not have them in some slum neighborhood out there… you have them in good neighborhoods… and it is rather difficult to change that… (…) We do a lot of renovations in welfare housing… These people have other sorrows… Can we afford the entrance fee for the swimming pool in summer…? Or can we not…? And if then the building owner comes and says, 'if you pay 40 francs more rent, but in return you save in thirty years, once the energy price is up, you save such and such....'.

This statement addresses difficulties encountered by building owners who provide housing for the low-income tier. Describing neighborhoods with low-income housing in Switzerland as 'slum' seems somewhat exaggerated to me. Nevertheless, this wording may indicate that some neighborhoods (typically found in the outer rings of the agglomerations) have substantial socio-economic problems. The relevant underlying problem is that cheap housing often is cheap because it is unattractive. Otherwise, building owners could set rents higher without risking long periods of vacancy. This means that for generally unattractive housings, there is an upper limit for the rental price. That upper limit constrains the building owners selection of renovation strategies, as generally only investments are done which can be recovered from the stream of rental payments.

Yet there is also the case where tenants actually value energy-efficiency. Talking about an award-winning recent renovation project, a representative of a building association summarized the inhabitant's attitude as follows:

> The tenants there, they find it top that the building has the Minergie standard and that such a good renovation was made. The awards the building won interested the tenants. For them that is also a gain in prestige… I think they would be willing to pay even more for something like that.

This illustrates that some tenants indeed have a willingness to pay for the benefits and co-benefits of energy-efficient housings.

Non-Financial Aspects of Energy-Efficient Housing

In the non-financial domain, the benefits of energy-efficient housing were much less contested among the interviewees. With the following statement, an architect points to the increased comfort of energy-efficient housings and their reduced level of external noises:

> The tenants certainly have an effect… in the domain of comfort… or also with noise… it is not just energy… noise is also an issue…

Such increases in comfort are typically also stressed by advocates of the Minergie standards. Now, after roughly a decade of promotion by the Minergie association, energy-efficient building designs have achieved general acceptance. Nevertheless, some issues with specific technologies remain, with ventilation systems being the prime example. While ventilation systems with heat recuperation are important elements of energy-efficient building designs, several interview partners expressed skepticism towards such systems or reported past difficulties. The first of the following two statements was made by a representative of a tenants association, the second was made by an architect:

> Ventilation systems are often an object of conflict. Particularly in renovated buildings, they are installed unprofessionally… which then leads to noise emissions or unpleasant drafts… But there is also a subliminal rejection… The idea of being in a closed building where the windows cannot be opened is claustrophobic for many people.

> Well… what I can say is that … each of these ventilations where I was involved… there always were complaints… Often unpleasant odors were an issue… drafts… one has to see something very clearly… if the tenant finds something then it is the ventilation… everything else… is unimportant.

These two statements raise the issue of how competent those planning and installing the ventilation systems are. Apparently, retrofitting a building with a ventilation system so that tenants are satisfied still poses a difficulty for many planners and installers. Yet as experience increases, ventilations can be expected to become unproblematic in the future. However, rejection of ventilation systems might be both, a cause and a consequence of non-mature technology. An architect working at a municipal agency provided the following anecdote:

> There are tenants, who as a matter of principle tape over the ventilations… we try hard to calibrate the thing, so that it works for a unit and the identical units above it. We exactly measure the quantities of air… but as soon as we are gone it is taped over and the tenants above or below have more air… they then ask, 'why do I have a draft…?'

Eventually, it turns out that the difficulties associated with ventilation systems might be a consequence of relying on central ventilation systems. In the following statement, a representative of building associations points to the benefits of non-centralized ventilation systems:

> Ventilation systems are a very good thing. Where we can, we now install ventilation systems [in renovations, MM]. Not because of energy-related constructions, but rather because of humidity and because of the improved indoor climate. (…) The central ventilation systems have indeed disadvantages. But the prejudice against ventilation systems corresponds to the state of technology 10 or 15 years ago. The non-centralized ventilation systems used today are very different. But people still think that in energy-efficient buildings you can't open the windows to hear the birds sing.

In this statement, and in some of the statements above, a wrong, yet widespread image is addressed. In fact, there is no reason why energy-efficient buildings should be built without windows that can be opened. This discussion exemplarily shows that even among professionals in the construction sector, distinctly different opinions prevail. It also shows that there is a substantial delay between the time when a technology is commercially available and the time a majority of actors in the value creation chain can adequately deploy such technology.

Influence of Tenants

None of the interviewees agreed with the idea that tenants had a direct influence on the level of energy-efficiency implemented. One building owner stated this very clearly:

> The tenant gets [what the building owner decides, MM]. The tenant does not decide.

Even in housing associations it is generally not the tenants of a building undergoing renovation who make the decisions. Often, all the members of an association might have some influence in the general approach the association takes to aging buildings. Yet in specific construction projects, often a committee with the appropriate know-how is charged with overseeing construction according to the general strategy of the association. However, on the aggregate level, the tenants influence the stock of building by way of the housing market.

5.4.2.2 Typology of Tenants

In the preceding subsection, differences among tenants became evident. Most differences concerned differences regarding tenants' income and willingness to pay for

housing. In general, low-income tenants were described as having a low willingness or capability to pay for energy-efficient housing. I interpret this to mean that tenants with a low income are more sensitive to the rental price than tenants with a higher income. In the following, I propose a typology consisting of three distinct types of tenants.

- Tenants of the type $\mathbf{T}_{costmin}$ behave as cost-minimizers. This means that the rental price is the most important criterion influencing the decision making. This type of tenant searches low-cost housing and hardly gives any consideration to amenities or sustainability considerations.
- Tenants of the type $\mathbf{T}_{evaluate}$ behave evaluating. This means they consider both, the rental price as well as attributes relating to comfort. Sustainability considerations, however, play only a minor role.
- Tenants of the type $\mathbf{T}_{benefitmax}$ behave as benefit maximizers. This means that the rental price is not particularly important, yet comfort aspects are very important for them. Sustainability considerations per se play only a minor role.

5.4.2.3 Explaining Changes in the Attractiveness of Housing Types for Tenants

Tenants can choose two different housing types. These are *paintjob housing* and *eeupgraded housing*. However, I do not model tenants' decision making. In order to do that, I would have to include a large number of variables. Econometric models, with parameters estimated over data representing tenants' choices, could be used to identify and quantify such variables. Instead, I omit all variables that I assume to be static over time. Furthermore, I focus only on such variables that I consider to explain changes in the attractiveness of a housing type *relative to* the other housing type.

Figure 5.2 shows a causal diagram of the influences which explain changes in the attractiveness of paintjob (left) and eeupgrading (right) housing. I assume that tenants base their decision on the EVALUATION OF […] TECHNOLOGY, on the YEARLY COST
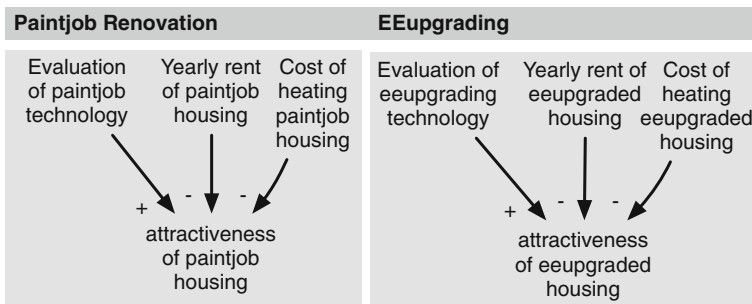
Fig. 5.2 Decision-function of tenants

OF […] HOUSING and the COST OF HEATING […]. The better the EVALUATION OF […] TECHNOLOGY is evaluated to be, the more attractive the corresponding housing design is. In contrast, the attractiveness of a housing design is decreased when the COST OF HEATING […] and the YEARLY RENT […] of a housing type rises.

5.4.3 Architects

5.4.3.1 The Situation Architects Are In

Role of the Architect

Architects are highly trained professionals who combine technology, economics and aesthetics in order to design and implement built structures. At the heart of the profession is its ability to integrate often conflicting issues. In order to actually implement construction projects under various constraints, architects must lead and collaborate with a broad range of construction specialists. Asked whether architecture is predominantly concerned with aesthetics, an architect among the interviewees strongly disagreed:

> Architecture is obviously never… I would never reduce it to aesthetics. Never… I wouldn't dream that up. (…) When we talk of architecture… then we mean it very broad… and that is not just my position… that is… the understanding of the profession that is shared by many. (…) there are very few cases that contain only aesthetic tasks.

Implications of Energy-Efficient Building Designs

Energy-efficient building designs in renovations have implications for architects. One architect finds that the emergence of energy-efficient building designs limits the range of possibilities architects have when planning a specific project:

> For us architects extremely much has changed through the whole discussions on Minergie… energy… The conditions got much more complex and we can do much less… a lot is now standardized. Before this, one could build much more freely… today… the requirements to avoid heath-bridges are of course… huge constraints.

The implementation of an energy-efficient building design requires that larger sums be invested. As architects frequently earn a fixed percentage of the construction costs (BFE 2004, 69), they would actually earn slightly more by implementing energy-efficient building designs. Yet the increase in complexity demands more effort on behalf of the architect. This is particularly true the first few times an architect implements energy-efficient building designs in renovations (BFE 2004, 69). This is because substantial learning must take place until an architect can efficiently plan an energy-efficient design for an existing building.

Interaction with Building Owners

BFE (2004, 69) argues that architects act as agents of the building owners. As such, they however do not completely represent the preferences of the building owners. Instead they are also guided by their own preferences, an issue known as principal-agent problem. I think this argument needs to be differentiated, depending on the level of professional know-how the building owner has. When dealing with professional building owners, architects should be considered to have only little influence on the level of energy-efficiency implemented, as the following two statements illustrate. The first is from a representative of professional building owners, the second from a representative of an association of real-estate administrations:

> Architects basically have no influence, because we specify these things. We demand that the Minergie label be acquired, and then all is clear.

> The big institutional building owners have directives where they state, 'that is for us state of the art'. And in renovations, they try to achieve that standard.

This means that in the simulation model, architects should not influence the decision making of building owners with professional know-how. However, for building owners with no professional know-how, architects should influence the decision making. The representative of an association of real-estate administrations quoted above continued his statement as follows:

> It depends whom do I have giving me advice, particularly it depends on the architect. What kind of architect do I choose? And what importance does he give to this topic of energy-efficiency…? There it is crucial to choose an architect who also has experience and references… who shows that he has initiative and does not just do what the client wants.

This statement provides some justification for seeing architects as shaping the preferences of building owners without professional know-how. Also the next statement, from a representative of a housing association supports this.

> The architect impressed us very much with his presentation, where he calculated with what oil price we would recover our investment through [lower, MM] side costs… This was impressive, because it became evident that it did not need a very big rise of the oil price.

In my view, the interesting issue here is how the situation seems to have been framed by the architect. Apparently, with the energy prices of today, the cost of investing into energy-efficiency cannot be completely recovered. Yet, by framing energy-efficiency in a positive way, its attractiveness is increased.

5.4.3.2 Typology of Architects

In the literature, BFE (2004, 69p.) propose a typology of architects that is built upon three possible reactions towards energy-efficiency. Architects can either actively discourage it, they can provide energy-efficient solutions upon request and they can actively promote it. In the following, I further simplify that typology, by assuming that architects belong to one of the following two categories:

- Architects of the type **indifferent** do not actively recommend building owners to implement energy-efficient building designs. This may be because they are opposed, indifferent or unaware of energy-efficient building designs in renovations.
- Architects of the type **promoting** actively promote energy-efficient building designs to building owners contemplating renovation.

5.4.3.3　Explaining Changes in the Attractiveness of Renovation Strategies for Architects

The typology of architects introduced above describes the two states architects can be in. Initially, the large majority of architects do not actively promote energy-efficient building designs. However, over time architects can change their state. Figure 5.3 shows a causal diagram of how I explain changes in the NUMBER OF ARCHITECTS WHO ACTIVELY SUPPORT ENERGY- EFFICIENT BUILDING DESIGNS. Specifically, as the TECHNOLOGICAL QUALITY […] rises, so does the TECHNOLOGICAL QUALITY […] rise. Architects do not perceive the state of technology at its current state, but rather with a […] PERCEPTION DELAY. However, as the TECHNOLOGICAL QUALITY […] AS PERCEIVED BY ARCHITECTS rises, so does the NUMBER OF ARCHITECTS […].

Meier (2007, 5) finds that in the last years the know-how of practitioners in the construction sector regarding energy efficiency and energy systems based on renewables has significantly increased. However, he finds that the large efficiency potentials can only be activated with substantial effort in the training of practitioners. This may be interpreted to mean that the NUMBER OF ARCHITECTS WHO ACTIVELY SUPPORT […] has been increasing in recent years, but has not reached a maximum value yet.

5.4.4 Advocacy Coalitions

5.4.4.1　Theoretical Foundation: Policy Change

In the following, I address the question why policy change occurs in Switzerland and how it can be explained. As a first step, I propose to examine a rather reductionist
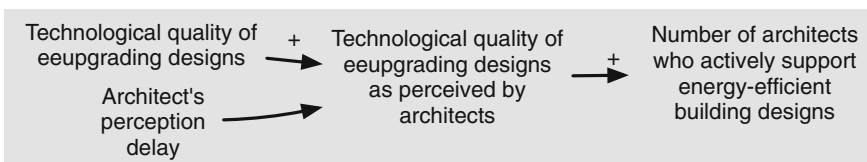
Fig. 5.3 Modeling changes in the attractiveness of renovation strategies for architects

input-output model of the functioning of the political system, which I nevertheless consider to be very valuable. Easton (1957) describes the political system as a black box, which takes inputs, such as demands and support, and transforms them into outputs, such as decisions or policies. These outputs feed back and affect the level of support received for the political system. Demands originate either from within the political system itself or from its environment (Easton 1957, 387p.) Consequently, policy change must involve at least one change. This change can be in the demands made by political actors to the political system, it can be a change in the inner structure of the political system or it can be a change in the way citizens and voters give support to the political system. In this sense, I define the political system to contain the state institutions and the civil society actors interacting with it.

Crude input-output models of the political system are useful for a fundamental understanding of the policy process. However, for the purpose of this study, they do not provide a sufficiently detailed explanation of how policy change occurs. This is because they entail a very aggregated macro-perspective. And they do not elaborate the mechanisms which actually cause change. Therefore, I propose to briefly review theories of the policy process given in Sabatier (2007) and then select one of them as a framework. These frameworks attempt to explain policy change over a long period of time in a policy subsystem or domain. The three frameworks in question are *policy network analysis*, the *punctuated equilibrium framework* and the *advocacy coalition framework*. Later, I will draw mostly on the advocacy coalition framework in order to describe the civil society actors presented in Sect. 5.3.2 as members of two distinct advocacy coalitions.

In policy network analysis, policy making is characterized by interactions of private and public actors. It occurs in "policy domain-specific subsystems which operate more or less independently of one another in a parallel fashion" (Adam and Kriesi 2007, 129). The idea at the core of this approach is that "actors are dependent on each other because they need each other's resources to achieve their goal" (129). This means that political actors are seen as mutually interlinked (146). Policy change is explained by the type of interactions (conflict, bargaining or cooperation) among members of a network and the distribution of power (concentration or fragmentation). Adam and Kriesi (2007, 145) expect that the potential for rapid, serial shift is highest when political power is fragmented and interaction takes the form of a conflict or bargaining. In contrast, the potential for policy change is rather low when there is cooperation, or bargaining in the context of concentrated power.

Punctuated equilibrium theory (Jones 1970; Jones et al. 1998; True et al. 2007) seeks to explain both stability and change in the domain of public policy. Its basic insight is that long periods of stability are interrupted by brief periods of substantial policy change. As the national political system cannot continuously deal with all issues confronting it, policymaking is usually delegated to expert-dominated policy subsystems. The power constellation in such policy subsystems may be that a single interest dominates policy-making or that there is competition among different interests. Over time, the power constellation may also change or issues may emerge to form their own distinct policy subsystem. Most of the time, only incremental change takes place because the power constellation remains constant. The policy subsystem

may even resist external pressures for some time. Yet, if pressures for policy change are sufficiently strong, previously uninvolved political actors may be compelled to participate in the policy subsystem, thereby possibly rewriting rules and changing the power constellation. This may entail moving an issue from the narrow domain of subsystem politics to the wide domain of macro-politics. There, substantial policy change may be initialized, after which the issue moves back to subsystem policy making where it settles on the new equilibrium (True et al. 2007).

The advocacy coalition framework (ACF) (Sabatier and Jenkins-Smith 1988, 1993; Sabatier 1998) is a framework for understanding the policy process, in particular policy change over long time periods, generally lasting a decade or longer. It was mainly developed in the context of environmental and energy policy change. It has been applied empirically in several dozen cases, and it has undergone a series of refinements (Sabatier and Weible 2007). In the following, I rely primarily on the most recent contributions. In the ACF, policy subsystems and the coalitions in there are selected as the unit of analysis. However, defining a policy subsystem poses a challenge, as the scope and the boundary of a policy subsystem is not readily obvious. Sabatier and Weible (2007, 193) give the following advice for delimiting a policy subsystem: "Focus on the substantive and geographic scope of the institutions that structure interaction."

Actors in a policy subsystem are aggregated into coalitions that consist of actors who both "(a) share a set of normative and causal beliefs and (b) engage in a nontrivial degree of co-ordinated activity over time" (Sabatier 1998, 103). Members of any coalition come from various private and governmental organizations, such as "interest group leaders, but also agency officials, legislators from multiple levels of government, applied researchers, and perhaps even a few journalists" (Sabatier 1998, 103). Generally, policy subsystems are thought to be populated by one to five coalitions (Sabatier 2007, 196).

The ACF contrasts with rational choice approaches that generally assume political actors to pursue rather simple material interests. Instead, the ACF understands that political actors also pursue normative goals which however have to be elicited empirically for each policy subsystem under study. More specifically, the ACF proposes a hierarchy of three levels of belief systems, namely *deep core beliefs* (involving very general assumptions about human nature and the relative priorities of various values), *policy core beliefs* (applications of deep core beliefs in the specific subsystem) and *secondary beliefs* (narrow and rather technical perspectives on specific issues within the policy subsystem). Deep core beliefs are seen to be substantially the result of socialization processes and are seen as very hard to change. Policy core beliefs, which are significantly affected by deep core beliefs, are also difficult to change. In contrast, secondary beliefs are easier to change, for example by new scientific and technical information (Sabatier and Weible 2007).

There are several sources of policy change in the ACF. Most importantly, events or shocks in external subsystems can bring about change (Weible et al. 2009, 124). Coalitions may draw on several resources when they attempt to influence public policy. These are *formal legal authority to make policy decisions*, support from *public opinion*, *information*, *mobilizable troops* such as members of the general public

willing to support the coalition, *financial resources* and *skillful leadership* (Sabatier and Weible 2007, 201pp.). External events change the distribution of such resources and may cause a dominant coalition to weaken and be replaced by a coalition advocating other policy core beliefs. Below I will argue that the emergence of climate change and energy as a societal problem situation constitute such external events. Further causes of policy change are policy-oriented learning, internal subsystem events and negotiated agreements (Weible et al. 2009, 124).

5.4.4.2 The Situation Actors in the Advocacy Coalitions Are In

For the purpose of my study, I summarize the very broad and heterogenous array of political positions found in Switzerland's energy and climate politics under two advocacy coalitions. In fact, the application of the advocacy coalition framework to Swiss energy and climate policy is well established (Kübler 2001; Kriesi and Jegen 2001; Ingold 2007). Before this can be done, however, the policy subsystem needs to be defined. Furthermore, the situation, within which members of any advocacy coalition act needs to be clarified.

For the purpose of my study, I think that *energy policy in buildings* is the adequate policy subsystem. In fact, there are several actors and institutions dealing specifically with energy in buildings. For example, the federal office for energy conducts a research program, maintains a specific office and conducts information campaigns dedicated to energy in buildings. Among the cantons, several have specific offices dedicated specifically to energy in buildings or more generally to sustainable construction. The cantons coordinate their energy policy in the conference of cantonal energy directors. In addition, there are several organizations and forums dealing with energy or sustainability in buildings (e.g. Minergie association, energho, eco-bau). However, this policy subsystem is not autonomous. Rather, it is nested in Switzerland's energy and climate policy subsystems.

Further, the situation in which members of such coalitions act can be described primarily as a struggle for power.[4] However, power is not of value per se, but as a means to promote the political positions of a coalition. Scientific knowledge, technology, the media and public opinion are all potential resources of power in such a political struggle. Specifically, Kriesi (2001) sees public opinion as the crucial link between the general public and actors in policy subsystem. He argues that consent of the public in specific issues is an important power resource for political actors which complements expertise, relationships, money and personal charisma. As science and the media create public awareness of climate change and energy as a societal problem situation, public opinion demands policy responses.

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[4] I this context, I find Max Weber's classical definition of power very useful. According to Weber (1958, 180), power is "(…) the chance of a man or of a group of men to realize their own will in a communal action even against the resistance of others who are participating in the action."

5.4.4.3 Typology of Advocacy Coalitions

In my literature research, I did not find any contributions which analyze advocacy coalitions in Switzerland's policy subsystem dealing with energy in buildings. However, there are some contributions that describe advocacy coalitions in climate and energy policy subsystems.

In an analysis of the policy process leading to Switzerland's CO_2 law, Lehmann and Rieder (2002) identify three advocacy coalitions (economy, greens and public administration) in Swiss climate policy. The *economy* coalition generally did not reject mitigation measures. However, its members generally preferred policy measures which would not harm Switzerland's international competitiveness. They generally demanded that any tax on CO_2 should be a fiscally neutral incentive tax (21p.). Members of the *green* coalition are generally less concerned about Switzerland's international competitiveness and have a strong preference for ambitious mitigation. While this coalition is rather skeptical regarding the effect of voluntary measures, it is open for market-based instruments as well as for command and control interventions by the state. Lehmann and Rieder (2002) identify the *public administration* as a third coalition, within which actors from various government agencies were represented. However, Lehmann and Rieder (2002, 23) state that the members of this advocacy coalition held various positions regarding the policy core. I find that this is a deviation from the general notion of advocacy coalitions which defines coalition membership on the merits of policy beliefs rather than membership in a government institution.

Ingold (2007, 2010) find evidence for only two substantive advocacy coalitions (pro-economy and pro-ecology). According to Kriesi and Jegen (2001) and Jegen (2003), two major advocacy coalitions are to be found in Switzerland's energy policy subsystem. As in the climate policy subsystem, they are described as "pro-growth" and "pro-ecology" coalitions. The pro-growth coalition consists of a "triple alliance of the electrical industry, cantonal governments and center-right parties controlling these governments" (Kriesi and Jegen 2001, 29). In contrast, the pro-ecology coalition consists of "ecologists (representatives of the ecological associations), politicians from the left (including the Green party), and consultants (new policy experts)" (Kriesi and Jegen 2001, 30). Kriesi and Jegen (2001, 255) explicitly find a "bipolar model of a dominant coalition faced by a rising coalition" to be both more accurate and theoretically more fruitful.

The literature presented above does not directly apply to the policy subsystem I am interested in here (energy in buildings). However, energy in buildings is an issue precisely because of climate change and energy use patterns. I therefore think that it is very reasonable to assume that two advocacy coalitions exist in the policy subsystem dealing with energy in buildings. I further assume that the coalitions are divided by the relative importance of ecology versus the economy. This means that there must be one advocacy coalition which wants to implement ambitious policies as soon as possible and one coalition which aims to limit state interventions into the stock of buildings to the minimum. I therefore propose the following two advocacy coalition types:

- Advocacy coalition that **demands** (further) public policy interventions
- Advocacy coalition that is **opposed to** (further) public policy interventions

5.4.4.4 Explaining Changes in the Power of Advocacy Coalitions

Basically, there are two approaches to conceptualizing the effect of the relative strength of the two coalitions on policy change. First, I could model how actors move from one coalition to the other. This approach is, however, somewhat inconsistent with the advocacy coalition framework. It assumes that deep core and policy core beliefs of political actors are quite stable over many years, which conflicts with the idea of actors readily changing coalitions. The second—and in my opinion more convincing approach—is to model the *power* of the advocacy coalitions relative to each other.

Figure 5.4 shows qualitatively how an increase in the POWER OF THE ADVOCACY DEMANDING (FURTHER) PUBLIC POLICY INTERVENTIONS is modelled. Specifically, there are four causes that drive the POWER OF THE ADVOCACY COALITION […]. PRESSURE FROM PERCEIVED ENERGY SHORTAGE is the earliest driver of policy change. In fact, the beginning of a substantial energy policy in Switzerland can be traced back to the oil crisis of 1973. I expect that high oil prices and a perceived shortage of fossil-fuel will continue to contribute to the POWER OF THE ADVOCACY COALITION […]. As MAINSTREAM SCIENCE'S CONFIDENCE IN CLIMATE CHANGE […] rises, a societal problem situation begins to emerge. In conjunction with a large GAP BETWEEN […] CURRENT EMISSIONS AND THE EMISSION RATE COMPATIBLE WITH THE 2° GOAL and a rising TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS, the POWER OF THE ADVOCACY COALITION DEMANDING FURTHER […] INTERVENTIONS is increased.
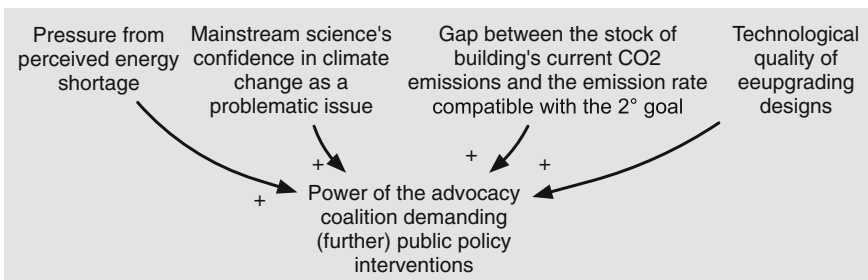
Fig. 5.4 Causes of an increase of the power of the advocacy coalition that demands further public policy interventions

5.5 Conclusions: Actors' Effect on the Diffusion Process

In this chapter I have developed a comprehensive perspective on the actors in the problem situation. Based on an ideal-typical description of the renovation process and a list of actors in the market, in civil society and in the state, I provided a comprehensive description of the most important actors. Finally, I now provide an analysis of actors effect on the diffusion of energy-efficient renovations.

Inspired by my reading of Eden and Ackermann (2004), I use a *power/interest grid* as a tool to do that. Eden and Ackermann (2004, 121p.) described the power/interest grid as a tool for describing and analyzing how stakeholders of an organization might influence and react to an organization's strategy. In the following, I adapt it to describe and analyze the most important actor affecting the diffusion of energy-efficient renovations. Based on the insights obtained from my interviews as described above, I position actors on the power/interest system of co-ordinates. I also indicate how some actors should be influenced, in order to promote the transformation of the stock of buildings.

Figure 5.5 shows the resulting power-interest diagram. Each subtype is represented by a circle. On the horizontal axis, the influence of an actor subgroup on the energy efficiency of the stock of buildings is shown. This corresponds to the *power* dimension. On the vertical axis, the *interest* in energy-efficiency of actors is shown. In addition, this figure shows with the red arrows how each actor subtype should be influenced, in order to accelerate the diffusion of energy-efficient renovations.

I position the two profit-oriented building owners types (1, 2) more to the right than the multi-criteria oriented building owners types (3, 4). This is because many more buildings are managed by profit-oriented building owners. As the profit-oriented building owners with professional know-how (1) manage less buildings than the profit-oriented building owners with no know-how (2), they are positioned somewhat to the left of them. Regarding the management of building owners, I find that the multi-criteria oriented building owners with professional know-how (3) should be influenced to manage more buildings. This is because they have the motivation and the know-how to contribute to the transformation of the stock of buildings. The profit-oriented building owners with professional know-how (1) owners should be influenced to have a greater interest in energy efficiency. As they seem to generally implement the legal requirements, this is not particularly urgent. Of crucial importance, however, is that profit-oriented building owners with no professional know-how (2) manage less buildings or become more interested in energy efficiency. The multi-criteria oriented building owners with no know-how (4) need not be influenced.

Regarding tenants, I think that the *costminimizers* (5) have the highest influence. Their power comes from the fact that they represent the majority of tenants and therefore yield substantial market power. Yet, they have little interest in energy-efficiency and the added comfort it brings. The *evaluating* tenant type (6) is found less frequently and therefore has a somewhat smaller influence. These tenants have some interest in energy-efficiency, yet it is of only minor importance. The *benefit maximizer* tenant type (7) has a strong interest in the benefits of energy efficiency. Due to the small share of tenants belonging to this type, its influence on the transformation of the

Fig. 5.5 Power-interest diagram of actors. Red arrows indicate how actors should be influenced, in order to accelerate the diffussion of energy-efficient renovations

stock of buildings is limited but not inexistent. I think that the evaluating (6) and the benefit maximizing (7) tenant type can be influenced through marketing instruments to have a greater interest in energy efficiency and the benefits it brings. Should energy-efficient housing be cheaper compared to non-energy-efficient housing, then also the costminimizer (5) tenant subtype would be interested in energy-efficiency.

Regarding architects, I think that those who actively promote energy efficiency (8) currently still have a rather small influence on the stock of buildings. This is however rapidly changing, and over the last five to ten years, the share of architects who are against or indifferent to energy-efficient building designs (9) have lost influence. This is closely associated with technological and economic improvements. In order to promote the transformation of the stock of buildings, architects should be influenced so that those actively promoting energy efficiency further gain influence.

Regarding the two advocacy coalitions, obviously the coalition that demands further public policy interventions has a high interest in energy-efficiency, while the other coalition has a low interest. I think that currently the two advocacy coalitions are about of similar strength. In order to promote the transformation of the stock of buildings, obviously the promoting coalition ought to increase its influence.

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Chapter 6
A Feedback Perspective on the Diffusion of Energy-Efficient Renovations

In this chapter the main feedback loops driving the diffusion of energy-efficient renovations are presented. Specifically, I show how building owners and tenants interact on the housing market. I also show how they interact with technology and public policy interventions. Based on this perspective, I develop preliminary conclusions for the development of the larger simulation model, and I discuss the potential value of my Causal Loop Diagram as a general framework.

6.1 Introduction

In order to develop a dynamic perspective on the causes of the diffusion of energy-efficient renovations, I use Causal Loop Diagrams (CLDs).[1] In doing so I address my fourth research question which is as follows: "What are the most important processes which cause the diffusion of energy-efficient renovations?".

The diffusion of energy-efficient renovations is operationalized with the variable SHARE OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS, which can take values between 0 and 1. Recall that the renovations that do not implement energy-efficient building designs either implement the paintjob renovation or the reconstruction strategy as introduced in Sect. 4.4.1.2. Like in both simulation models (presented in Chaps. 4 and 7), the time horizon implied by this analysis runs from 1975 to 2100. However, most of my argument concerns the years between 1975 and 2010. The argument proceeds by introducing one feedback loop after another and explaining how each loop affects the diffusion process. Because almost all of the foundations upon which this analysis is built were covered in the preceding chapters, I only give very few references. For quick reference purpose, Table 6.1 lists all loops and their polarity.

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[1] Causal Loop Diagrams were introduced in Sect. 2.3.5, on p. 41.

Table 6.1 Overview of the feedback loops used to explain the diffusion of energy-efficient renovations

Loop	Name	Polarity
A	Energy-efficient renovations transform the stock of buildings	–
B	Demand for energy-efficient housing	–
C	Supply of energy-efficient housing	–
D	Market-driven technology improvement and its perception by building owners	+
E	Market-driven technology improvement and its perception by tenants	+
F	Public policy accelerates the improvement of technology	–
G	The availability of adequate technology creates further pressure for public policy interventions	+
H	Public policy accelerates the diffusion of energy-efficient building designs	–
I	Public policy tightens mandatory standards	+
J	Public policy increases the cost of heating	–

A polarity of + means that the loop is reinforcing, a polarity of – means that the loop is balancing

6.2 Energy-Efficient Renovations Transform the Stock of Buildings (Loop A, Balancing)

Loop A is a simplified representation of the small model of the stock of buildings presented in Chap. 4. It shows how the stock of buildings is transformed from a situation of low energy-efficiency to a situation of high energy-efficiency. A rising SHARE OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS causes the NUMBER OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS to rise (arrow 1 in Fig. 6.1). As the NUMBER OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS rises, the NUMBER OF NEE BUILDINGS IN BAD CONDITIONS decreases (arrow 2). However, a reduced NUMBER OF NEE BUILDINGS IN BAD CONDITION leads to the reduction of the NUMBER OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS (arrow 3). As the NUMBER NEE BUILDINGS decreases, the YEARLY CO_2 EMISSIONS FROM BUILDINGS decrease too (arrow 4).

Loop A is a balancing loop. This means that taken for itself it converges to equilibrium. Here, the equilibrium is reached when the NUMBER OF NEE BUILDINGS IN BAD CONDITION remains at zero. Then there are also no renovations implementing energy-efficient building designs. By contrasting this CLD with the small model of the stock of buildings, the crucial difference between CLDs and actual simulation models becomes evident: CLDs are excellent tools for visualizing the feedback structure of a system and draw attention to the dynamics. They however are very limited in precision and detail.
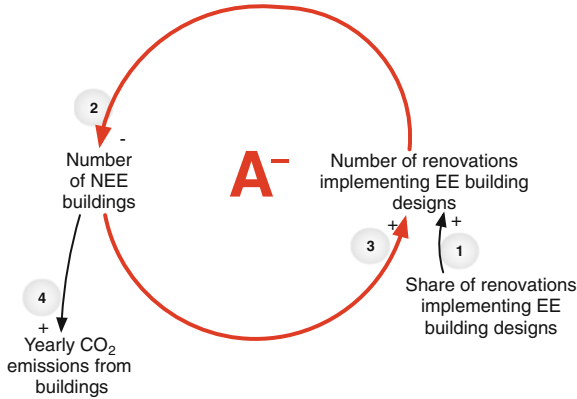
Fig. 6.1 Loop A: Energy-efficient renovations transform the stock of buildings. Consists of *arrows* 2 and 3

6.3 Demand for Energy-Efficient Housing (Loop B, Balancing)

Loop B represents the demand side of the housing market. It shows how the rental price for energy-efficient housing and the cost of heating relate to the demand for energy-efficient housing. Before the structure of causality is addressed, I need to clarify that in reality there is no market for energy-efficient housing that is separated from the market for non-energy-efficient housing. Rather, housings should be seen as a collection of attributes, of which energy-efficiency is one among many others (see Sect. 3.5.4 for the corresponding discussion of hedonic choice). While energy-efficiency and the co-benefits it brings are generally not the decisive attribute of housing, it is nevertheless well established that tenants draw utility from and have a willingness to pay for energy efficiency and its co-benefits (Ott et al. 2006; Jakob 2006). Examples for co-benefits of energy-efficiency are increased levels of comfort brought about by insulation and the better quality of the indoor air brought about by ventilation systems. In the following, the market for housings with the attribute "energy-efficiency" relative to housings without this attribute is analyzed.

The ATTRACTIVENESS OF EE HOUSING FOR TENANTS governs the demand-side of the housing market. As the AVERAGE RENTAL PRICE FOR EE HOUSING rises, the ATTRACTIVENESS OF EE HOUSINGS FOR TENANTS is reduced (arrow 5 in Fig. 6.2). The COST OF HEATING is the second determinant of attractiveness. As it rises, the ATTRACTIVENESS OF EE HOUSINGS FOR TENANTS is increased (arrow 7). A rising ATTRACTIVENESS OF EE HOUSINGS FOR TENANTS leads to an increase in DEMAND (arrow 6). In line with standard microeconomic theory (Mas-Collel et al. 1995; Varian 1993), an increase in DEMAND is seen to bring about an increase of the AVERAGE RENTAL PRICE FOR EE HOUSING (arrow 8), thereby again decreasing the ATTRACTIVENESS OF EE HOUSINGS FOR TENANTS (again arrow 5).
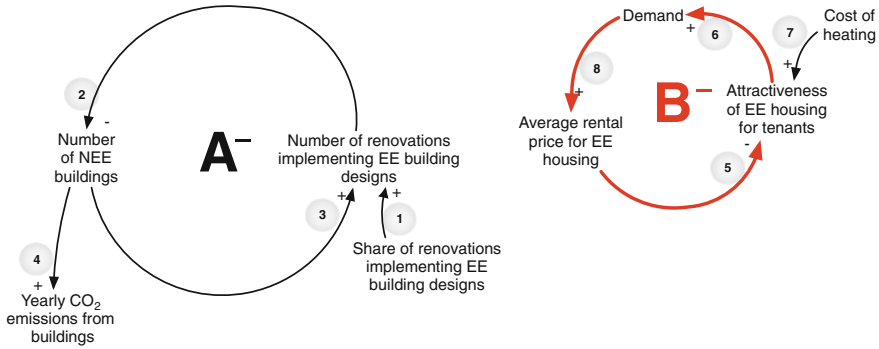
Fig. 6.2 Loop B: Demand for energy-efficient housing. Consists of *arrows* 5, 6 and 8

Loop B also turns out to be a balancing loop. The equilibrium it ultimately attains depends on external conditions such as the cost of heating and the supply side as presented in the following loop C (Fig. 6.3).

6.4 Supply of Energy-Efficient Housing (Loop C, Balancing)

Loop C represents the supply side of the housing market. It shows how the rental price for energy-efficient housing relates to the supply of energy-efficient housing. As the Average Rental Price for EE Housing rises, the Net Present Value of EE Renovations is increased (see arrow 9 in Fig. 6.3). In turn the Attractiveness of EE Building designs for Building Owners is increased (arrow 10). As the Attractiveness of EE Building Designs for Building Owners rises, the Share of Renovations Implementing EE Building Designs is increased relative to the two other renovation strategies (arrow 11). This eventually increases the absolute Number of Renovations Implementing EE Building Designs (arrow 1). An increase in the Number of Renovations Implementing EE Building Designs leads to an increase in Supply (arrow 12). Again following the logic of the market, an increase in Supply leads to a reduction of the Average Rental Price for EE Housings (arrow 13), which then reduces the Net Present Value of EE Renovations (again arrow 9).

Loop C turns out to be a balancing loop. This means that by itself loop C converges to an equilibrium determined by external conditions. Limiting the analysis to loops A, B and C, the following preliminary conclusion can be drawn. The pace of transformation of the stock of buildings is controlled by building owners. They are however not independent in their decision making, as they are influenced by the tenant's demand for energy-efficient housing. Tenants, in turn, are primarily influenced by the price of heating, respectively the energy price. In a situation of sustained high energy prices the diffusion of energy-efficient renovations would happen quasi
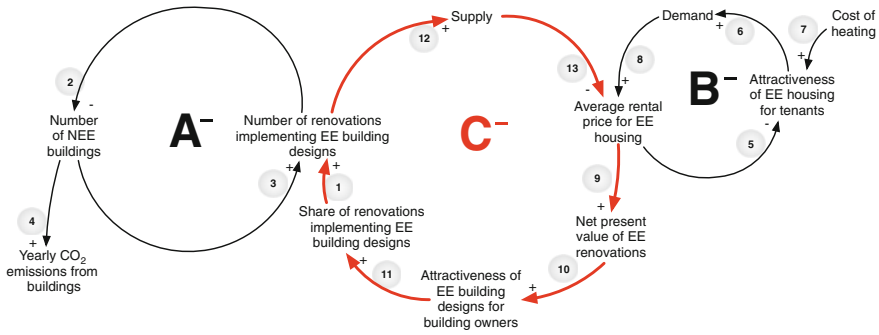
Fig. 6.3 Loop C: Supply of energy-efficient housing. Consists of *arrows* 9, 10, 11, 1, 12 and 13

automatically. In such a situation, tenants would have a clear and significant economic interest in energy-efficient housing. In Switzerland, however, the energy price has not reached a level where widespread, pressing demand for energy-efficient housing materialized on the real-estate market (see Sect. 3.4.1).

While the market structure as described in loops B and C is at the heart of my explanation, the role of technology and public policy needs to be considered too. In Sects. 6.5 and 6.6. I explain how changes in the state of technology shape the decision making of building owners and tenants on the housing market.

6.5 Market-Driven Technology Improvement and its Perception by Building Owners (Loop D, Reinforcing)

In the previous sections, the technology required to implement energy-efficient renovations was implicitly assumed to be available at every point in time. This conceptualization of technology is not adequate. Only a few years ago, advanced energy-efficient renovations such as those fulfilling the Minergie-P standard were pioneering work. Modern insulation materials such as vacuum insulation panels or ventilation systems with heat pumps recycling heat from exhaust air are innovations which are currently diffusing from niche to mass markets. Hence, the emergence of effective and cost-efficient technology over time needs to be accounted for. Loop D captures the causes of technology improvements and cost reductions and describes how such effects influence building owners' decision making (see Sect. 3.6.5 on p. 80 for a more detailed account of technological progress in energy-efficient building designs).

As the NUMBER OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS increases, the CUMULATED NUMBER OF EE RENOVATIONS rises (arrow 14 in Fig. 6.4) and the PERFORMANCE- TO- COST RATIO OF EE TECHNOLOGIES rises (arrow 15). This is because with each energy-efficient renovation know-how and experience is accumulated (see Sect. 3.6.5 for a discussion of the causes of technological progress). When the technologies used to implement energy-efficient building
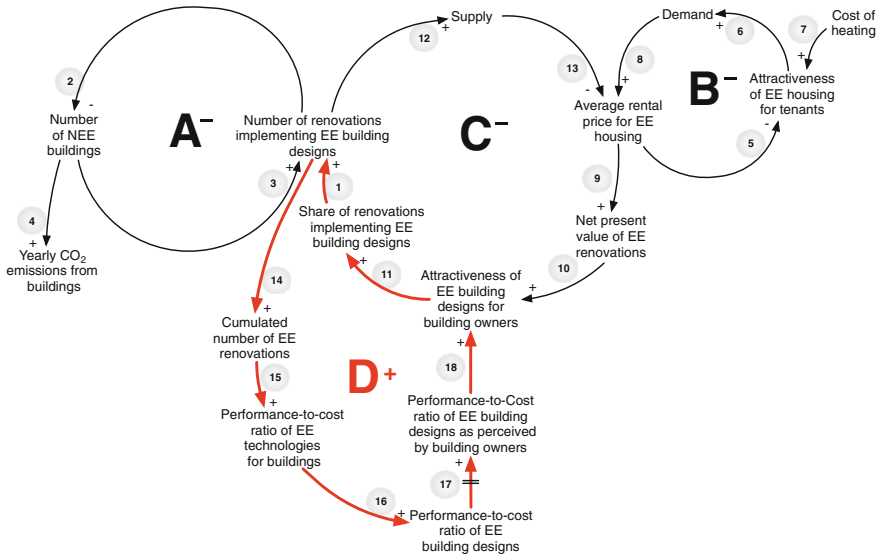
Fig. 6.4 Loop D: Market-driven technology improvement and its perception by building owners. Consists of *arrows* 14, 15, 16, 17, 18, 11 and 1

designs become better and more cost-efficient, then the PERFORMANCE- TO- COST RATIO OF EE BUILDING DESIGNS increases too (arrow 16). This is because construction companies and architects become increasingly better at adapting and integrating technologies into energy-efficient building designs.

The state of technology is perceived by building owners. Yet, this does not occur immediately. Rather, there is a delay of several years between the effective state of technology and the state of technology as it is perceived by building owners. The less know-how a building owner has or gets from an architect, the longer this delay is. Eventually, however, a rising PERFORMANCE- TO- COST RATIO OF EE BUILD- ING DESIGNS increases the PERFORMANCE- TO- COST RATIO OF EE BUILDING DESIGNS AS PERCEIVED BY BUILDING OWNERS (arrow 17) and hence increases the ATTRACTIVENESS OF EE BUILDING DESIGNS FOR BUILDING OWNERS (arrow 18). In addition to the NET PRESENT VALUE OF EE RENOVATIONS, technology is the second dynamical element influencing the building owners's decision making.

Taken for itself, loop D is reinforcing because the accumulation of experience leads to improvements of technology and thus contributes to further applications. This loop primarily interacts with the supply loop C and therefore affects the building-stock by way of loop A. For the sake of simplicity, architects are not explicitly represented in the feedback perspective presented here. I justify this with the fact that building owners ultimately are the deciding entity, whereas architects in general provide advice and hence can be seen as a component in the building owners perception and decision making process. In addition, as technology progresses, some architects who were opposed or indifferent to energy-efficient building designs become

architects in support of energy-efficient building designs.[2] This is caused by the same logic of increased experience, better technology and increased applications as described in loop D.

6.6   Market-Driven Technology Improvement and its Perception by Tenants (Loop E, Reinforcing)

Loop E describes the effect of improving technology on the demand side of the housing market. The causes of increasing performance and decreasing costs are exactly the same as presented under loop D.

As the Performance- to- Cost Ratio of EE Building Designs rises, the Performance of EE Building Designs as Perceived by Tenants rises too (arrow 19 in Fig. 6.5). Like in the case of the building owners' perception of the Performance- to- Cost Ratio of EE Housing Designs, I argue that tenants perceive the current state of technology with a delay. Specifically, there is a delay of several years until a rise in the current Performance- to- Cost Ratio of EE Building Designs causes an increase in the Performance of EE Housing Designs as Perceived by Tenants. This has several reasons: First, issues in the domains of energy, construction and housing technology are often non-issues for tenants, and they consequently do not invest the time and effort required to adequately evaluate the performance of energy-efficient building designs. Second, the image of energy-efficient housing designs among tenants seems to be based on a mix of hearsay and unstructured bits of information found in the popular media. And finally, negative information associated with technological problems or failures seem to spread more rapidly than positive information associated with the flawless operation of technological innovations. However, when the Performance of EE Buildings Designs as perceived by tenants rises, the Attractiveness of EE Housing for Tenants eventually rises too (arrow 20). Note that tenants only perceive the performance component of energy-efficient building designs and neglect the cost component. For the tenants the high costs of energy-efficient housing designs is only relevant if it eventually affects the Average Rental Price for EE Housing.

Loop E is reinforcing which means that—taken for itself—it would strive for an ever-increasing improvement of technology. However, loop E interacts with other loops. First, it interacts with loop B by increasing the demand for energy-efficient housing and this consequently contributes to an upward pressure on rental prices. This then affects loop C, as it causes building owners to increase the share of energy-efficient renovations. Eventually, loops B, C, D and E work to transform the stock

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[2] In reality, it seems likely that a small number of architects might become dissatisfied with energy-efficient building designs and in fact become opposed. As this study is concerned with aggregate developments, I omit processes where the application of unmatured technology impedes the diffusion process. See Müller et al. (2008) for some preliminary comments on this issue.
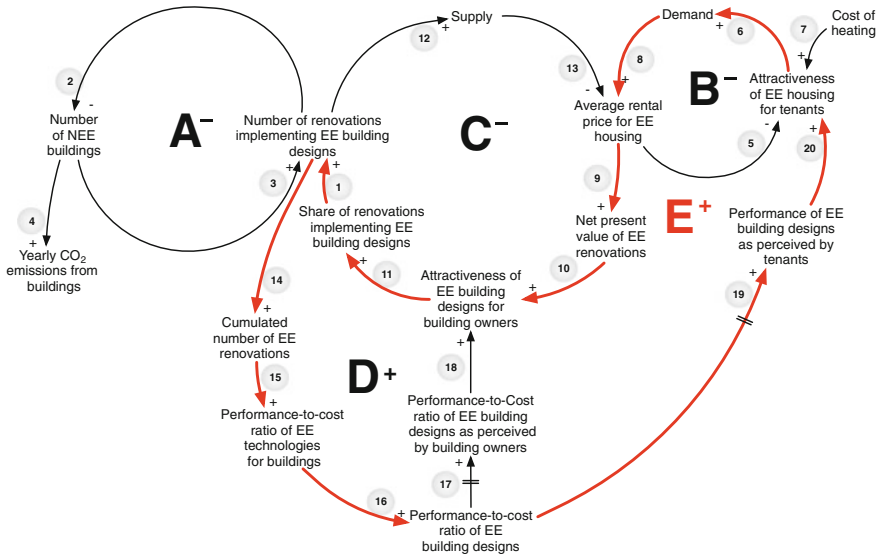
Fig. 6.5 Loop E: Market-driven technology improvement and its perception by tenants. Consists of *arrows* 14, 15, 16, 19, 20, 6, 8, 9, 10, 11 and 1

of buildings, by way of loop A, towards a state of energy efficiency and low CO_2 emission.

Initially, these loops are not very effective in transforming the stock of buildings on their own. This is because the technology loops D and E have a startup problem. In the beginning, technology for energy-efficient building designs is either non-existent or unmatured. In consequence a very unfavorable PERFORMANCE- TO- COST RATIO OF EE BUILDING DESIGNS prevails. This prevents building owners from carrying out energy-efficient renovations and actors in the construction industry consequently do not develop and improve technologies. If actors in the construction industry would expect sufficiently high future energy prices, they could make the necessary investments into energy-efficient technology, thereby eventually activating the two loops. However, such high energy prices have not materialized in the past. In the following, public policy interventions aiming at increasing the state of technology are described.

6.7 Public Policy Accelerates the Improvement of Technology (Loop F, Balancing)

Loop F shows how the emergence of climate, energy and the stock of buildings as a societal problem situation causes civil society actors to demand public policies in response to the problem situation from the state. In response to such pressure, the state intervenes in support of energy-efficient technologies. The following argument is substantially based on Sect. 5.4.4.
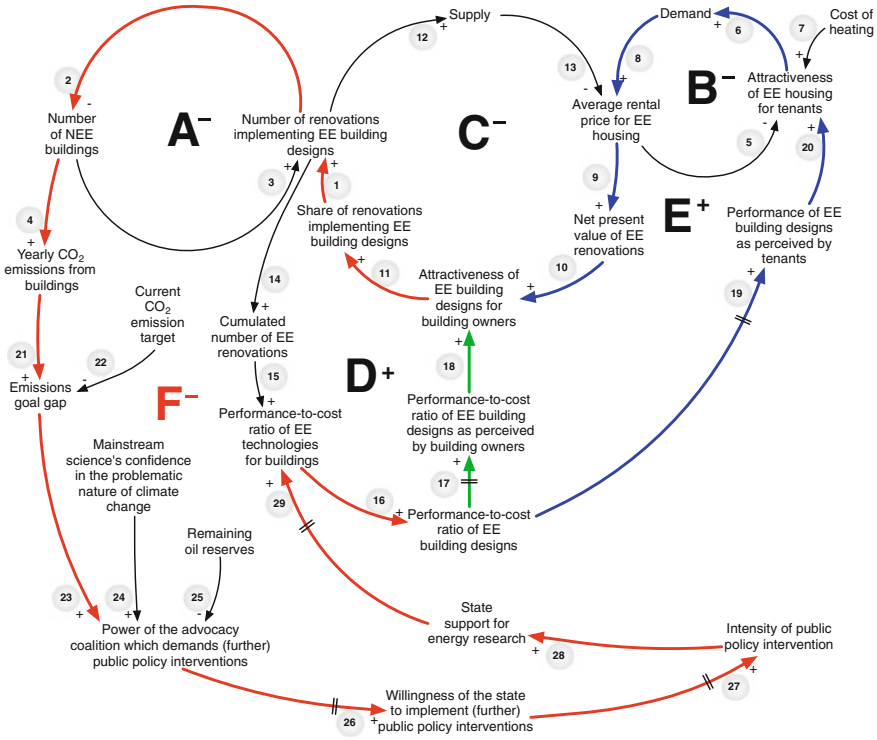
Fig. 6.6 Loop F: Public policy accelerates technology improvement. Consists of *arrows* 2, 4, 21, 23, 26, 27, 28, 29, 16 and then branches off to loop D by way of *arrows* 17, 18 and to loop E by way of *arrows* 19, 20, 6, 8, 9 and 10. It finally runs further by way of *arrows* 11 and 1

The larger the NUMBER OF NEE BUILDINGS is, the larger is the YEARLY CO_2 EMISSIONS FROM BUILDINGS are (arrow 4 in Fig. 6.6). As the YEARLY CO_2 EMISSIONS FROM BUILDINGS rise, the EMISSIONS GOAL GAP is increased (arrow 21). The CO_2 EMISSION TARGET is a politically determined variable. It is taken as the share of CO_2 emissions that residential multifamily buildings can emit given Switzerland's current climate policy.

Initially, in the year 1975, there was no CO_2 emission target, which corresponds to a very high emission target. In recent years it has been falling, as Switzerland adopted increasingly strict climate policy goals. As the CO_2 EMISSION TARGET falls, the EMISSIONS GOAL GAP increases (arrow 22). In response to the emergence of climate, energy and the stock of buildings as a societal problem situation, civil society actors begin to demand public policy interventions addressing the problem situation. The chance of implementing such policies is determined by the POWER OF THE ADVOCACY COALITION WHICH DEMANDS (FURTHER) PUBLIC POLICY INTERVENTIONS. Several variables affect it. It rises when the EMISSIONS GOAL GAP increases (arrow 23). It rises when MAINSTREAM SCIENCE'S CONFIDENCE IN THE PROBLEMATIC NATURE OF CLIMATE CHANGE increases (arrow 24). And it rises

as the Remaining Oil Reserves are reduced (arrow 25). If mainstream science were to reach the conclusion that the emission of CO_2 does not contribute to climate change, this causality would be substantially weakened. This is also true if large deposits of oil were to be found or become accessible. In both cases, members of the advocacy coalition demanding further public policy interventions would find it more difficult to convince the public of the need for increasing or even maintaining the current level of intervention.

As the Power of the Advocacy Coalition which demands (further) Public Policy Interventions rises, the Willingness of the State to Implement (further) Public Policy Interventions also rises (arrow 26). However, there is a substantial delay until changes in the Power of the Advocacy Coalition which demands (further) Public Policy Interventions eventually affect the Willingness of the State to Implement (further) Public Policy Interventions. I justify this delay by assuming that it takes several years until actors in governments, parliaments and administrations change their political position or are replaced, by elections, promotions and the like. As the Willingness of the State to Implement (further) Public Policy Interventions rises, eventually the actual Intensity of Public Policy Intervention rises (arrow 27), although this also occurs with a delay. The delay occurs because politicians and the public administrations require time for the design, communication, legislation and implementation of policies.

The variable Intensity of Public Policy Intervention refers to the degree of actual intervention of the state, as opposed to the planned level of intervention. It represents the *outcome* of politics, although on a very abstract and theoretical level as it cannot be observed as such. However, it can be operationalized with the number and the scope of the instruments implemented. The higher the Intensity of Public Policy Intervention is, the more instruments are applied, and the broader the scope of those instruments is. I use this variable in order to explain the sequencing of the following types of policy instruments. At a rather low Intensity of Public Policy Intervention, the state supports energy research. This is the first type of policy instruments (loop F, as described in this section). As the Intensity of Public Policy Intervention increases, the following three types of policy instruments increasingly gain prominence. These are instruments accelerating the diffusion of energy-efficient buildings designs in renovations (loop H), instruments which introduce and subsequently tighten mandatory standards (loop I) and instruments which increase the cost of heating (loop J).

As the Intensity of Public Policy Intervention increases, the State Support for Energy Research is increased (arrow 29). Eventually this leads to an increase of the Performance- to- Cost Ratio of EE Technologies for Buildings (arrow 29) and an increase of the Performance- to- Cost Ratio of EE Building Designs (arrow 16). Note that in the big simulation model the State Support for Energy Research is operationalized as a non-linear function. There state support first increases, yet as energy-efficient building designs become competitive on the market, State Support for Energy Research decreases.

Loop F is balancing because energy-efficient renovations reduce the NUMBER OF NEE BUILDINGS which ultimately reduces the effect from the CO_2 EMISSION GOAL GAP. This eventually reduces the POWER OF THE ADVOCACY COALITION WHICH DEMANDS (FURTHER) PUBLIC POLICY INTERVENTIONS. Eventually, it is exogenous variables which drive this loop. In particular, increases in MAINSTREAM SCIENCE'S CONFIDENCE IN THE PROBLEMATIC NATURE OF CLIMATE CHANGE and reductions in the REMAINING OIL RESERVES drive this loop. Should the pressure built up by these two exogenous variables fade, then this whole structure driving public policy interventions would be weakened.

Loop F contributes to starting up loops D and E. Eventually, an improving performance to cost ratio of energy-efficient building designs contributes to a rising attractiveness of energy-efficient renovations for building owners and to a rising attractiveness of energy-efficient housings for tenants. Hence, loops B and C are strengthened by STATE SUPPORT FOR ENERGY RESEARCH.

6.8 The Availability of Adequate Technology Creates Further Pressure for Public Policy Interventions (Loop G, Reinforcing)

Loop G shows how the availability of adequate technology for energy-efficient renovations creates further pressure for public policy interventions. As the PERFORMANCE TO COST RATIO OF EE BUILDING DESIGNS rises, the POWER OF THE ADVOCACY COALITION WHICH DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS is increased (arrow 30 in Fig. 6.7). The emergence of technical solutions is particularly important because the other three causes of change in the relative strength of the advocacy coalition (arrows 23, 24 and 25) only are drivers of the societal problem situation. They only create pressure for state interventions, rather than providing solutions. As long as the implementation of energy-efficient building designs in renovations has not reached a minimum level of technological maturity, opponents of further public policy interventions retain a lot of argumentative power. Specifically, any attempt by governments to implement instruments in support of the diffusion of energy-efficient building designs or mandatory regulations too early would result in a political fiasco. Here, I define 'too early' to indicate a time when the performance or the costs of energy-efficient building designs are unacceptable to the majority of building owners and actors in the construction industry. However, the better the PERFORMANCE- TO- COST RATIO OF EE BUILDING DESIGNS becomes, the more persuasive demands for instruments of the other types become. This enables actors in the state to design and implement policies of increasing scope.

In conclusion, I find loop G to be reinforcing. This is because better technology reinforces the power of the advocacy coalition in favor of further policy interventions. This increase the INTENSITY OF PUBLIC POLICY INTERVENTION, which in turn further contributes to improvements of technology. Loop G is a motor of the diffusion process, as long as climate and energy continue to societal problems. However, should
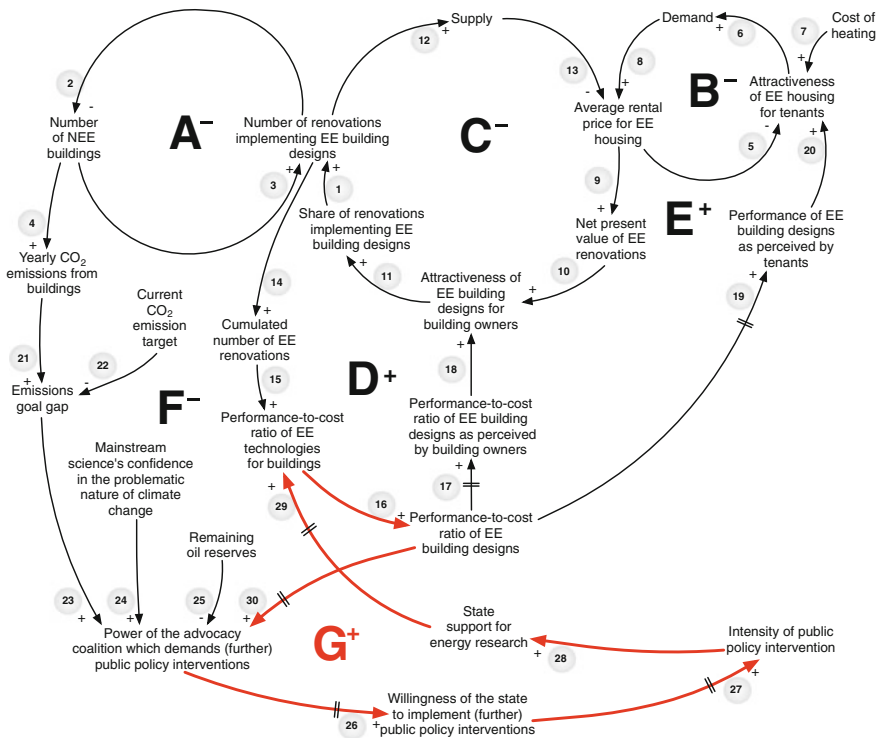
Fig. 6.7 Loop G: The availability of adequate technology creates further pressure for public policy interventions. Consists of *arrows* 30, 26, 27, 28, 29 and 16

the drivers of the problem situation (climate, energy and the emissions goal gap) be substantially weakened, then arrow 30 is no longer valid. In the absence of any energy or climate problems no further policy instruments would be implemented. This means that in the big simulation model the equation underlying the POWER OF THE ADVOCACY COALITION WHICH DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS must be specified such that the PERFORMANCE- TO- COST RATIO OF EE BUILDING DESIGNS alone cannot drive policy change.

6.9 Public Policy Accelerates the Diffusion of Energy-Efficient Building Designs (Loop H, Balancing)

As loops F and G push for an increasing INTENSITY OF PUBLIC POLICY INTER-VENTION, a second type of policy instruments aimed at accelerating the diffusion of energy-efficient building designs gains prominence.[3] Specifically, loop H describes

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[3] See Sect. 6.7, specifically p. 191, for a discussion of the different policy types.
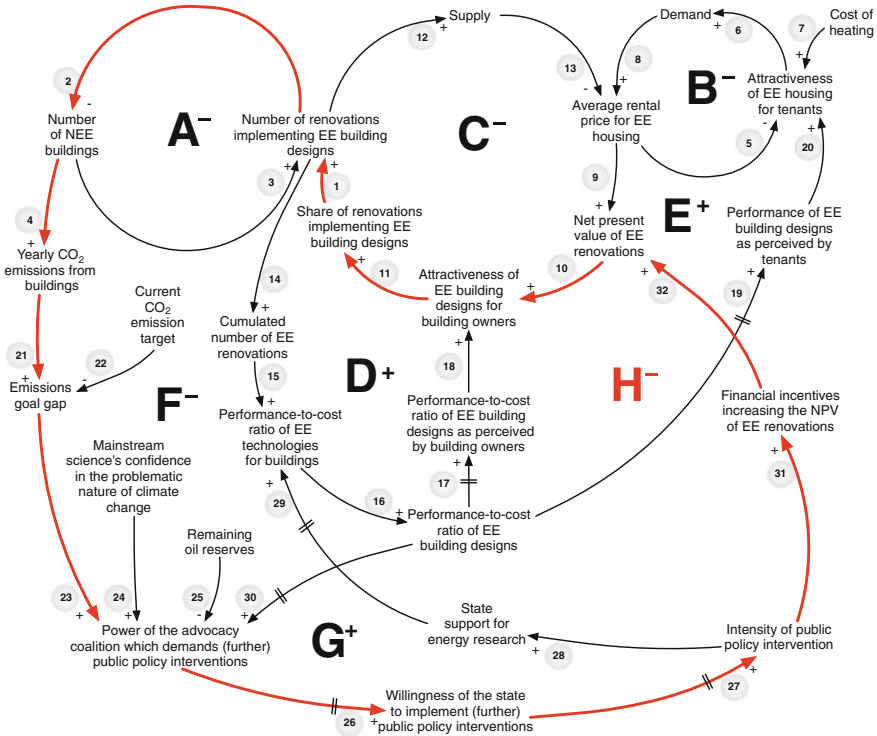
Fig. 6.8 Loop H: Public policy accelerates the diffusion of energy-efficient building designs. Consists of *arrows* 31, 32, 10, 11, 1, 2, 4, 21, 23, 26 and 27

how FINANCIAL INCREASING THE NPV OF EE RENOVATIONS are implemented by the state, as the INTENSITY OF PUBLIC POLICY INTERVENTION rises above a sufficiently high level (arrow 31). As the FINANCIAL INCREASING THE NPV OF EE RENOVATIONS rise, eventually the NET PRESENT VALUE OF EE RENOVATIONS too rises (arrow 32). This ultimately increases the ATTRACTIVENESS OF EE BUILDINGS FOR BUILDING OWNERS (arrow 10) (Fig. 6.8).

The rationale underlying this second type of policy instruments is that once the PERFORMANCE-TO-COST RATIO OF EE BUILDING DESIGNS is sufficiently high, public policy needs to support the diffusion of such building designs from niche to mass market. Among the instruments which create FINANCIAL INCREASING THE NPV OF EE RENOVATIONS, there are various subsidies which building owners get for energy-efficient renovations. Yet, also changes in tax or tenancy laws are included if they make it financially more attractive for building owners to implement energy-efficient renovations.

In conclusion, I find that loop H is balancing. It primarily affects the supply loop C. Yet the stimulus received from changing the financial incentives in favor of energy-efficient renovations eventually spills over to other loops. Specifically, loops

D and E are further strengthened due to the increased opportunities for technological learning, which come with increased renovations. Further, as the increased supply of energy-efficient housing puts downward pressure on rental prices, the demand loop B also is affected.

6.10 Public Policy Tightens Mandatory Standards (Loop I, Reinforcing)

Loop I shows that the strictness of energy standards rises together with the improving state of technology. Mandatory standards are a third type of instruments. They are implemented by the state in response to the emergence of climate, energy and the stock of buildings as a societal problem situation.

Specifically, as the INTENSITY OF PUBLIC POLICY INTERVENTION rises, the STRICTNESS OF REGULATIONS ON ENERGY IN BUILDINGS is increased (arrow 33 in Fig. 6.9). Yet as it is increased, the ATTRACTIVENESS OF EE BUILDINGS DESIGNS FOR BUILDING OWNERS is decreased (arrow 34). This is because having to adhere to stricter energy standards may cause more inconveniences in construction, as less advanced technology must be used. Also, the extra costs incurred in order to achieve stricter energy standards in renovations reduces the attractiveness of making a building energy-efficient.[4] In consequence, the SHARE OF RENOVATIONS IMPLEMENTING EE HOUSING DESIGNS is reduced (arrow 11). However, I assume that the reduced ATTRACTIVENESS OF EE BUILDINGS caused by stricter regulations is only temporary. Over time, this is compensated for as loops D and E continue to improve energy-efficient housing designs and reduce its costs.

I find loop I to be reinforcing when analyzed by itself. Loop I primarily affects the supply loop C. Yet the effects also spill over to loops B, D and E. Eventually loop I shows the limitations of CLDs. Stricter regulations cause several effects which cannot be adequately represented in the CLD without overly increasing complexity. For example, although the SHARE OF RENOVATIONS IMPLEMENTING EE BUILDING DESIGNS is reduced by an increasing STRICTNESS OF REGULATIONS ON ENERGY IN BUILDINGS, those renovations which get implemented may lead to bigger emission-reductions. This will be more adequately accounted for in the simulation model.

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[4] In the rich simulation model presented in Chap. 7, this will be discussed in greater detail. For the sake of simplicity, I do not explicitly differentiate between increased costs due to stricter regulations and the non-financial aspects of stricter regulations.
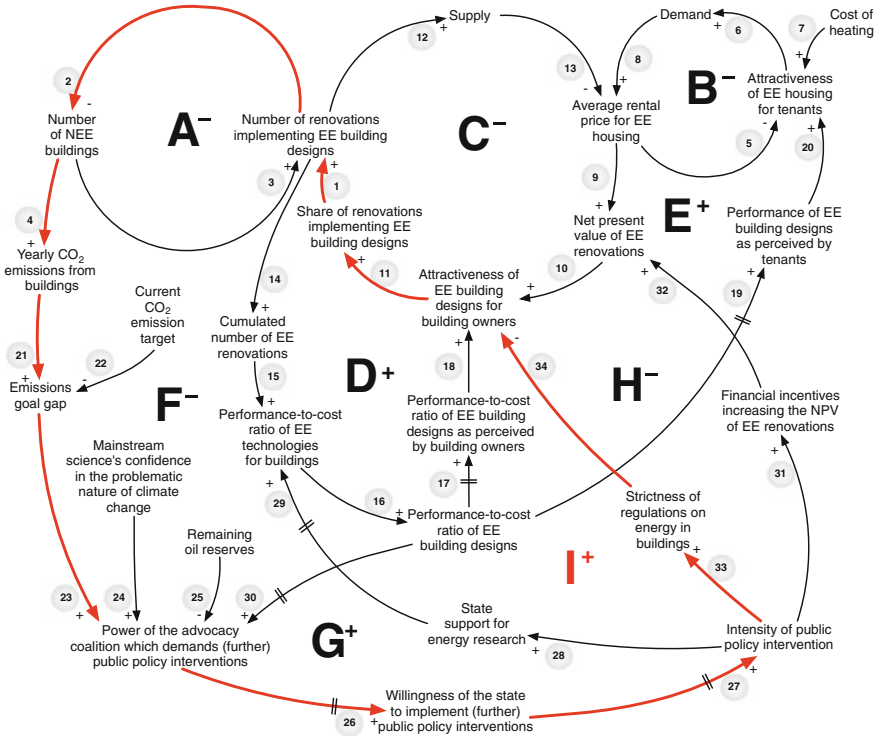
Fig. 6.9 Loop I: Public policy tightens mandatory standards. Consists of *arrows* 33, 34, 11, 1, 2, 4, 21, 23, 26 and 27

6.11 Public Policy Increases the Cost of Heating (Loop J, Balancing)

Loop J shows that TAXES ON ENERGY are implemented as a fourth type of policy instruments. They too are implemented by the state in response to the emergence of climate, energy and the stock of buildings as a societal problem situation. Initially, the COST OF HEATING is substantially affected by the WORLD MARKET PRICE FOR FOSSIL ENERGIES. As the WORLD MARKET PRICE FOR FOSSIL ENERGIES rises, the COST OF HEATING also rises (arrow 35 in Fig. 6.10). However, as the INTENSITY OF PUBLIC POLICY INTERVENTION rises, TAXES ON ENERGIES are increased (arrow 36). This directly increases the COST OF HEATING (arrow 37), which eventually increases the ATTRACTIVENESS OF EE HOUSING FOR TENANTS (arrow 7) and thus contributes to an increased DEMAND for energy-efficient housing (arrow 6).

Loop J turns out to be balancing. The more a high COST OF HEATING contributes to the reduction of CO_2 emissions, the slower the pace of policy change towards high levels of public policy interventions becomes in the future. Eventually, loop J provides
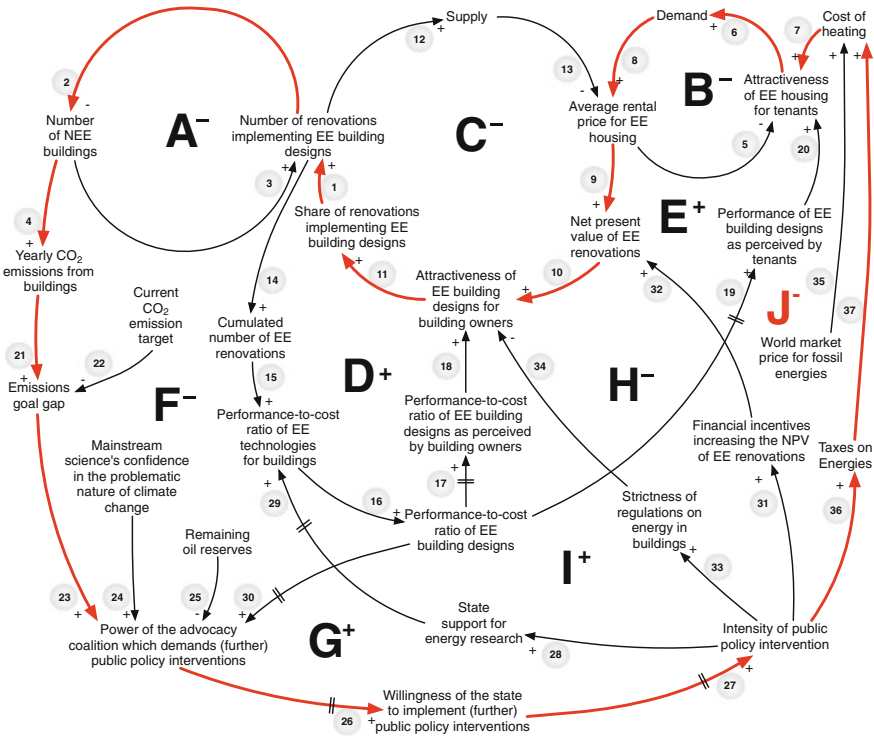
Fig. 6.10 Loop J: Public policy increases the price of energy. Consists of *arrows* 36, 37, 7, 6, 8, 9, 10, 11, 1, 2, 4, 21, 23, 26 and 27

an incentive for tenants to demand energy-efficient housing. Thus, increasing the price for fossil energy is a crucial element of the transition of Switzerland's energy system related to buildings.

6.12 Discussion and Conclusions

Based on the feedback perspective presented in this chapter, the following insights emerge as important, particularly in prospect for the development of the larger simulation model.

First, I find that the market structures required to transform the stock of buildings to a high level of energy-efficiency are in place. Yet, due to low energy prices, the market mechanism does not address energy-efficiency. However, a substantial rise in fossil energy prices could achieve the transformation of the stock of buildings to high levels of energy-efficiency based only on the interaction of supply and demand represented in loops B and C. However, as long as energy is inexpensive relative

to tenants' income, inefficient energy use does not substantially reduce the welfare of tenants and no substantial transformation of the stock of buildings should be expected.

Second, the technology required for the implementation of energy-efficient building designs in renovations has a startup problem. This is because actors in the market (at least implicitly) expect energy prices to remain at a similar level as in the past. If prices for energy were high and expected to remain high over the coming years and decades, then the private sector would invest into research and development of energy-efficient technologies and building designs. In particular, firms investing early into research and development might reap sustained benefits if they could capture early-mover advantages. However, at low energy prices and substantial uncertainty concerning the future development of energy prices, the development of energy-efficient technologies and building designs is a somewhat risky strategy for the private sector. Consequently only a small number of actors invest into research and development of energy-efficient building designs.

Third, the pace of the transformation substantially depends on exogenous variables, namely the WORLD MARKET PRICE FOR FOSSIL ENERGIES, the CURRENT CO$_2$ EMISSION TARGET, MAINSTREAM SCIENCE'S CONFIDENCE IN THE PROBLEMATIC NATURE OF CLIMATE CHANGE and the REMAINING OIL RESERVES. Treating these variables endogenously would be inappropriate, as they are determined by processes operating beyond the boundaries of my study.

A fourth finding of this perspective is that improvements in the PERFORMANCE-TO-COST RATIO OF EE BUILDING DESIGNS actually further increase the pressure on the state to implement more far-reaching policies (loop G). This is somewhat counter-intuitive because improvements of the PERFORMANCE-TO-COST RATIO OF EE BUILDING DESIGNS are to a significant degree already the result of state support for energy research. Actors in the state increased the STATE SUPPORT FOR ENERGY RESEARCH primarily in order to reduce the pressure from actors demanding more far-reaching policies. Now, they find that their support for technology research only alleviated pressure in the short term. Yet in the long term technological improvements lead to further demands for policies supporting the widespread application of now matured technologies.

A fifth insight is that the state needs to maintain an adequate balance between the STRICTNESS OF REGULATIONS ON ENERGY IN BUILDINGS and the PERFORMANCE-TO-COST RATIO OF EE BUILDING DESIGNS AS PERCEIVED BY BUILDING OWNERS during the whole diffusion process. Failure to do so might induce political resistance to public policies. Here, FINANCIAL INCENTIVES INCREASING THE NPV OF EE RENOVATIONS may prove a valuable tool to fine-tune that balance.

Finally, I find that there are several delays in the system which makes the diffusion of energy-efficient renovations a sluggish endeavor. For example, the time which passes until an increase in the STATE SUPPORT FOR ENERGY RESEARCH actually results in a change of the ATTRACTIVENESS OF EE BUILDING DESIGNS FOR BUILDING OWNERS may well be in the order of a decade. This finding and the very slow speed of transition described in the small model of the stock of buildings in

Chap. 4 makes it very clear that the transformation of Switzerland's stock of buildings is a "long-term policy challenge" (Sprinz 2008).

The feedback loops presented above provided a high-level perspective on the main processes driving the diffusion of energy-efficient renovations. Causal Loop Diagrams facilitate the communication of the main feedback loops driving a model. In contrast, in formal models the 'big picture' gets buried under detail, complexity and richness. While the feedback perspective presented in this chapter captures the most important causes of the diffusion of energy-efficient renovations, it necessarily remained rather qualitative. Therefore, this perspective should be considered as a preliminary step on route to the formal simulation model. There, I then can give further insights into the specific interactions of different feedback loops, and show how different types of the main actors shape the diffusion process in different ways.

Nevertheless, the feedback perspective presented in this chapter may be of value for actors involved in the societal problem situation, particularly for those outside academia. This is because it has the potential to serve as a framework into which a very broad range of real-world phenomena can be placed. It allows positioning a whole range of actors (such as those described in Chap. 5) according to their function. For example, installers of ventilation systems can be situated in loops D and E, particularly into arrows 16, 17 and 19. It also allows positioning a whole range of policies and instruments (such as those described in Sect. 3.7). For example, a change in the tax law may allow building owners to fully deduct investments into energy-efficiency from their income. This can be seen as an intervention into loop H, in particular into arrows 31 and 32.

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Part III
Results: A Synthetic Model for Policy Analysis

Chapter 7
A Rich Model of the Diffusion Dynamics of Energy-Efficient Renovations

7.1 Introduction

In this chapter, I address the fifth research question of this study. It reads: *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?* I answer this question by developing a large System Dynamics model. That model draws on the four preceding analytical chapters. It synthesizes those four perspectives in order to provide a dynamic theory of the diffusion process. Specifically, the large model is based on the small model of Switzerland's stock of residential, multifamily buildings presented in Chap. 4. In the small model, all three renovation strategies were put exogenously into the model. Now, the rise in the share of eeupgradings is explained endogenously. This is achieved by implementing the feedback loops described in Chap. 6 into the simulation model. Further, key results from the analysis of actors presented in Chap. 5 were implemented into the simulation model. For example, I used subscripts to incorporate the four types of building owners or the three types of tenants. Chapter 3, where I presented an analysis of climate, energy and the stock of buildings as a societal problem situation, provided various theoretical, conceptual and empirical foundations on which the simulation model is built.

By providing such a synthesis, the work presented in this chapter carries the analysis further and it goes beyond the analytical chapters. On the one hand, this is because the model selects highly relevant issues and integrates them. On the other hand, quantitative modeling allows for implementing further detail.

In the following, I will show how the model was set up (see Sect. 7.2) and present an overview over the model boundaries and sectors (see Sect. 7.3). Then, the model and the behavior of key variables are systematically described (Sects. 7.4–7.7). I then report on the behavior of the model under various scenarios (Sect. 7.8) and discuss the model testing procedures used to ensure the quality of the model (see Sect. 7.9). Finally, Sect. 7.10 offers some conclusions.

7.2 Setup

General Setup

The general setup of the big model closely follows the small model presented in Chap. 4 (see page 115), as it is built upon it.

- **Reference modes**: The primary reference mode of the big model is the share of eeupgrading renovations that should be increased ideally to unity and the CO_2 emissions from the stock of buildings that should be decreased.
- **Temporal and spatial dimensions**: The model runs over a time of 125 years, i.e. from the year 1975 to the year 2100. The period spanning the years 1975–2008 is based on empirical data where available. The model covers the whole of Switzerland without making any further geographical differentiation
- **Level of Aggregation**: As in the small model, this model generally has a high level of aggregation. The model has some disaggregation introduced by subscripting different types of the same actor (building owners, architects, tenants), yet it still remains at a rather high level of aggregation.

Model Behavior

Throughout this chapter I will show the behavior of my model for the *base scenario*. That scenario represents the case that I think is the most likely behavior. Inspecting the model behavior in the most reasonable parameterization also contributes to model testing. Later I will use the behavior of the model in the base scenario to compare the effects of various interventions.

Subscripts

Subscripts allow a model structure to be repeated for different instances of a variable.[1] In my model, several equations are subscripted, in order to track different types. For example, the building-stock model is now calculated for each building owner type. Subscripts are expressed by adding the relevant subscript in the name of the variable. For example, from the name of the variable ATTRACTIVENESS OF NPV BY BO TYPE, it can be seen that it contains subscripts for each type of building owners. The following subscripts are used:

- **by BO type** refers to the four subscripts used for building owners, namely *profit-professional*, *profit-non-professional*, *multicriteria-professional* and *multicriteria-non-professional*.

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[1] See page 44 or http://www.vensim.com/subscript.html, accessed 28 June 2011, for further information on subscripts.

- **by tenant type** refers to the three subscripts used for tenant types, namely *cost-minimizers*, *evaluators* and *ecological*.
- **by strategy** refers to the two subscripts used for renovation strategies, namely *paintjob renovations* and *eeupgradings*.
- **by housing type** refers to the two subscripts used for *paintjob housing* and *eeupgraded housing*.

7.3 Overview of Model Modules, Sectors and Boundaries

In the following, I provide a general overview of the model. As can be seen in Fig. 7.1, the resulting model is described as consisting of four modules that consist of different sectors. The four modules are as follows.

- **Module 1: The stock of buildings** This module is a slightly extended version of the building-stock model described in Chap. 4. First, buildings are now differentiated according to the type of building owner they belong to. Second, the shares of the paintjob and eeupgrading renovation strategies are changed endogenously, as a function of the relative attractiveness of the two strategies (see module 2).
- **Module 2: Supply and demand on the housing market** This module contains several sectors that together model supply and demand on the housing market. Therefore, the decision-functions of building owners and tenants are included, and a market mechanism is used to co-ordinate their decision making. Further
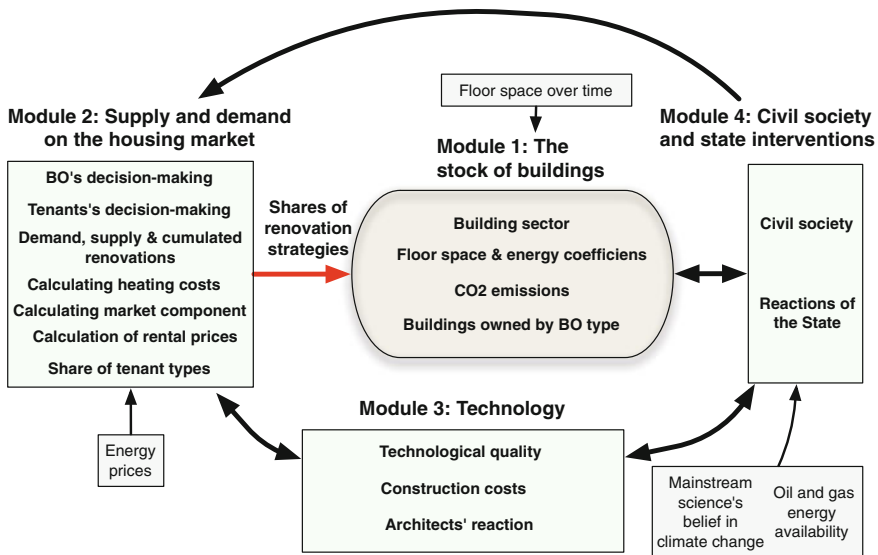
Fig. 7.1 Overview of the large model's modules and sectors

sectors perform auxiliary functions, such as calculating the cumulated number of renovations, rental prices or heating costs. Finally, the module includes a stock structure that can model changes in the share of each type of tenant.

- **Module 3: Technology** This module tracks the evolution of technology. Specifically, it models how the technological quality of eeupgradings rises, and how the costs for both renovation strategies decrease. In addition, it models how architects react to technological change and increasingly become active supporters of energy-efficient buildings designs in renovations.
- **Module 4: Civil society and state interventions** This module explains changes in the relative power of the two advocacy coalitions. Further, it explains three state interventions: *research and development*, *subsidies* and *reductions of the legal energy coefficient*.

In the following, I provide a detailed description of the model's sectors (see Sects. 7.4–7.7).

7.4 The Stock of Buildings (Module 1)

Tracking Shares of Buildings Managed by Building Owner Type

In Sect. 5.4.1.2, I introduced four types of building owners. Each of these four types represents a specific behavior among building owners (see Table 5.3 for the four types of building owners and the corresponding share of buildings owned).

In order to be able to manipulate the share of buildings managed by each type of building owner, I included the structure seen in Fig. 7.2. With that structure, one
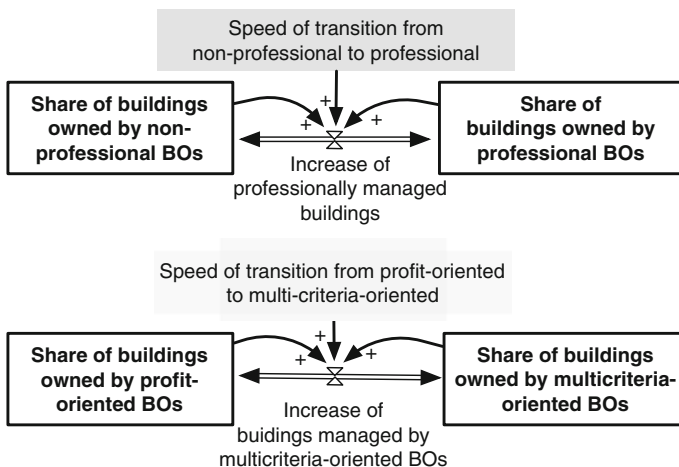
Fig. 7.2 Modeling changes in the distribution of building owners over the four types

Table 7.1 Shares of the four building owner types used in the base scenario

Type of building owner	Share
Profit-oriented, professional:	0.2
Profit-oriented, non-professional:	0.6
Multicriteria-oriented, professional:	0.05
Multicriteria-oriented, non-professional:	0.15

can change the share of buildings managed by profit-oriented versus multicriteria-oriented building owners. Further, one can change the share of buildings managed by professional versus non-professional building owners. The share of buildings managed by each building owner type can then be calculated as the product of the two corresponding stocks.

For example, the SHARE OF BUILDINGS OWNED BY PROFIT-ORIENTED BUILDING OWNERS WITH NO PROFESSIONAL KNOW-HOW (s_profitprofessional) is calculated by multiplying the SHARE OF BUILDINGS OWNED BY PROFIT-ORIENTED BUILDING OWNERS (s_profitoriented) with the SHARE OF BUILDINGS OWNED BY NONPROFESSIONAL BOs (s_nonproffessional), as seen in Eq. 7.1. The shares for the other three types of building owners are calculated analogously.

$$s\_profitprofessional = s\_profitoriented * s\_nonproffessional \qquad (7.1)$$

However, in the base scenario, the SPEED OF TRANSITION FROM NON-PROFESSIONAL TO PROFESSIONAL and the SPEED OF TRANSITION FROM PROFIT-ORIENTED TO MULTI-CRITERIA-ORIENTED are set to zero. Hence, the shares of buildings managed by building owner type remains constant, as given in Table 7.1 above.

Ultimately, this structure allows to investigate the effects of changes in the ownership structure of the stock of buildings. For example, by setting the variable SPEED OF TRANSITION FROM NON-PROFESSIONAL TO PROFESSIONAL to a value larger than zero, a gradual shift from non-professional ownership to professional can be modeled. This is because the flow rate CHANGE IN PROFESSIONALISM (change) is calculated as a function of the SPEED OF TRANSITION FROM NON-PROFESSIONAL TO PROFESSIONAL (speed), the SHARE OF BUILDINGS OWNED BY NON-PROFESSIONAL BOs (share_nonprofessional) and the SHARE OF BUILDINGS OWNED BY PROFESSIONAL BOs (share_professional), as given in Eq. 7.2.

$$change = speed * share\_nonprofessional * share\_professional \qquad (7.2)$$

Subscripting the Stock of Buildings by Building Owner Type

In order to calculate the number of buildings owned by each building owner type I used the structure presented in Fig. 7.3. Each of the six stocks of buildings is
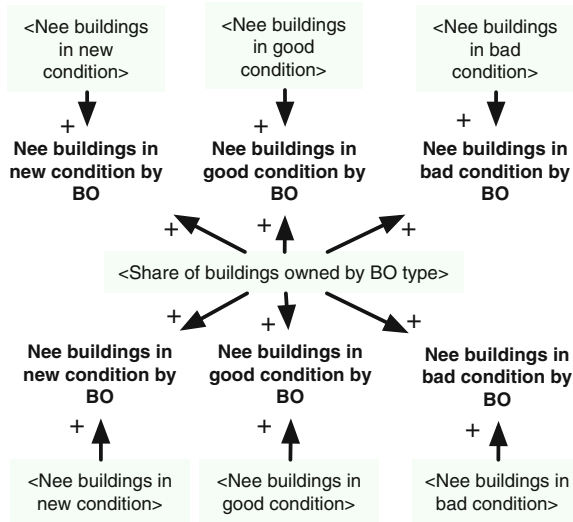
Fig. 7.3 Structure used to subscript the building-stock

multiplied with the SHARE OF BUILDINGS OWNED BY BO TYPE. For example, the number of NEE BUILDINGS IN BAD CONDITION OWNED BY PROFIT- ORIENTED, PROFESSIONAL BUILDING OWNERS (Nee_bad_profitprofessional) is obtained by multiplying the number of NEE BUILDINGS IN BAD CONDITION (NEE_bad) with the SHARE OF BUILDINGS OWNED BY PROFIT- ORIENTED, PROFESSIONAL BUILDING OWNERS (s_profitprofessional) (see Eq. 7.3) Calculations for the other three types of building owners and the other five types of buildings are conducted analogously.

$$\text{Nee\_bad\_profitprofessional} = \text{NEE\_bad} * \text{s\_profitprofessional} \qquad (7.3)$$

7.5 Supply and Demand on the Housing Market (Module 2)

In this module, I model how building owners and tenants decide and how they interact on the housing market.

7.5.1 Setup of the Module

Housings

Each of the two endogenous renovation strategies leads to the creation of a specific type of housing:

- Renovations implementing the paintjob renovation strategy lead to the creation of *paintjob housing*.
- Renovations implementing the eeupgrading renovation strategy lead to the creation of *eeupgraded housing*.

Each building is defined to contain 10 identical housings that are not further differentiated according to number of rooms, floor space or other characteristics.

Market Mechanism

The market mechanism used in this model serves a very specific and very limited purpose. I would like to stress that I have not developed a model of Switzerland's real-estate market or anything similar. Rather, the function of the market mechanism in this model is to find an equilibrium rental price in each time period. The following assumptions underline the market mechanism in my model:

- For each time period, the market scope is defined to be limited to the buildings currently under renovation.
- I assume that all tenants in buildings under renovation move out of their housing, choose a new housing and move back into a housing in the same time period. Every tenant who moves out of a housing moves into a new one.
- Building owners choose which renovation strategy to implement. Tenants choose what type of housing they prefer.
- The rental price, specifically the MARKET PRICE COMPONENT OF THE RENTAL PRICE, is adjusted such that the supply and the demand for each type of housings is equal in every time period.
- There is only one rental price for each housing type.

Obviously, this conceptualization of the market mechanism does not account for real-world issues such as migration of tenants, unrented housings and the interaction of economic growth with housing choices, to name but a few. However, this market mechanism balances the choices of tenants and building owners in the model. For example, an increase of the rental price for eeupgraded housings increases the attractiveness of the eeupgrading renovation strategy for building owners. Yet at the same time, it decreases the attractiveness of eeupgraded housing for tenants.

7.5.2 Building Owners' Decision Making and the Supply of Housings

The decision-functions of building owners, qualitatively introduced in Sect. 5.4.1.3, are modeled quantitatively. Figure 7.4 shows the specific structure that was used. As can be seen, building owners are influenced by finances (rent increases), technology
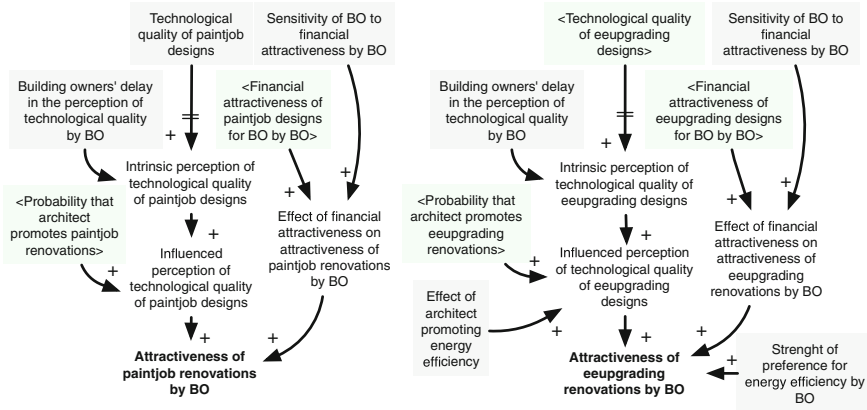
Fig. 7.4 Structure used to model building owners' decision-functions. On the *left* branch the attractiveness of paintjob renovations is calculated, on the *right* branch the attractiveness of eeupgradings is presented

and architects. These three influences are further discussed in the subsequent paragraphs.

Rent Increase from Renovations

After implementing a building renovation, building owners need to increase the rent in order to recapture their investment. This holds for all renovation strategies. As is seen in Eq. 7.4, the EFFECT OF FINANCIAL ATTRACTIVENESS ON ATTRACTIVENESS ON PAINTJOB RENOVATIONS […] (e_finance_p) is calculated as a function of the FINANCIAL ATTRACTIVENESS OF PAINTJOB DESIGNS FOR BO […] (financial_attract) and the SENSITIVITY OF BO TO FINANCIAL ATTRACTIVENESS (sensitivity). The values used for SENSITIVITY OF BO TO FINANCIAL ATTRACTIVENESS are 1.1 for the two profit-oriented building owner types and 0.9 for the two multi-criteria-oriented building owner types. Note that these are not empirical values. Rather, the values for this parameter were set such, that the model produced the behaviour that I deem to be the most likely.

$$e\_finance\_p = financial\_attract^{sensitivity} \tag{7.4}$$

Perception of Technology

The TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS is calculated endogenously. In contrast, the TECHNOLOGICAL QUALITY OF PAINTJOB TECHNOLOGY is assumed to be at its maximum value, set to 0.95 (see Sect. 7.6.1). However, the

technological quality (qual) is not perceived by actors at its current value. Rather, it is modeled with a delay (see Eq. 7.5). This delay only affects eeupgradings because the paintjob technology is considered constant. The delay time is set to be 5 years for non-professional building owners. For professional building owners it is 1 year because they are assumed to be better and more systematically informed. Hence, the INTRINSIC PERCEPTION OF TECHNOLOGICAL QUALITY OF […] DESIGNS (intrinsic_perception) is obtained with a delay. It is called "intrinsic perception", because this is the building owners' perception without the influence of architects.

$$\text{intrinsic\_perception} = \text{DELAY}(\text{qual}, [1 \text{ year}, 5 \text{ years}]) \qquad (7.5)$$

Influence of Architects

Architects influence the building owners' decision making process. In order to account for this, I included building owners' INFLUENCED PERCEPTION OF TECH-NOLOGICAL QUALITY OF […] DESIGNS (influenced_perception) into the model. It is a function of the INTRINSIC PERCEPTION OF TECHNOLOGICAL QUALITY OF […] DESIGNS (intrinsic_perception), of the PROBABILITY THAT ARCHITECTS PROMOTE […] RENOVATIONS (probability) and a parameter called EFFECT OF ARCHITECT PROMOTING ENERGY EFFICIENCY (effect_architect). Equation 7.6 gives the details. Note that the EFFECT OF ARCHITECT PROMOTING ENERGY EFFICIENCY is set to 1 for the two professional types of building owners and to 0.5 for the two non-professional types of building owners. This way, non-professional building owners discount the advice from architects, whereas professional building owners behave like architects.

$$\text{influenced\_perception} = \text{intrinsic\_perception} * \text{probability} * \text{effect\_architect} \quad (7.6)$$

Attractiveness

The ATTRACTIVENESS OF EEUPGRADING RENOVATIONS (A_ee) is calculated as a function of the INFLUENCED PERCEPTION OF TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (influenced_perception_e), of the EFFECT OF FINANCIAL ATTRACTIVENESS ON ATTRACTIVENESS OF EEUPGRADING RENOVATIONS […] (e_finance_e) and of the STRENGTH OF THE PREFERENCE FOR ENERGY EFFI-CIENCY (P_e) (see Eq. 7.7). The STRENGTH OF THE PREFERENCE FOR ENERGY EFFICIENCY expresses the inherent attractiveness of the energy-efficient option to the two multicriteria-oriented building owner types. It is set to 1 for profit-oriented building owners, and it is set to 2 for the others.

$$\text{A\_ee} = \text{influenced\_perception\_e} * \text{e\_finance\_e} * \text{P\_e} \qquad (7.7)$$
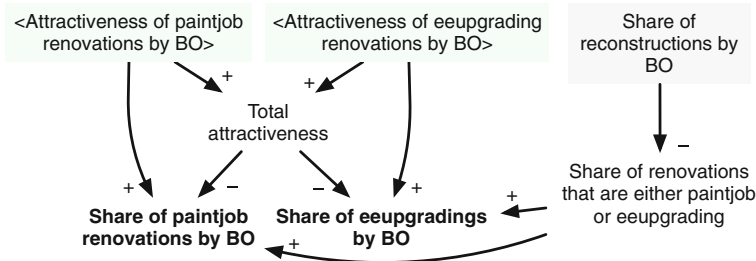
Fig. 7.5 Modeling changes in the shares of the two renovation strategies

Calculation of Relative Shares

In the large simulation model, the shares of paintjob renovations and eeupgradings are calculated endogenously, while the SHARE OF RECONSTRUCTIONS is set constant. Reconstructions occur much less frequently then the other two renovation strategies. Hence, the SHARE OF RECONSTRUCTIONS is set to 0.05 throughout the model's runtime and for each type of building owners.

In order to ensure that the three shares add up to unity, I used the structure shown in Fig. 7.5. This structure compares the ATTRACTIVENESS OF PAINTJOB RENOVATIONS with the ATTRACTIVENESS OF EEUPGRADING RENOVATIONS. The higher the attractiveness of a renovation strategy is, the higher is the share of renovations implementing that renovation strategy. Because the SHARE OF RECONSTRUCTIONS is constant and the shares of the three renovation strategies must add up to unity, the SHARE OF RENOVATIONS THAT ARE EITHER PAINTJOB OR EEUPGRADING can be set to 1-SHARE OF RECONSTRUCTIONS.

More specifically, the TOTAL ATTRACTIVENESS is calculated by adding the ATTRACTIVENESS OF PAINTJOB RENOVATIONS (A_P) to the Attractiveness of eeupgradings (A_E) (see Eq. 7.8).

$$\text{total attractiveness} = A\_P + A\_E \tag{7.8}$$

Based on the total attractiveness, the shares of the two endogenous renovation strategies can be calculated. For example, the SHARE OF EEUPGRADINGS is calculated as a function of the ATTRACTIVENESS OF EEUPGRADING RENOVATIONS (A_E), the TOTAL ATTRACTIVENESS and the SHARE OF RENOVATIONS THAT ARE EITHER PAINTJOB OR EEUPGRADING (share_p_or_e) (see Eq. 7.9). The calculation for the SHARE OF PAINTJOB RENOVATIONS is conducted analogously. Note that this calculation is subscripted and hence it is carried out for each type of building owner.

$$\text{share\_eeupgrading} = \frac{A\_E}{\text{total attractiveness}} * \text{share\_p\_or\_e} \tag{7.9}$$
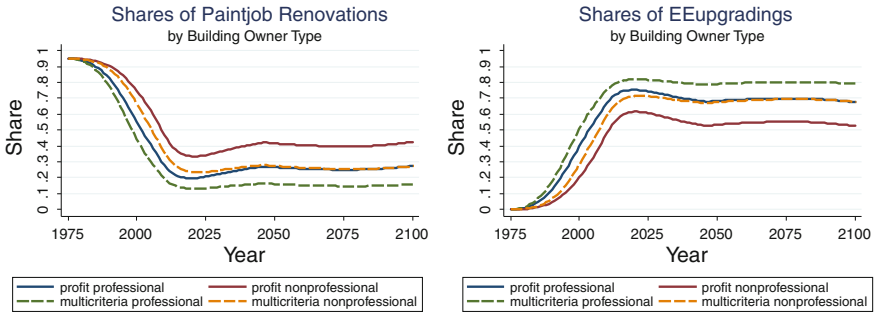
Fig. 7.6 Shares of renovations by building owner type. The shares of renovations conducted with the paintjob strategy are shown on the *left*, the shares of renovations conducted with the eeupgrading strategy are shown on the *right*

Behavior

Upon simulation, the model changes the shares of the two endogenously modeled renovation strategies. Figure 7.6 gives the shares of these two strategies for the four building owner types. As can be seen, a technological substitution process from paintjob renovations to eeupgradings unfolds. More specifically, the SHARE OF EEUPGRAD-INGS begins to rise around the year 1985. It is apparent that non-professional building owners lag behind professional building owners. This is because professional building owners have a delay of 1 year (compared to the 5 years of non-professional BOs). In the light of the theory of the diffusion of innovations (see Sect. 3.6.1), professional building owners can be described as pioneers and early adopters, whereas the non-professional building owners rather belong to the majorities and the laggards. It further is apparent that non-professional building owners have a lower share of eeupgradings. This is mostly because they less frequently rely on professional know-how from architects.

7.5.3 Tenants' Decision Making and the Demand for Housings

Tenant Categories

In Sect. 5.4.2.2, I introduced three different tenant types. These three types are also included into the large model. Table 7.2 gives the share of tenants that belong to each type.

The model structure shown in Fig. 7.7 allows to manipulate the distribution of tenants over the three tenant types. Each stock contains the share of the corresponding tenant type and each stock can flow into any of the other two. For example, the NET CHANGE BETWEEN ECOLOGICALLY CONSCIOUS AND COST-MINIMIZERS (net_change) is a function of the SHARE OF TENANTS BEHAVING AS

Table 7.2 Shares of tenants belonging to each of the three tenant types used in the base scenario

Tenant Type	Share
TENANTS BEHAVING AS COST- MINIMIZERS	0.3
TENANTS BEHAVING AS COST- BENEFIT EVALUATORS	0.6
TENANTS BEHAVING AS ECOLOGICALLY CONSCIOUS	0.1
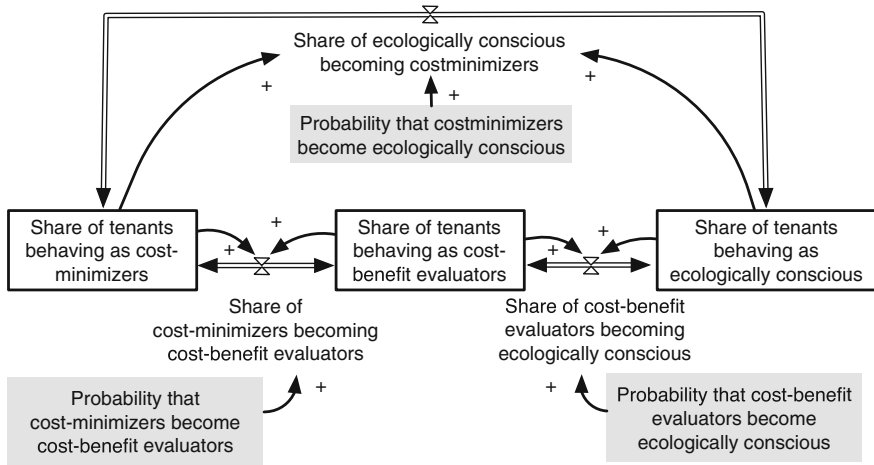
Fig. 7.7 Model structure used to change the distribution of tenants over the three types

COST- MINIMIZERS (STcostmin), the SHARE OF TENANTS BEHAVING AS ECOLOG-
ICALLY CONSCIOUS (STecolog) and an exogenous parameter (s_costmintoeco) (see
Eq. 7.10).

$$\text{net\_change} = \text{STcostmin} * \text{STecolog} * \text{s\_costmintoeco} \qquad (7.10)$$

In the base scenario presented in this chapter, however, the distribution of tenants
over the three types remains constant (i.e, the values for all flows remain zero all the
time). Yet, in Chap. 8 this structure will be used to model changes in the distribution
of tenants over the three types.

In Sect. 5.4.1.3, the decision-functions of tenants were presented qualitatively.
Now I introduce the specific structure and the equations used to simulate tenants'
decision making quantitatively. As seen in Fig. 7.8, two influences determine the
attractiveness of a renovation strategy. These are the cost of renting and the techno-
logical quality of the housing designs. In addition, the attractiveness of eeupgraded
housings is influenced by the UTILITY DRAWN FROM CO- BENEFITS OF ENERGY
EFFICIENCY. I argue that ecologically oriented tenants draw utility from the fact that
a building is energy-efficient and that they value the co-benefits energy efficiency
brings. In contrast, tenants of the cost-minimizer type do not draw any utility from the
fact that a building is energy efficient or from the co-benefits energy-efficiency brings.
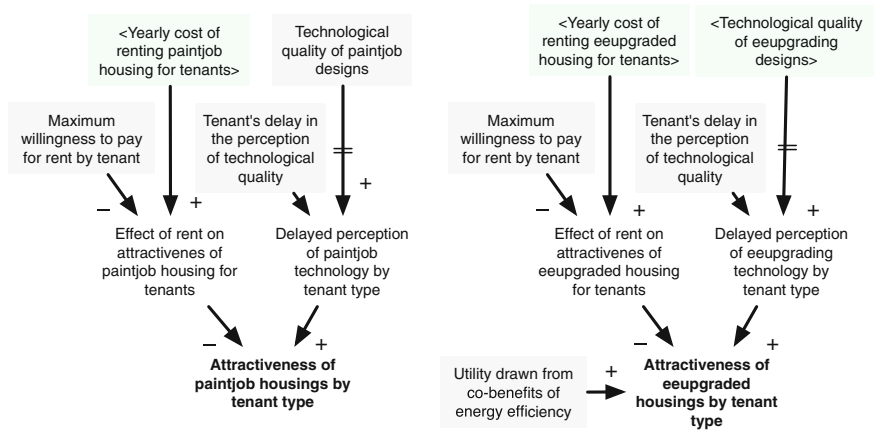
Fig. 7.8 Structure used to model tenants' decision making. The *left* branch shows how the attractiveness of paintjob renovations is calculated, the *right* branch shows the same for eeupgradings

Cost of Renting

For both housing types, the EFFECT OF RENT ON ATTRACTIVENESS […] (effect _rent) is calculated as a function of the YEARLY COST […] (cost) and the MAXIMUM WILLINGNESS TO PAY […] (maximum) as seen in Eq. 7.11. The values used for the SENSITIVITY […] are -0.9 for cost-minimizer tenants, -1 for evaluator tenants and -1.1 for ecological tenants. This expresses that the cost-minimizer tenants are the ones that are most sensitive to the cost of renting, whereas the ecological tenants are the least sensitive to the cost of renting.

$$\text{effect\_rent} = \frac{(\text{maximum} - \text{cost})}{\text{maximum}} \qquad (7.11)$$

Perception of Technology

Tenants perceive the state of technology with a delay. The DELAYED PERCEPTION OF TECHNOLOGY […] (delayed_perception_tech) is the actual TECHNOLOGICAL QUALITY […] (quality) with a delay of 5 years in the case of costminimizers and evaluators and 1 year in the case of ecologically oriented tenants. This expresses that ecologically oriented building owners are more likely to be informed about the current state of technology.

$$\text{delayed\_perception\_tech} = \text{DELAY}(\text{quality}, [1 \text{ year}, 5 \text{ years}]) \qquad (7.12)$$
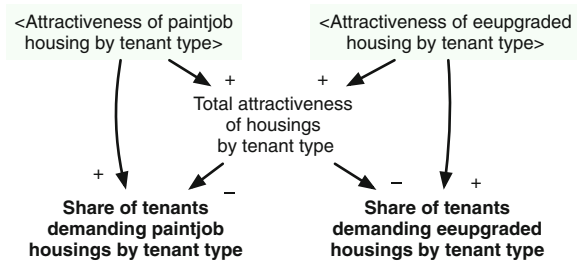
Fig. 7.9 Structure used to model changes in the share of tenants searching the two housing types
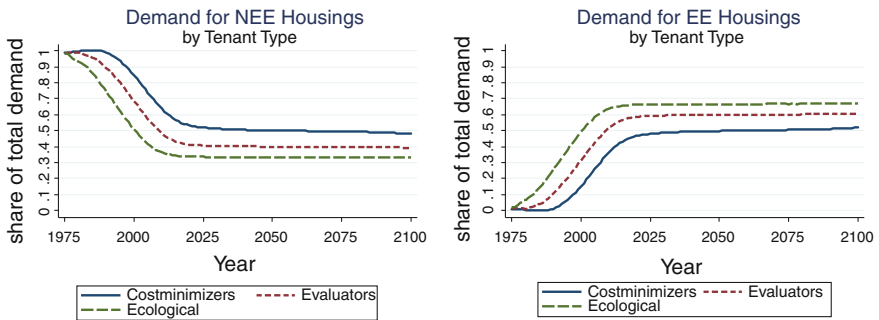
Fig. 7.10 Share of tenants demanding paintjob housings (*left*) and eeupgraded housings (*right*). The behavior is shown for each tenant type

Attractiveness of Housing Types for Tenants

The ATTRACTIVENESS OF […] HOUSINGS BY TENANT TYPE (attractiveness) is calculated as a function of the perception of technology (percT) and the EFFECT OF RENT (effR). In addition, the attractiveness of eeupgrading housings are influenced by the UTILITY DRAWN FROM CO- BENEFITS OF ENERGY- EFFICIENCY (utility). Equation 7.13 shows how the attractiveness of eeupgraded housings is calculated.

$$\text{attractiveness} = \text{percT} * \text{effR} * \text{utility} \qquad (7.13)$$

Calculation of Relative Shares

In order to ensure that the SHARE OF TENANTS DEMANDING PAINTJOB HOUSINGS […] and the SHARE OF TENANTS DEMANDING EEUPGRADED HOUSINGS […] add up to unity, the structure shown in Fig. 7.9 was used. This structure compares the ATTRACTIVENESS OF PAINTJOB HOUSING […] with the ATTRACTIVENESS OF EEUPGRADED HOUSING […]. The higher the attractiveness of a housing type is, the higher is the share of tenants demanding housing of that type.

The TOTAL ATTRACTIVENESS […] is calculated by adding up the ATTRACTIVE-NESS OF PAINTJOB HOUSING […] and the ATTRACTIVENESS OF EEUPGRADED HOUSING […] together. Then, for example, the SHARE OF TENANTS SEARCHING PAINTJOB HOUSINGS […] (sP) is calculated by dividing the ATTRACTIVENESS OF PAINTJOB HOUSING […] (attrP) through the TOTAL ATTRACTIVENESS […] (total), as seen in Eq. 7.14.

$$sP = \frac{attrP}{total} \tag{7.14}$$

Behavior

Figure 7.10 shows the resulting behavior in the base scenario. It shows the SHARE OF TENANTS DEMANDING PAINTJOB HOUSINGS BY TENANT TYPE on the left exhibit, and the SHARE OF TENANTS DEMANDING EEUPGRADED HOUSINGS BY TENANT TYPE on the right.[2] As can be seen, all three tenant types follow a similar dynamic. The share of tenants searching paintjob housing falls from unity and stabilizes at a lower level in an s-shaped movement. Correspondingly, the share of tenants searching eeupgraded housing rises. However, tenants of the type *ecological* rise first, followed by *evaluators* and eventually *costminimizer*. In the light of the theory of the diffusion of innovations (Rogers 2003), the ecological tenant type can be described as a pioneer and as an early adopters. The evaluator tenant type roughly corresponds to the early majority, while the costminimizer tenant type roughly corresponds to the late majority and the laggards.

7.5.4 Rental Prices and Costs of Renting

Rental prices for housings after renovation are calculated from three elements:

- The **BASE RENT** is the rent that tenants pay prior to the renovation. It reimburses the building owner for the cost of the land and the costs of the elements of the house that remained untouched by the renovation.
- The **CONSTRUCTION COST COMPONENT** is the part of the rent that allows building owners to recover the investment costs of the renovation.
- The **MARKET PRICE COMPONENT** is the surcharge that building owners can charge if they encounter high demand. It can also be conceived of as the discount building owners have to give to tenants when the demand for their housing is low.

These three components are paid by tenants and received by building owners. In addition, tenants pay for the cost of heating. Therefore, those costs also need to be

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[2] Remember that the market scope is limited to the buildings under renovation. Hence, this figure does not show the share of tenants renting paintjob or eeupgraded housing in the whole stock of buildings. It only refers to those buildings that are under renovation (see Sect. 7.5.1).
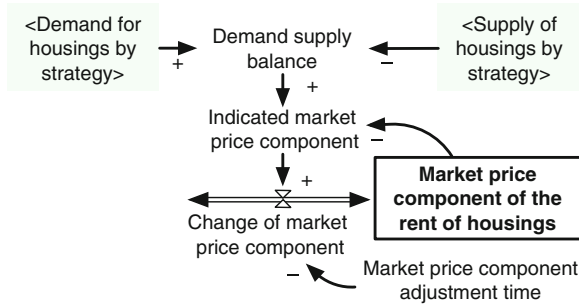
Fig. 7.11 Structure used to model the market component of rental prices

included in the costs of renting. In the following, I introduce the structures used to model the formation of rental prices for the two housing types.

7.5.4.1 Market Price Component

Figure 7.11 shows the structure used to implement the market mechanism. This structure compares demand and supply for the two types of housing and adjusts the market price component so that supply and demand for the two types of housing are equal.

More specifically, the DEMAND SUPPLY BALANCE (balance) is calculated according to Eq. 7.15 (paintjob housings are calculated in analogy).

$$\text{balance} = \frac{\text{demand for eeupgraded housings} + 1}{\text{supply of eeupgraded housings} + 1} \tag{7.15}$$

Adding the value 1 to both terms protects against divisions through zero. Such a division cannot be processed by the simulation software. When demand and supply are equal, the demand supply balance takes a value of 1. If, for example, there is more demand than supply, the value increases above 1, indicating that prices should rise. The indicated rent […] (rent_indicated) is calculated according to Eq. 7.16. Then, the corresponding CHANGE IN INDICATED MARKET PRICE […] (rent_change) is calculated according to Eq. 7.17.

$$\text{rent\_indicated} = \text{balance} * \text{market price component} \tag{7.16}$$

$$\text{rent\_change} = \frac{\text{indicated rent} - \text{rent for housings}}{\text{adjustment time}} \tag{7.17}$$

The MARKET PRICE […] ADJUSTMENT TIME is set to 3 years. The initial value of the MARKET PRICE COMPONENT […] is set to 0.01. Figure 7.12 shows the behavior of the MARKET PRICE COMPONENT OF THE RENT OF HOUSINGS for the two housing types in the base scenario. As can be seen in this figure, the market price
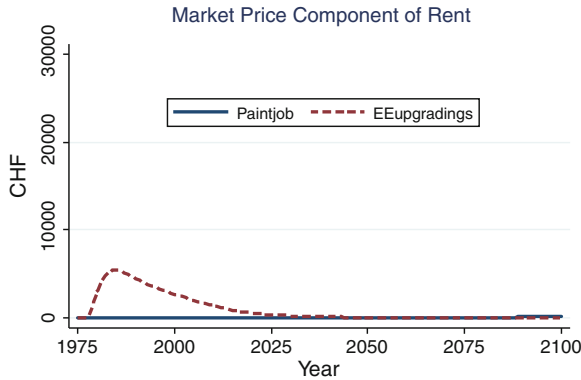
Fig. 7.12 Behavior of the market component of the rental prices of the two housing types

component of eeupgradings rises over the first 10 years or so. This rise occurs in a period when no eeupgradings were implemented and hence it should not be interpreted to be of significance. Rather, this rise is caused by the model starting up and aiming for an equilibrium. The subsequent reduction of the market price component, however, is caused by increased supply relative to demand. As supply and demand come closer to equilibrium, the MARKET PRICE COMPONENT OF THE RENT OF HOUSINGS is gradually reduced to zero.

7.5.4.2 Calculation of Heating Costs

The cost of heating a housing was calculated based on oil and gas heating systems only. In the calculations I considered the four different types of floor space differentiated over heating system (oil/gas) and efficiency (non-energy-efficient/energy-efficient). I further considered the average energy efficiency of non-energy-efficient and energy-efficient floor space, the average efficiency of oil and gas heating systems and the cost of oil and gas.

The exhibit on the left of Fig. 7.13 shows the price of heating fuels used in the calculations. I used real prices of the year 2000 rather than current prices. The values until the year 2008 are historic values. The values 2009–2100 were derived based on trajectories from the IEA/OECD (2008, 68p). However, the prices on the IEA's trajectory cannot be directly put into the model as they do not include taxes and other costs specific to Switzerland. Therefore, I anchored the trajectories of the IEA to the average value of the years 2007 and 2008. This means that the price remains constant until the year 2015, and then grows at roughly 1.5 % per year.

The exhibit on the right of Fig. 7.13 shows the average costs of heating the two types of housings. As can be seen, the costs of heating rise more slowly as compared to the prices of fuels. This is because the efficiency of heating systems rises and because the energy-efficiency of both types of housings gradually improves over time.
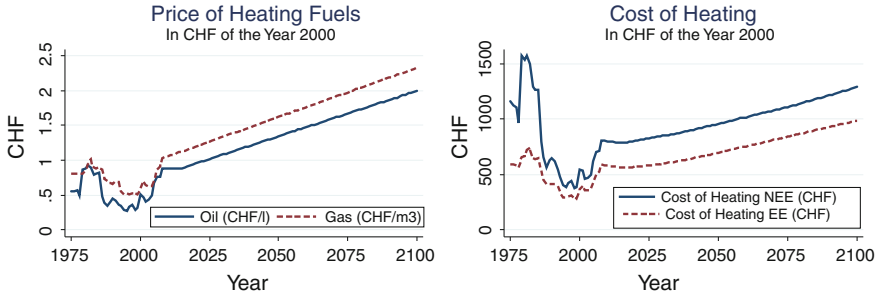
Fig. 7.13 Past and projected prices for heating oil and gas (*left exhibit*). Past and projected costs of heating the two types of housing (*right exhibit*). Source: Data from BFS (n.d.) and own calculations and assumptions. Projections (2008–2100) were assumed by approximately inter- and extrapolating projections by IEA/OECD (2008, p. 67)

7.5.4.3 Construction Cost Component, Base Rent and Total Rents and Costs

Model Structure

Figure 7.14 shows the structure used to calculate the construction cost component and derive the rent paid by tenants. On the left side of the figure the calculations for the paintjob housings are shown. On the right side the calculations for the eeupgraded housings are shown.

For both housing types, the CONSTRUCTION COST COMPONENT […] (component _construction) per housing is calculated as a function of the CURRENT REAL CONSTRUCTION COST […] (cost_construction), the BO'S PROFIT MARGIN […] (margin) and the number of HOUSINGS PER BUILDING (number) (see Eq. 7.18). The BO'S PROFIT MARGIN […] is set to 0.08 for the two profit-oriented building owner types and it is set to 0.05 for the two multi-criteria-oriented building owner types.
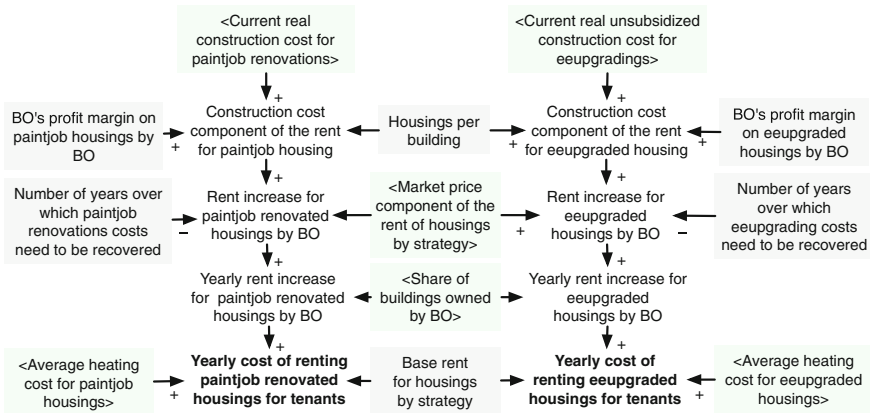
Fig. 7.14 Structure used to model the rent received by BOs and the cost of renting for tenants

$$\text{component\_construction} = \frac{\text{cost\_construction} * (1 + \text{margin})}{\text{number}} \qquad (7.18)$$

Then, the RENT INCREASE [...] (rentincrease) is calculated as a function of the CONSTRUCTION COST COMPONENT [...] (component_construction), the NUMBER OF YEARS OVER WHICH [...] RENOVATIONS COSTS NEED TO BE AMORTIZED (years) and the MARKET PRICE COMPONENT (component_market) of the corresponding renovation strategy (see Eq. 7.19).

$$\text{rentincrease} = \text{component\_market} + \frac{\text{component\_construction}}{\text{years}} \qquad (7.19)$$

Note that I do not consider the time value of money in the model. Instead, I use a linear amortization scheme. I conduct this simplification because in earlier implementations of the model I found that discounting future rental streams yielded no additional insight and in fact produced unrealistic results. Due to the long time periods involved, differences between income streams, for example, tended to 'evaporate' in the long run. Further, rents tend to be increased over time in order to account for inflation. What is more, my model is so highly aggregated that detailed modeling of discounted income streams does not yield more insight than using a linear function. Hence, I consciously choose the simplified, linear implementation described above. The NUMBER OF YEARS [...] was set to 25 years for both housing types.

Finally, the YEARLY COST OF RENTING [...] HOUSING FOR TENANTS can be calculated by adding the AVERAGE HEATING COST [...] and the BASE RENT to the RENT INCREASE FOR [...] RENOVATED HOUSINGS. After renovation, building owners receive the sum of BASE RENT and YEARLY RENT INCREASE [...] (model structure not shown).

Behavior

Figure 7.15 shows the total rent received by building owners after renovation in the exhibit on the left. The yearly cost of renting housing paid by tenants are shown in the exhibit on the right of that figure. As can be seen, the rent for eeupgraded housings initially rises strongly. This initial rise is due to the model initializing and trying to find a balance. Because in the early years of the diffusion process no eeupgradings are implemented, this initial rise of the rent is not significant. Eventually, however, the high rental price for eeupgradings sinks and eventually converges toward zero, as the model reaches its steady state.
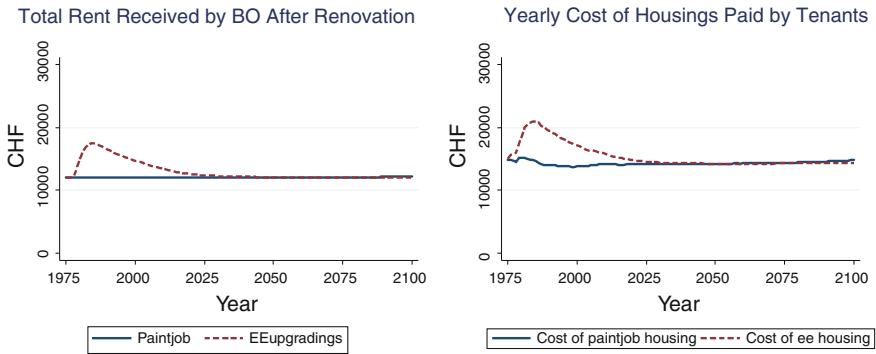
Fig. 7.15 Behavior of housing market variables

7.5.4.4 Auxiliary Calculations

Calculation of Total Supply and Demand

It is necessary to calculate the supply of buildings renovated by the two strategies over all building owner types. Further, it is necessary to calculate the demand of housings of the two housing types over all tenant types. This is achieved by summing up the values for each building owner or tenant type (represented by subscripts in the equations). As this does not yield any particular insight I do not describe this and refer to the published model (see the electronic supplement). There, further details can be found.

Calculation of Cumulated Implementations

Fur subsequent calculations, the CUMULATED NUMBER OF EEUPGRADING REN-OVATIONS and the CUMULATED NUMBER OF PAINTJOB RENOVATIONS need to be tracked. This is done with a stock-and-flow structure (not shown) where the number of renovations according to each strategy is added to the corresponding stock.

7.6 Technology (Module 3)

Instead of modeling specific technologies such as ventilation, insulation, planning or system integration, I limit my analysis of technology to building designs. Specifically, I assume the existence of a building design for paintjob renovations and a building design for eeupgradings. Hence, the term *technology* refers to whole building designs.

In order to understand the role of technology in the diffusion process, both the *technological quality* as well as the *costs of implementing* the two building designs

need to be considered. In the following, I first show the structures used to model changes in the technological quality (see Sect. 7.6.1). Then I show the structures used to model costs (see Sect. 7.6.2). Finally, I discuss the reactions of architects to changes in the quality of energy-efficient building designs (see Sect. 7.6.3).

7.6.1 Technological Quality of the Two Renovation Strategies

Index of Technological Quality

The technological quality of both renovation strategies is operationalized with an index of technological quality. This index runs from 0 to 1. A value of 0 implies that the technology is not available. A value of 1 implies that the technology is matured and that every application of it succeeds. By interpreting this index in a probabilistic manner, the values between 0 and 1 can be interpreted as the probability that the application of the technology succeeds. However, the fact that the maturing of the technological quality is expressed quantitatively should not distract from the fact that I use this index in a conceptual rather than in a strictly empirical manner. I express the idea that in the year 1975 the technology required to implement an energy-efficient renovation was not yet matured and that such an endeavor implied a substantial risk of failure. As energy-efficient building designs become better, the risk of failure is reduced.

Only the eeupgrading technology is modeled in a dynamic way. This is because I assume that the technology for conducting paintjob renovations is generally available with minimal risk. In order to account for some minimal risk despite being technologically matured, the technological quality of paintjob renovations is set to a value of 0.95.

As seen in Fig. 7.16, the TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS is modeled as a stock. It is increased by a flow (INCREASES IN TECHNOLOGICAL QUALITY […]). The initial value of the stock is set to 0.01. In order to control the stock such that it does not rise beyond the MAXIMAL TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS, I calculate the ROOM FOR IMPROVING THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS as the positive difference between the MAXIMUM TECHNOLOGICAL QUALITY […] and the stock. As the TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS rises, the room for improvements converges towards zero. The maximum value eeupgrading technology can reach is set to 0.95.

As seen in Eq. 7.20, the flow rate INCREASE IN TECHNOLOGICAL QUALITY […] (increase_technology) is calculated as a function of the EFFECT OF PUBLIC R&D EXPENDITURES[…] (effRD), the EFFECT OF LEARNING […] (effL) and the ROOM FOR IMPROVING EEUPGRADING TECHNOLOGY (room).

$$\text{increase\_technology} = (\text{effRD} + \text{effL}) * \text{room} \qquad (7.20)$$
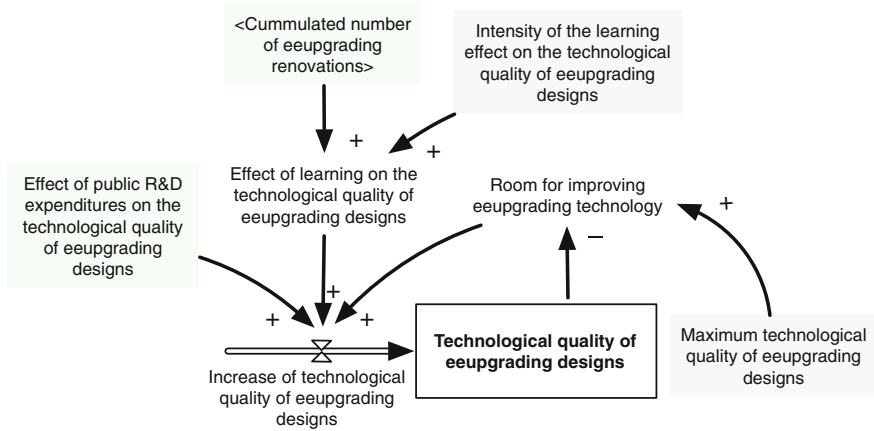
Fig. 7.16 Structure used to model the improvement of the technological quality of eeupgrading designs. As the cumulated number of eeupgradings and the intensity of R&D as a result of political intervention increase, the technological quality of eeupgrading designs increases

The EFFECT OF LEARNING [...] (effL) is calculated as a function of the CUMU-LATED NUMBER OF EEUPGRADED RENOVATIONS (cumulated) and the INTENSITY OF THE LEARNING EFFECT [...] (Intensity_effL) (see Eq. 7.21). The INTENSITY OF THE LEARNING EFFECT [...] is a parameter that is used to calibrate the model and it is set to $1.2*10^{-5}$. Note that the calculation of the EFFECT OF PUBLIC R&D EXPENDITURES [...] will be described in greater detail in Sect. 7.7.2.

$$effL = Intensity\_effL * cumulated \qquad (7.21)$$

Model Behavior

The two parameters INTENSITY OF THE LEARNING EFFECT [...] and INTENSITY OF THE EFFECT OF PUBLIC R&D [...] were set such that the behavior of the two effects on technological quality became plausible. This means that the EFFECT OF PUBLIC R&D [...] should be important in the early phase of the diffusion process. Eventually, the EFFECT OF LEARNING [...] should become the more important effect (see the exhibit on the right in Fig. 7.17).

As seen in the left exhibit of Fig. 7.17, paintjob technology is constant whereas the quality of the eeupgrading technology rises in an s-shaped manner. Starting from nearly zero in the year 1975 it reaches a value of about 0.55 in the year 2000 and continues to converge towards its maximum value. The right exhibit of Fig. 7.17 shows the behavior of the EFFECT OF PUBLIC R&D and the EFFECT OF LEARN-ING [...]. Two things are noteworthy in that figure. First, the effect of R&D was set to somewhat predate the effect of learning. This is adequate because publicly funded R&D initiates technological improvements, whereas the construction indus-
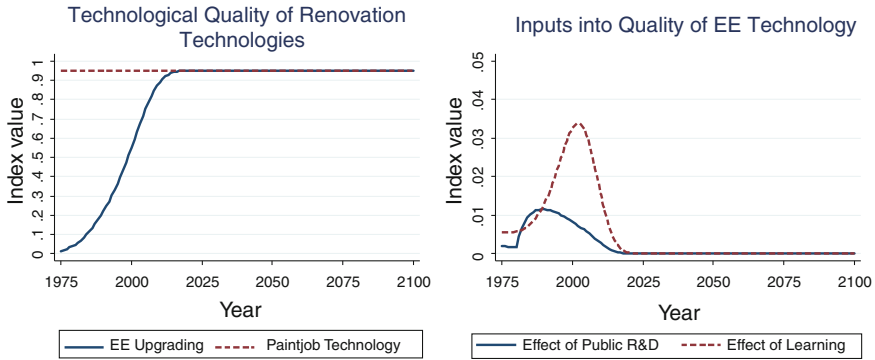
Fig. 7.17 The exhibit on the *left* shows the behavior of the technological quality of the paintjob and the eeupgrading renovation strategies. The exhibit on the *right* shows the behavior of the EFFECT OF PUBLIC R&D EXPENDITURE […] and the EFFECT OF LEARNING […]. These two inputs change the technological quality of the eeupgrading renovation strategy

try reaps the benefits of learning. Second, the effect of learning is 2 to 3 times bigger than the effect of publicly funded R&D. This means that most of the technological improvements come from industrial R&D efforts rather than publicly funded R&D.

The model was calibrated such that the EFFECT OF PUBLIC R&D roughly reproduces the empirical data on Swiss government expenditures for energy efficiency research and development presented in Chap. 3 (see Fig. 3.6 on p. 97). Note that the EFFECT OF PUBLIC R&D in the large simulation model converges toward zero, whereas the empirical government expenditures for R&D begin to rise after the year 2005. In my model I assume that energy-efficient renovations eventually cease being innovations and hence are no longer supported by public R&D.

7.6.2 Construction Costs of the Renovation Strategies

Figure 7.18 shows the structure used to model changes of the construction costs of the two renovation strategies. The most important driver of cost reductions are learning effects, brought about by the accumulation of experience with a particular renovation strategy. In addition, the costs of eeupgrading are increased by costs brought about by stricter regulations and the costs of eeupgrading are reduced by subsidies given for eeupgradings.

Specifically, the EFFECT OF LEARNING ON CONSTRUCTION COST […] (effect_learning) is calculated as a function of the CUMULATED NUMBER OF […] RENOVATIONS (cumulated), the INITIAL CUMULATED NUMBER OF […] RENOVATIONS (initial) and the LEARNING COEFFICIENT(coefficient) as seen in Eq. 7.22. The INITIAL CUMULATED NUMBER OF […] RENOVATIONS was set to 20 000 for paintjob renovations and to 500 for eeupgradings.
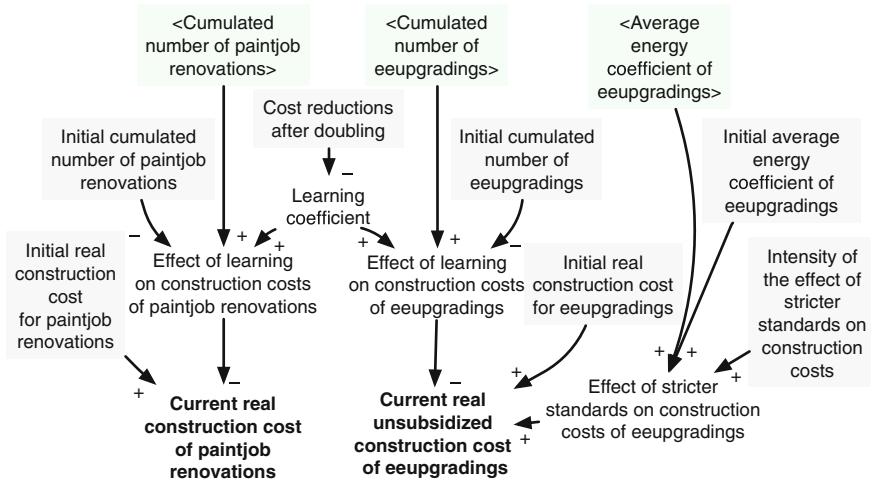
Fig. 7.18 Structure used to model the construction costs for the paintjob and for the eeupgrading renovation strategy. On the *left* branch, paintjob renovations are shown and on the *right* branch eeupgradings are shown

$$effect\_learning = \left(\frac{cumulated}{initial}\right)^{coefficient} \tag{7.22}$$

The LEARNING COEFFICIENT (coefficient) was calculated as a function of COST REDUCTIONS AFTER DOUBLING (reductions) as seen in Eq. 7.23. The formulation of Eqs. 7.22 and 7.23 follows Sterman (2000, p. 338).

$$coefficient = \log_2(1 - reductions) \tag{7.23}$$

The CURRENT REAL UNSUBSIDIZED CONSTRUCTION COST FOR PAINTJOB RENOVATIONS (cost_ paintjob) is calculated as a function of the INITIAL REAL CONSTRUCTION COST FOR PAINTJOB RENOVATIONS (initialpcost) and the EFFECT OF LEARNING ON CONSTRUCTION COST OF PAINTOB RENOVATIONS (effectp) (see Eq. 7.24).

$$cost\_paintjob = initialpcost * effectp \tag{7.24}$$

Similarly, the CURRENT REAL UNSUBSIDIZED CONSTRUCTION COST FOR EEUPGRADINGS (cost_ eeupgrading) is calculated as a function of the INITIAL REAL CONSTRUCTION COST FOR EEUPGRADINGS RENOVATIONS (initialeecost) and the EFFECT OF LEARNING ON CONSTRUCTION COST OF EEUPGRADINGS (effectee). To that, the EFFECT OF STRICTER STANDARDS […] (effectstandard) is added (see Eq. 7.25).

$$cost\_eeupgrading = (initialeecost * effectee) + effectstandard \tag{7.25}$$
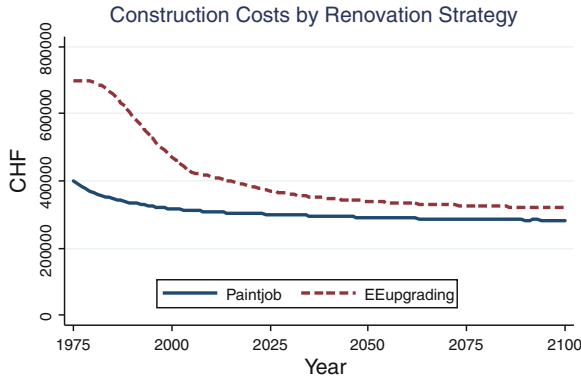
Fig. 7.19 Construction costs for the two renovation strategies. Prices are in real prices of the year 2000. Subsidies are not (yet) considered

The EFFECT OF STRICTER STANDARDS […] (effectstandard) is calculated as a function of the AVERAGE ENERGY COEFFICIENT OF EEUPGRADINGS (coefficient), the INITIAL AVERAGE ENERGY COEFFICIENT OF EEUPGRADINGS (initial) and the parameter INTENSITY OF THE EFFECT OF STRICTER ENERGY STANDARDS […] (param) (see Eq. 7.26).

$$\text{effectstandard} = \text{param} * (\text{initial} - \text{coefficient}) \tag{7.26}$$

Figure 7.19 shows the behavior of the construction costs for the two renovation strategies in the base scenario. As can be seen, the cost of eeupgradings is initially much higher than the cost of paintjob renovations. Over time, learning effects significantly reduce the cost of eeupgradings. Note that the prices given here are not strictly empirical. In the early years, no energy-efficient renovations were conducted, due to the very low levels of technological quality. In line with standard practice in System Dynamics modeling, I use the construction costs as an operationalization of changes. Here, I want to express that the construction costs of energy-efficient renovations are higher than the costs of paintjob renovations. Further, I want to express that the potential for cost reductions is higher for energy-efficient renovations. This is because they start as an innovation, whereas paintjob renovations have become standard practice.

7.6.3 Architects' Reactions to Technological Change

Structure

Figure 7.20 shows the structure used to model architects' response to technological progress. As the quality of the technology for energy-efficient renovations increases,
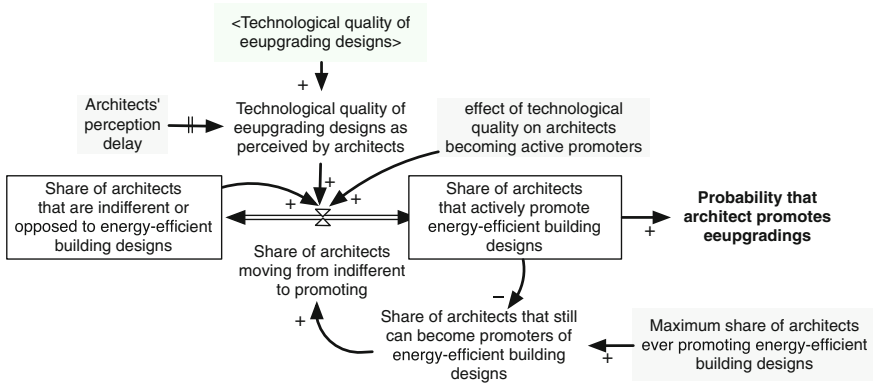
Fig. 7.20 Structure used to model architects' response to technological progress

the share of architects that actively support energy-efficient building designs also rises. There are two stocks, one representing the SHARE OF ARCHITECTS THAT ARE INDIFFERENT OR OPPOSED TO EE BUILDING DESIGNS, and one representing the SHARE OF ARCHITECTS THAT ACTIVELY PROMOTE EE BUILDING DESIGNS. The two stocks add up to unity. They are connected by a flow called SHARE OF ARCHITECTS MOVING FROM INDIFFERENT TO PROMOTING. For positive values of the flow rate, the SHARE OF ARCHITECTS THAT ACTIVELY PROMOTE EE BUILDING DESIGNS is increased. By interpreting the SHARE OF ARCHITECTS THAT ACTIVELY PROMOTE […] in a probabilistic manner, I set it equal to the PROBABILITY THAT ARCHITECTS PROMOTE ENERGY EFFICIENCY.

The TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS AS PERCEIVED BY ARCHITECTS (quality_architects) is calculated as a function of technological quality of eeupgrading designs (quality). It is calculated with a delay of 1 year (see Eq. 7.27). The very short time delay occurs because architects are expected to be quite well informed about technological developments in their field.

$$\text{quality\_architects} = \text{DELAY}(\text{quality}, 1 \text{ year}) \qquad (7.27)$$

I set the MAXIMUM SHARE OF ARCHITECTS EVER PROMOTING ENERGY-EFFICIENT BUILDING DESIGNS to 0.75. The SHARE OF ARCHITECTS THAT STILL CAN BECOME PROMOTERS […] is then the positive difference between the MAXIMUM SHARE […] and the SHARE OF ARCHITECTS THAT ACTIVELY PROMOTE […]. I set a value below 1 because it is not plausible that all architects will support energy-efficient building designs. A value of 0.75 seems plausible because it signifies a solid majority of active promoters while allowing for a substantial minority of architects that are indifferent or opposed.

The SHARE OF ARCHITECTS MOVING FROM INDIFFERENT TO PROMOTING (change_architects) is calculated as a function of the SHARE OF ARCHITECTS THAT STILL CAN BECOME PROMOTERS […] (S), TECHNOLOGICAL QUALITY OF EEUP-
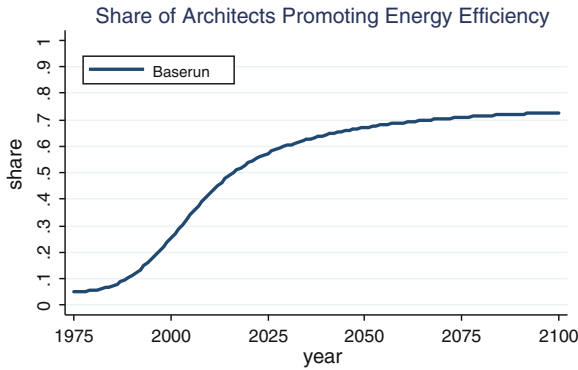
Fig. 7.21 Probability that architects promote energy efficiency

GRADING DESIGNS AS PERCEIVED BY ARCHITECTS (TQA) and a parameter called
EFFECT OF TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS ON ARCHI-
TECTS BECOMING ACTIVE PROMOTERS (e) (see Eq. 7.28). The parameter e has
a value of 0.09. That value was set such that the SHARE OF ARCHITECTS THAT
ACTIVELY PROMOTE EE BUILDING DESIGNS […] exhibits a gradual rise.

$$\text{change\_architects} = S * TQA * e \qquad (7.28)$$

Model Behavior

Figure 7.21 shows the behavior of the SHARE OF ARCHITECTS THAT ACTIVELY
PROMOTE EE BUILDING DESIGNS. It follows the s-shaped curve that is typical for
social diffusion processes (Rogers 2003). The share of architects promoting eeup-
gradings rises most between about 1995 and 2025 and then gradually converges
towards the maximum value at 0.75. This is consistent with findings of Meier (2007).

7.7 Civil Society and State Interventions (Module 4)

7.7.1 Civil Society

Modeling Policy Change

Figure 7.22 shows the structure used to model the drivers of policy change in civil
society. The two advocacy coalitions are each represented by a stock, with the
INCREASE IN POWER […] (increase) as the connecting flow rate. The flow rate is
calculated as a function of the INDICATED POWER […] (indicated), the POWER OF
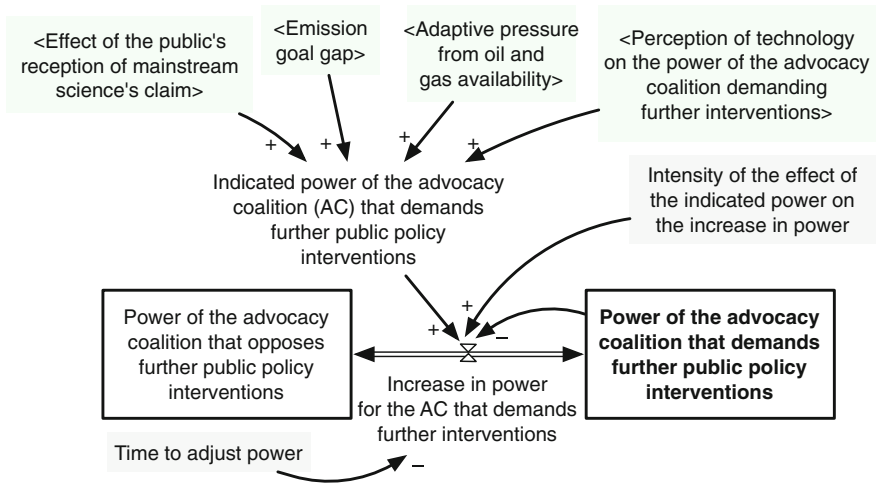
Fig. 7.22 Structure used to model the impact of the four drivers of policy change on the balance of the advocacy coalitions

THE ADVOCACY COALITION THAT DEMANDS FURTHER PUBLIC POLICY INTER-VENTIONS (power) and two parameters. These are the multiplicative scaling parameter INTENSITY OF THE EFFECT […] (intensity) and the TIME TO ADJUST POWER (delay) set to 4 years which is used to delay the adjustment of the stock to the indicated value. Equation 7.29 shows how the flow rate is calculated:

$$\text{increase} = \frac{(\text{indicated} * \text{intensity}) - \text{power}}{\text{delay}} \tag{7.29}$$

The INDICATED POWER OF THE ADVOCACY COALITION […] (indicated) is calculated as a function of the following four drivers of policy change.

- Driver 1: EFFECT OF THE PUBLIC'S RECEPTION OF MAINSTREAM SCIENCE'S CLAIM (eff_climate)
- Driver 2: EFFECT OF EMISSIONS RATIO ON INDICATED POWER (eff_CO$_2$)
- Driver 3: ADAPTIVE PRESSURE FROM OIL AND GAS ENERGY AVAILABILITY (AP)
- Driver 4: EFFECT OF THE PUBLIC'S PERCEPTION OF EEUPGRADING TECHNOL-OGY (eff_tech).

Equation 7.30 shows how the indicated power is calculated. Note that the variables related to climate change (ratio, eff_climate, eff_tech) are multiplied with each other. This is because for maximal pressure from the climate discourse, all three variables need to be high. In contrast, the adaptive pressure from oil and gas availability is independent from the climate discourse. Therefore, it is modelled as additive. In the following, the four inputs into this model structure are discussed.

$$\text{indicated} = (\text{eff\_climate} * \text{eff\_CO}_2 * \text{eff\_tech}) + \text{AP} \qquad (7.30)$$

Driver 1: Effect of the Public's Reception of Mainstream Science's Claim
(eff_climate)

The variable MAINSTREAM SCIENCE'S BELIEF IN CLIMATE CHANGE captures the
fact that mainstream science has accumulated increasingly strong evidence that
anthropogenic climate change is a problematic fact (see Chap. 3). This driver of
policy change is operationalized with an index. It runs between 0 and 1. A value
of 0 denotes that mainstream science has not developed any evidence regarding the
problematic nature of climate change. A value of 1 denotes that mainstream science
has settled on a generally accepted consensus. In the situation of such a consensus,
there is no dissent in the scientific community. The maximum value that this variable
takes in the base scenario is set to a value of 0.95. This is to account for the fact that
there probably will never by completely unanimous consent.

The specific behavior of this variable is based on the following reflections: In the
year 1975 there was no broad consensus in mainstream science that climate change
would be problematic issue. In contrast, when the IPCC received the nobel peace
price in the year 2007, a crucial milestone in the recognition of climate change was
reached. I thus set the value to 0.9 in that year. In order to move from zero to the
maximum value, the variable was set to follow an s-shaped growth pattern. In order
to derive the EFFECT OF THE PUBLIC'S RECEPTION OF MAINSTREAM SCIENCE ON
INDICATED POWER (eff_climate), MAINSTREAM SCIENCE'S CONFIDENCE IN THE
PROBLEMATIC NATURE OF CLIMATE CHANGE (confidence) was delayed by 5 years
(see Eq. 7.31). The top left exhibit in Fig. 7.24 shows the behavior of the resulting
EFFECT OF THE PUBLIC'S RECEPTION OF MAINSTREAM SCIENCE ON INDICATED
POWER.

$$\text{eff\_climate} = \text{DELAY}(\text{confidence, 5 years}) \qquad (7.31)$$

Driver 2: Effect of Emissions Ratio on Indicated Power (eff_CO$_2$)

Figure 7.23 shows the structure that was used to model the impact of CO_2 emission
rates on the INDICATED POWER OF THE ADVOCACY COALITION THAT DEMANDS
FURTHER PUBLIC POLICY INTERVENTIONS. The CURRENT CO_2 EMISSIONS FROM
BUILDINGS (emissions) is calculated by the building sector, as described in Chap. 4.
The LEVEL OF YEARLY EMISSIONS OF CO_2 COMPATIBLE WITH THE 2° GOAL
(level) is set to 500 000 tons per year.[3] I define this variable to be a scientifically
determined emission rate rather than a politically determined emission target. I argue

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[3] Note that this figure is an educated assumption. The role of this structure is to explain how
changes of the actual emissions impact on the power of the advocacy coalition. The dynamics that
this structure produces are rather insensitive to the precise figure set for the LEVEL OF YEARLY
EMISSIONS OF CO_2 COMPATIBLE WITH THE 2° GOAL.

Fig. 7.23 Structure used to
model the effect of a CO_2 goal
gap
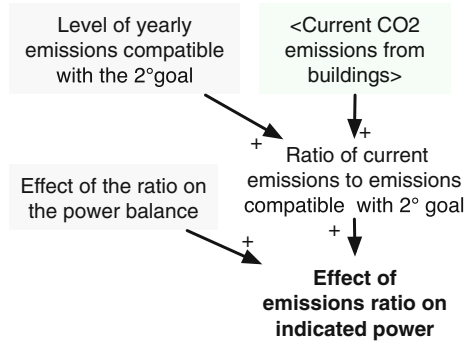
that it is the deviation from the scientific rate that motivates political action. Politically set emission targets are a response to the claims-making of political actors. In my observation the politically determined emission rates have generally been substantially above the emission rate called for by the scientific community.

Equation 7.32 shows that the EFFECT OF EMISSIONS RATIO ON INDICATED POWER (eff_CO_2) is calculated by dividing the CURRENT CO_2 EMISSIONS […] (current) by the LEVEL OF YEARLY EMISSIONS OF CO_2 COMPATIBLE WITH THE 2° GOAL (goal). The variable EFFECT OF THE RATIO ON THE POWER BALANCE (parameter) is used to calibrate the model.

$$\text{eff\_CO}_2 = \frac{\text{current}}{\text{goal}} * \text{parameter} \tag{7.32}$$

Driver 3: Adaptive Pressure from Oil and Gas Energy Availability (AP)

In order to model the effect of the gradually depleting fossil energy resources, I use an index of oil and gas availability. It is operationalized to take values between 0 and 1. A value of 0 denotes a situation where there are no concerns about the availability of oil and gas supplies in Switzerland. In contrast, a value on the index near one would characterize a situation where fossil energy resources are perceived as almost completely depleted. The bottom left exhibit in Fig. 7.24 shows the behavior of the ADAPTIVE PRESSURE FROM OIL AND GAS AVAILABILITY. As can be seen, the pressure gradually rises from about 0.133 in the year 1975 to about 0.297 in the year 2100. This modest rise represents my assumption that Switzerland will slowly substitute fossil energy resources as they become more scarce. Therefore, the adaptive pressure only rises gradually. This operationalization is roughly consistent with the literature quoted in Sect. 3.4.1. Some authors predict the depletion of oil and gas resources over the next 30 or 40 years (Shafiee and Topal 2009), whereas some authors maintain that rising prices motivate new discoveries (Watkins 2006).
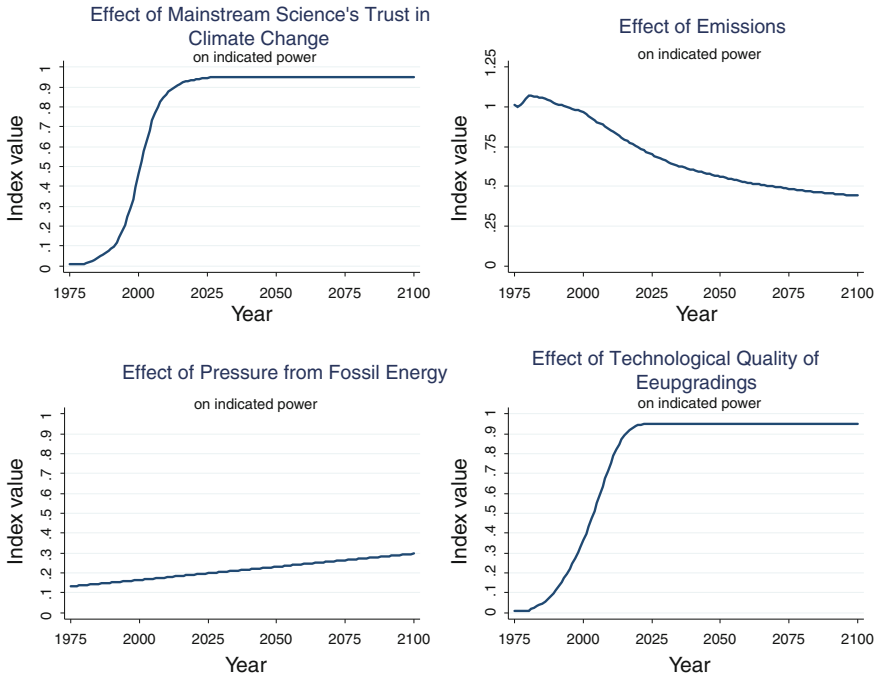
Fig. 7.24 Behavior of the four causes of policy change in the base scenario

Driver 4: Effect of the Public's Perception of EEupgrading Technology (eff_tech)

The TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (quality) is the fourth driver of policy change. However, I assume that it is not perceived at is current state. Rather, the public's perception is delayed, set here to a duration of 5 years. In consequence, the EFFECT OF THE PUBLIC'S PERCEPTION OF EEUPGRADING TECHNOLOGY (effect) is calculated according to Eq. 7.33. The exhibit on the bottom right of Fig. 7.24 shows the EFFECT OF THE PUBLIC'S PERCEPTION OF EEUPGRADING TECHNOLOGY.

$$effect = DELAY(quality, 5\ years) \tag{7.33}$$

Behavior

Figure 7.24 shows the behavior for the four causes of policy change in the base scenario. Figure 7.25 shows the resulting behavior for the POWER OF THE ADVOCACY COALITION THAT DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS.
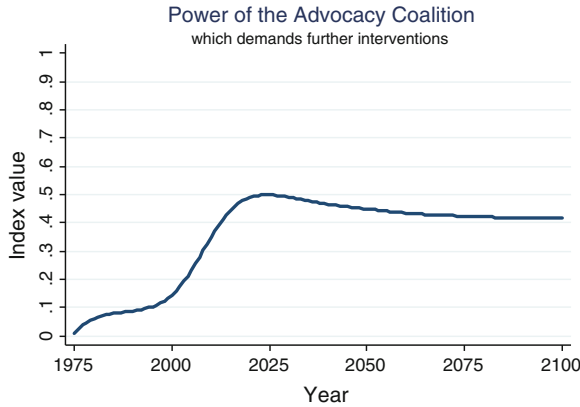
Fig. 7.25 Behavior of the power of the advocacy coalition that demands further public policy interventions

7.7.2 Reactions of the State

Pressure

As the POWER OF THE ADVOCACY COALITION IN CIVIL SOCIETY THAT DEMANDS (FURTHER) PUBLIC POLICY INTERVENTIONS (power) rises, the INTENSITY OF PUBLIC POLICY INTERVENTION INTO THE BUILT ENVIRONMENT (intensity) is increased. However, I assume that there is a delay of 5 years between any change of the POWER OF THE ADVOCACY COALITION […] and the INTENSITY […] (see Eq. 7.34).

$$intensity = DELAY(power, 5 \ years) \qquad (7.34)$$

As the INTENSITY OF PUBLIC POLICY INTERVENTION INTO THE BUILT ENVI-RONMENT rises, three kinds of reactions of the state are triggered:

- Reaction 1: Intensification of research and development
- Reaction 2: Subsidies
- Reaction 3: Reductions of the legal energy coefficient

Reaction 1: Intensification of R&D

The intensification of R&D is the first reaction of the state. As the INTENSITY OF PUBLIC POLICY INTERVENTION […] (intensity) rises, the EFFECT OF PUBLIC R&D EXPENDITURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (effect) is also increased (see Fig. 7.26). In addition, the POTENTIAL FOR IMPROV-ING THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (potential) needs to be considered. This is the difference between the maximal technological quality

Fig. 7.26 Structure used to model the effect of public R&D expenditures
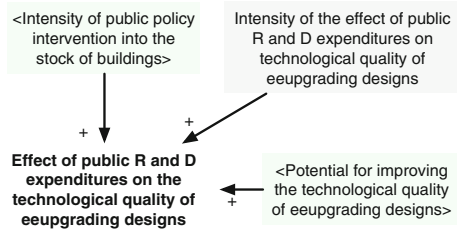
eeupgradings can attain and the actual technological quality. As the technological quality of the eeupgrading renovation strategy rises, the POTENTIAL FOR IMPROV-ING […] converges towards zero. The smaller the potential for improvement is, the smaller the R&D expenses should become. Finally, a multiplicative parameter called INTENSITY OF THE EFFECT OF PUBLIC R&D EXPENDITURES ON TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (parameter) is used to calibrate the structure. Equation 7.35 shows how the EFFECT OF PUBLIC R&D EXPENDITURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (effect) was calculated.

$$\text{effect} = \text{intensity} * \text{potential} * \text{parameter} \tag{7.35}$$

Figure 7.27 shows the behavior of the EFFECT OF PUBLIC R&D EXPENDI-TURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS in the base scenario.
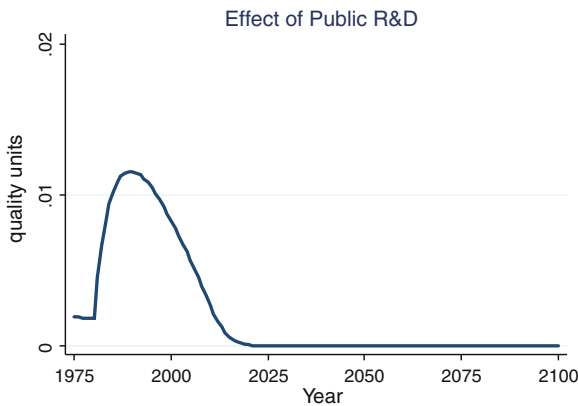
Fig. 7.27 Behavior of the effect of public R&D
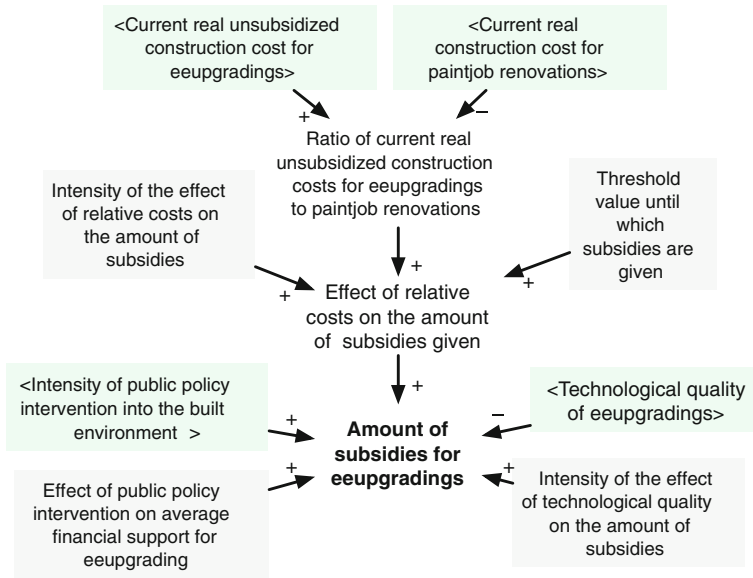
Fig. 7.28 Structure used to model the amount of subsidies given for energy-efficient renovations

Reaction 2: Subsidies

Subsidies are a second reaction of the state. Figure 7.28 shows the structure used to model the AMOUNT OF SUBSIDIES FOR EEUPGRADINGS given to building owners. In addition to the INTENSITY OF PUBLIC POLICY INTERVENTION [...] the two following endogenous inputs are considered:

- The TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS (quality) needs to be considered, because subsidies are not given as long as the technological quality of eeupgradings remains low.
- The RATIO OF CURRENT REAL UNSUBSIDIZED CONSTRUCTION COSTS FOR EEUPGRADINGS TO PAINTJOB RENOVATIONS (ratio) needs to be considered, because subsidies are only given as long as there is a sufficiently wide discrepancy in costs.

The RATIO OF CURRENT REAL UNSUBSIDIZED CONSTRUCTION COSTS [...] (ratio) is calculated by dividing the construction costs for eeupgradings (cost_ee) through the construction costs for paintjob renovations (cost_p) as shown in Eq. 7.36.

$$\text{ratio} = \frac{\text{cost\_ee}}{\text{cost\_p}} \tag{7.36}$$

The EFFECT OF RELATIVE COSTS ON THE AMOUNT OF SUBSIDIES GIVEN (effect_relativcost) is calculated as a function of the RATIO OF CURRENT REAL
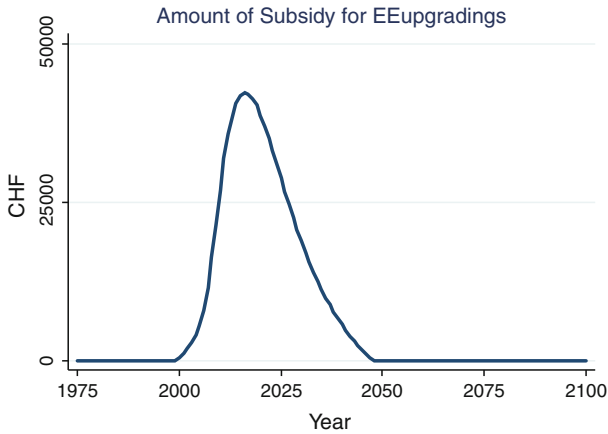
Fig. 7.29 Amount of subsidy for eeupgradings

UNSUBSIDIZED CONSTRUCTION COSTS […] (ratio), the INTENSITY OF THE EFFECT OF RELATIVE COSTS […] (param_relativcost) and the THRESHOLD VALUE […] (threshold) (see Eq. 7.37). As will be shown below, this formulation with the maximum function shuts down any subsidies once the ratio becomes smaller than the threshold value.

$$\text{effect\_relativcost} = \text{MAX}(0, (\text{ratio} * \text{param\_relativcost}) - \text{threshold}) \quad (7.37)$$

The AMOUNT OF SUBSIDIES FOR EEUPGRADINGS is then calculated by multiplying the EFFECT OF RELATIVE COSTS […] (effect_relativcost) with the INTENSITY OF PUBLIC POLICY INTERVENTION […] (intensity), the TECHNOLOGICAL QUALITY OF EEUPGRADINGS (quality) and with two multiplicative parameters used for calibrating the amount of subsidies (EFFECT OF PUBLIC POLICY INTERVENTION ON AVERAGE FINANCIAL SUPPORT FOR EEUPGRADINGS and INTENSITY OF THE EFFECT OF TECHNOLOGICAL QUALITY ON THE AMOUNT OF SUBSIDIES, abbreviated as param_intensity and param_quality). Equation 7.38 shows how the AMOUNT OF SUBSIDIES […] (subsidies) was calculated, and Fig. 7.29 shows its behavior.

$$\text{subsidies} = \text{effect\_relativcost} * \text{param\_intensity} * \text{intensity} * \text{param\_quality} * \text{quality} \quad (7.38)$$

Reaction 3: Reductions of the Legal Energy Coefficient

Reductions of the legal energy coefficient are a third reaction of the state. Figure 7.30 shows the structure used to model the effect of a rising INTENSITY OF PUBLIC POLICY INTERVENTION INTO THE STOCK OF BUILDINGS on the AVERAGE ENERGY
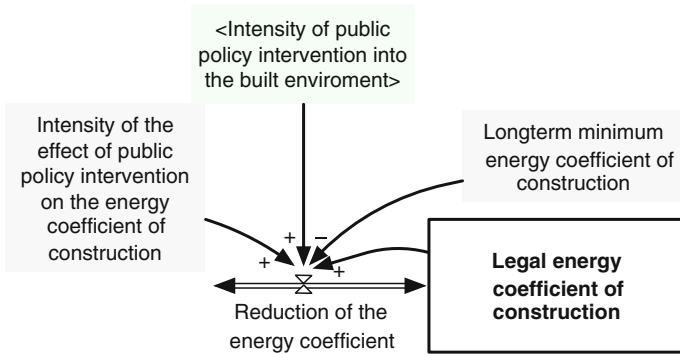
Fig. 7.30 Structure used to model reductions in the energy coefficient

COEFFICIENT OF CONSTRUCTION. The energy coefficient is modeled as a stock, with an initial value of 475. The stock is reduced when the REDUCTION OF ENERGY COEFFICIENT is above zero.

The flow rate is calculated as a function of the INTENSITY OF PUBLIC POLICY INTERVENTION […] (intensity), the LONGTERM MINIMUM ENERGY COEFFICIENT OF CONSTRUCTION (minimum; set to $150\,\text{MJ/m}^2\text{a}$ in the base scenario), the AVERAGE ENERGY COEFFICIENT OF CONSTRUCTION (coefficient), and a multiplicative calibration parameter EFFECT OF PUBLIC POLICY INTERVENTION ON THE ENERGY COEFFICIENT OF CONSTRUCTION (parameter_coefficient). Equation 7.39 shows how the REDUCTION OF THE ENERGY COEFFICIENT was calculated.

$$\text{reduction} = (\text{coefficient} - \text{minimum}) * \text{intensity} * \text{parameter\_coefficient} \quad (7.39)$$

Figure 7.31 shows the behavior of the LEGAL ENERGY COEFFICIENT OF CONSTRUCTION in the base scenario that is obtained from simulating the large model. In addition, the figure shows the average energy coefficient of new construction that was taken from the literature (also see Fig. 4.4, on p. 126 in Chap. 4). I find that the model reproduces the dynamics in the data sufficiently well.

7.8 Selected Insights from Model Analysis

The simulation model can now be used to quantitatively analyze the diffusion process. Below, I exemplarily discuss the effect of energy prices and the start-up difficulties of the energy-efficient building designs. Further, I analyze the importance of external drivers. Note that the actual policy analysis will be presented in Chap. 8.
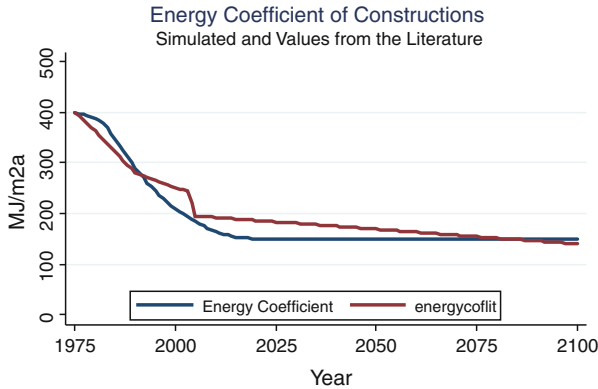
Fig. 7.31 Behavior of the legal energy coefficient of construction in the simulation model (Energy Coefficient) compared to the projections obtained from the literature (energycoflit)

7.8.1 Effect of Energy Price

In Sect. 6.11 I explained that high energy prices might accelerate the diffusion of energy-efficient renovations. Now, I use the large simulation model to analyze quantitatively what the effects of higher energy prices are. Between the years 1975 and 2010 the values given in Fig. 7.13 were used. After that, the values given in Fig. 7.13 were multiplied with 3. This corresponds to a threefold increase of oil and gas prices by a factor of 3 in the years from 2010 to 2100.

Because it is the tenants who pay the cost of heating, I analyze how such a drastic price increase impacts on demand. Figure 7.32 shows the behavior of the SHARE OF TENANTS DEMANDING EEUPGRADED HOUSINGS for each of the three tenant types. Further, it shows the tenants' behavior in the triple-fold energy price scenario and in the base scenario. What is interesting is that the share of tenants that demand eeupgraded housings rises only for the costminimizer type. Relative to the base scenario, the SHARE OF TENANTS DEMANDING EEUPGRADED HOUSINGS only increases by about 2 % in the year 2025, by about 3 % in the year 2050 and by about 4.5 % in the year 2100. For the ecological and evaluator tenant types, the change is insignificant.

This behavior seems plausible because the cost-benefit evaluating tenants and the ecologically oriented tenants are less sensitive to cost increases. In contrast, tenants of the cost-minimizing type are those who are the most sensitive to price increases. Taken together, however, the demand for eeupgraded housings is increased only a little. The increase is so small because rising energy prices also increase the heating costs of eeupgraded housings. In addition, even with a three-fold rise of energy prices the cost of heating remains rather small compared to the rent. For example, after a tripling of energy prices the AVERAGE HEATING COSTS FOR NON- EE HOUSINGS rise from about 800 CHF to about 2400 CHF per year. However, the yearly rent for the housing is about 13 300 CHF. In conclusion, even if the price of energy would
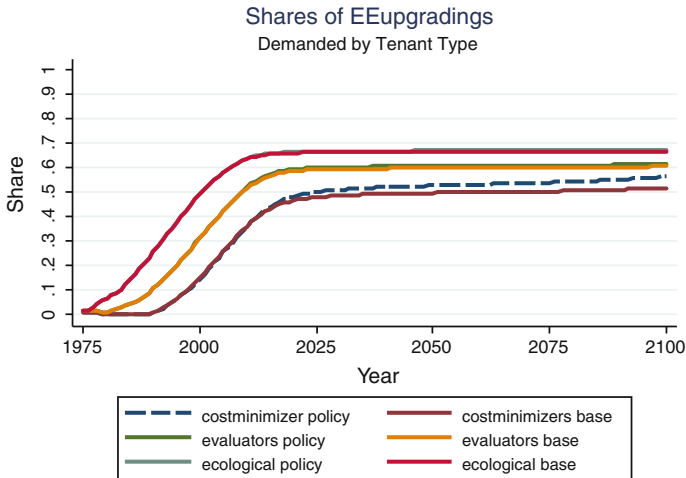
Fig. 7.32 Behavior of the share of tenants demanding eeupgraded housings after a three-fold increase of energy prices

rise by a factor of three, the cost of renting a non-ee housing would rise only by about 10–15 %.[4]

These findings does not mean that rising energy prices generally are without effect. Yet it cautions against the expectation that even small increases of energy prices would substantially transform the stock of buildings. Energy, even if it were twice as expensive as it is now would remain affordable for the majority of the population. Even when investments into energy efficiency are economically profitable, the fact that building owners carry the cost whereas tenants obtain the benefits remains a powerful obstacle.

7.8.2 Start-Up Difficulties of Technology

Previously, in Sect. 6.6.1, I argued that the technology for energy-efficient building designs has a start-up problem. I justified state support for energy-efficient building designs by pointing out that once technology had reached a sufficiently high quality, it would diffuse more easily through market mechanisms.

However, what insight into the importance of state support for research and development does the model yield? In order to further analyze this, I set up a simulation where technology is increased only by learning effects. I operationalized this by

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[4] Remember that I only consider energy costs for space heating. In reality, the side-costs of rented apartments also include the energy costs used for warm water. Yet, thermal energy efficiency in buildings is not causally related to the energy used for warm water. Hence, in reality, a tripling of energy prices would probably increase the cost of renting by about 20–30 %, including warm water.
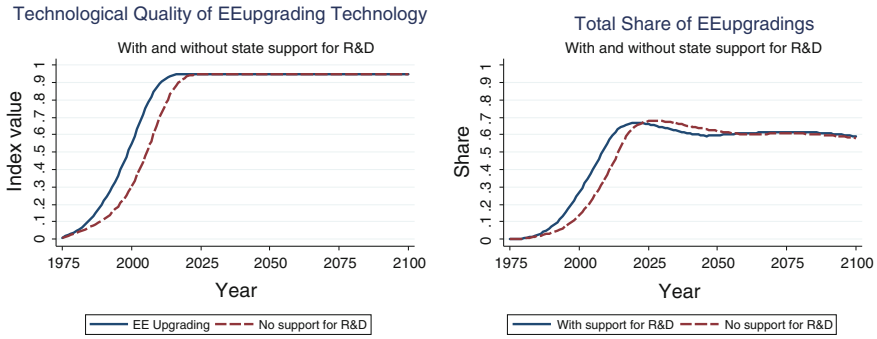
Fig. 7.33 Effects of lacking public R&D expenditures on the technological quality of eeupgrading designs

setting the parameter INTENSITY OF THE EFFECT OF PUBLIC R&D ON TECHNO-LOGICAL QUALITY to 0.

The exhibit on the left of Fig. 7.33 shows the resulting behavior of the technological quality of eeupgrading designs with and without state support for R&D. As can be seen, the technology follows a similar dynamic, just with a considerable delay. Without state support for R&D, technology is at a value of 0.31 in the year 2000. With state support for R&D, it is at 0.55. Without state support for R&D, it would take 6 to 7 full years until the technological quality of eeupgradings would have caught up. What is more, without state support for R&D, the technological quality of eeupgradings reaches its maximum value only in the year 2029 rather than in the year 2022.

The exhibit on the right of Fig. 7.33 shows the TOTAL SHARE OF EEUPGRADINGS with and without state support for R&D. As can be seen, it rises only with a delay. Without state support for R&D, only about 37 % of renovations are conducted with the eeupgrading renovation strategy in the year 2010. When state support for R&D is in place, about 55 % of renovations implement energy-efficient building designs at that point in time. I conclude from this that state support for R&D serves an important role. Relying on market mechanisms alone would have significantly delayed the diffusion process.

7.8.3 Importance of Exogenous Drivers

In Sect. 3.12 I argued that the diffusion process is substantially driven by exogenous drivers. In order to investigate how the diffusion process would unfold without such exogenous drivers, I altered three variables as follows:

- MAINSTREAM SCIENCE'S CONFIDENCE IN THE PROBLEMATIC NATURE OF CLIMATE CHANGE was set to 0 for the whole time.

- ADAPTIVE PRESSURE FROM OIL AND GAS AVAILABILITY was set to 0 for the whole time.
- The EFFECT OF PUBLIC R&D EXPENDITURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS was set to 0 (this is technically necessary in order to eliminate the effect of a 5 year long delay between civil society and the state).

The lack of exogenous drivers (climate change, energy availability) causes the POWER OF THE ADVOCACY COALITION THAT DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS to rapidly converge towards zero (from an initial value of 0.01). In consequence, there is no state support for R&D, there are no subsidies, and the energy coefficient remains at its initial high value. As can be seen in Fig. 7.34, the TOTAL SHARE OF EEUPGRADINGS nevertheless rises, yet with a considerable delay. In the long run, the TOTAL SHARE OF EEUPGRADINGS converges to the value in the base scenario. However, the "hump" that occurs between about the years 2010 and 2035 in the base scenario is missing. This is because there are no subsidies.

The small variation in the share of eeupgradings obscures the full consequences of a lack of external drivers related to climate change and energy use. The exhibit on the right in Fig. 7.34 shows the current CO_2 emission rate from the stock of buildings. Because in this scenario the state implemented no policies, the CO_2 emission rate is substantially augmented. This is because the LEGAL ENERGY COEFFICIENT [...] was never reduced. This finding illustrates that the transformation of the stock of buildings towards low emissions is driven by external governance structures.

7.9 Model Testing Procedures

Model testing is a crucial element of the System Dynamics methodology (also see Sect. 2.3.7). It proceeds iteratively, as a series of model tests and possibly subsequent model adaptations. Unfortunately, the outcome from such a model testing process is not a "true" or a "valid" model. Instead, model testing can at best provide a *better*
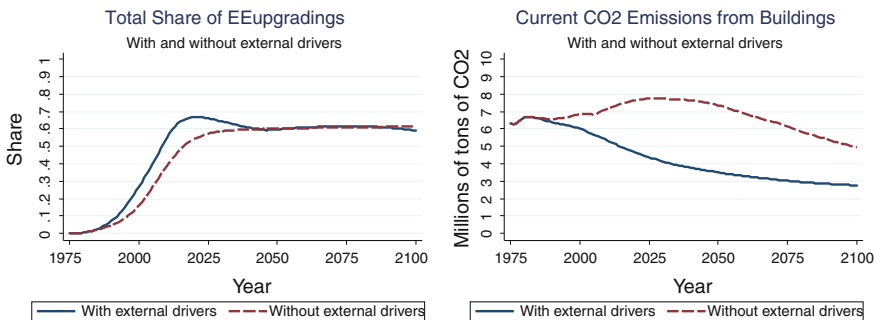
Fig. 7.34 Effects of a lack of exogenous drivers of policy change on the TOTAL SHARE OF EEUPGRADINGS (*left*) and the CURRENT CO_2 EMISSIONS FROM BUILDINGS (*right*)

model than the one that was initially tested. Further, model testing leads to a critical evaluation of the quality of a simulation model.

Before I could test the large simulation model, I had to review the relevant literature (Schwaninger and Grösser 2009; Sterman 2000) in order to evaluate what tests should be used. Once it was clear what tests were to be used, I described their application in the appendix. Appendix C contains a description of each test and elaborates on the results of a tests' application. In addition, the electronic supplement describes the sensitivity analysis that was performed. In the following, I summarize and discuss the results from model testing.

Contextual Tests

Table 7.3 lists the contextual tests that were conducted. The table shows that the final version of my large simulation model (arguably) passes all these tests. However, all these tests are non-formal tests. The arguments that led me to conclude that the model passes these tests are listed in Appendix C.1.

Structure Tests

Table 7.4 lists the tests that were used to evaluate the model structure. As can be seen, the large simulation model is considered to have passed all structure tests. Due to the strong grounding of the model in the empirical and theoretical literature, I am confident that the model structure is highly useful and adequate. Developing the analytical perspectives proved particularly helpful in doing so. The arguments that led me to conclude that the model passes these tests are listed in Appendix C.1 .

Table 7.3 Contextual model tests

Test	Result
Issue identification	Passed
Adequacy of methodology test	Passed
Boundary adequacy	Passed
Integration time step	Passed
Testing time horizon	Passed
Family member test	Passed

Table 7.4 Structural model tests

Test	Result
Structure examination test	Passed
Dimensional consistency	Passed

Table 7.5 Behavioral model tests

Test	Result
Parameter examination test	Assumed passed
Sensitivity analysis	Passed

Behavioral Tests

Table 7.5 lists the tests that were used to evaluate the model's behavior. Behavioral tests analyze whether the model reproduces observed behaviors in the real world. However, conducting behavioral tests proved to be rather challenging because numerical data[5] (specifically in time series form) was often not available. With the exception of some variables related to the stock of buildings, energy prices and general data on CO_2 emissions, almost always proxies and educated assumptions had to be used. The insights developed in the analytical chapters helped to find reasonable behaviors and parameter values. In addition, various stages of the small and the large model were discussed with practitioners and experts. Several adjustments were made in response to critical comments (see the electronic supplement for the validating interviews). Hence, I conclude that the parameter examination test should be assumed to be passed.

In order to test how sensitive the model is to uncertainty in the parameters, I conducted extensive sensitivity analysis. The full report is provided in the electronic supplement. Sensitivity analysis was conducted by drawing the initial values of particularly interesting variables (called intervention lever) 200 times from a random uniform distribution from 50 to 150 % of its base scenario. With each draw, the model was simulated. This allowed to analyze how sensitive key variables (e.g. TOTAL SHARE OF EEUPGRADINGS) behaved relative to variance in initial conditions. Table 7.6 summarizes the results of this sensitivity analysis. As can be seen, the large model is very robust. This means that some uncertainty in the calibration of the model is not a problem.

Conclusions to Model Testing

In conclusion, I find that the model structure should be considered to be rather well established. Regarding the behavior of the model, the picture is less clear. The problem is that there is no numerical data for most variables. This seriously restrains any attempt to rigorously base the model on data without conducting extensive empirical work (which clearly is beyond the scope of this study). Therefore, the most interesting and powerful behavioral tests, such as correlation coefficients or goodness of fit, could not be applied. Yet, extensive sensitivity analysis showed that uncertainty in

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[5] Such data would allow to evaluate the quality of the simulation model also with quantitative procedures. However, when such numerical information was available I used it to develop and calibrate the model. Unfortunately, this means that the data can no longer be used in model testing. Testing a model with data that was used to calibrate it would be somewhat tautological.

Table 7.6 Summary of sensitivity analysis of intervention levers

Intervention lever	EEupgrading	CO_2
Building owners' perception of the technological quality of energy-efficient building designs	0.6–0.7	Insensitive
Building owners delay in the perception of technological quality	Insensitive	Insensitive
Financial attractiveness of eeupgraded housings for BOs	0.6–0.7	Insensitive
Probability that architects promote energy-efficient building designs	0.6–0.7	Insensitive
Building owners' preference for energy-efficient building designs	0.6–0.7	Insensitive
Tenants' perception of technological quality of energy-efficient building designs	0.6 and 0.65	Insensitive
Tenants' delay in the perception of technological quality of energy-efficient building designs	Insensitive	Insensitive
Tenants' reaction to energy prices	Insensitive	Insensitive
Tenants' maximum willingness to pay for rent	0.65–0.7	Insensitive
Tenants' utility from cobenefits of ee	0.65–0.7	Insensitive
Architects' perception of technological quality of energy-efficient building designs	0.6 and 0.7	Insensitive
Architects' delay in the perception of technological quality of eeupgrading building designs	Insensitive	Insensitive
Effect of public R&D on technological quality	Insensitive	Insensitive
Effect of learning on the technological quality of eeupgrading designs	Insensitive	Insensitive
Initial construction costs	Insensitive	Insensitive
Effect of learning on construction costs of eeupgrading designs	0.55–0.75	Insensitive
Effect of stricter standards on construction costs	0.65–0.75	Insensitive
Publics' perception of mainstream science's claim	0.65–0.75	Insensitive
Publics' perception delay of mainstream science's claim	Insensitive	Insensitive
Level of yearly emissions of CO_2 compatible with the 2° goal	0.65–0.7	Insensitive
Pressure from fossil energy shortage	Insensitive	4.3–6.0
Perception of technological quality by civil society actors	0.65–0.7	Insensitive
Delay in the perception of technological quality by civil society actors	Insensitive	Insensitive
Effect of technological quality on the amount of subsidies	0.65–0.7	Insensitive
Threshold value until which subsidies are given	0.6–0.85	Insensitive
Reductions of legal energy coefficient	0.55–0.75	Insensitive
Increasing the share of professional building owners	Insensitive	Insensitive
Increasing the share of multi-criteria-oriented building owners	Insensitive	Insensitive
Increase the share of ecologically oriented tenants	Insensitive	Insensitive

Note that the results all apply for the year 2020 only. Full sensitivity graphs are available in the electronic supplement

the model calibration is probably less of a problem than expected. In fact, I am quite confident that this simulation model captures the essential dynamics of the diffusion process. This means that it can be used to conduct policy analysis despite uncertainties related to the calibration of the model. Specifically, this means that the model can be used to analyze whether an intervention accelerates or delays the diffusion process. With due caution, the model can be used to quantify the magnitude of the effect. However, it cannot be used for point estimates or "predictions".

7.10 Conclusions

In this chapter, I addressed my fifth research question: How should the diffusion of energy-efficient renovations be represented in a rich System Dynamics simulation model? In order to proceed, I synthesized and further substantiated the work presented in Chaps. 5 (actors) and 6 (feedback perspective) by way of a quantitative simulation model. In doing so, I extended the small model of Switzerland's stock of residential multifamily buildings (Chap. 4). As a result, I obtained an empirically based, quantitative, dynamic theory of the diffusion dynamics of energy-efficient renovations in Switzerland's stock of buildings. The model was tested in order to assure a high quality. I concluded that the model structure should be seen to be highly useful and adequate, and that the model behavior should be seen as a reasonable approximation which nevertheless could be improved by focussed empirical research.

As a preliminary result, I found that a triple increase of the energy price would affect primarily the cost-minimizer tenant type. I found that relying only on market mechanisms would substantially delay the diffusion process. Finally, I could show how the lack of external drivers (such as the energy price, concerns over climate and adaptive pressure from the availability of fossil energy) would have substantially delayed the diffusion of energy-efficient renovations and have yielded a much higher CO_2 emission rate. In the following chapter I use the model to analyze interventions that could accelerate the diffusion of energy-efficient renovations.

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Chapter 8
Transformation of the Societal Problem Situation

8.1 Introduction

The previous chapters have yielded a rigorous understanding of the societal problem situation and the role of energy-efficient renovations in its alleviation. However, the final research question of this study remains to be addressed. It reads as follows: "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?" By addressing this question, I contribute to the analysis of the transformation of the societal problem situation.

First, I provide a theoretical foundation, where I discuss how a societal problem situation may be transformed in a collaborative manner by involving several actors (see Sect. 8.2). This should be read as a complement to Chap. 3, where I described climate change, energy use, and the stock of buildings as constituting a societal problem situation. Second, I use the large simulation model to identify potentially powerful intervention levers. I systematically analyze these intervention levers.[1] Specifically, I shock the model with a STEP of 50 % in the year 2010 and analyze how selected variables will behave in the year 2020 (see Sect. 8.3). As a third step, I use the large simulation model to analyze how policy packages consisting of several intervention levers influence the behavior of selected variables (see Sect. 8.4). In Sect. 8.5, I review the implications of my model-based work (see Sect. 8.5.1) and then I move beyond model-based analysis. I propose two regulations for the transformation of the stock of buildings (see Sect. 8.5.2). I propose a business model for organizations that might support building owners in managing their buildings (see Sect. 8.5.3). I discuss how interventions into the renovation process might

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[1] In this context, intervention levers are best described as the target of policies or measures. They are a specific part of the model that is affected by a change brought about by a policy. For example, the variable TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS AS PERCEIVED BY BUILDING OWNERS can be seen to be an intervention lever that might be influenced by instruments such as technical information or by improvements of the technology.

enhance the efficiency gains obtained from renovations (see Sect. 8.5.4). Finally, I elaborate on what instruments can generally be used to address intervention levers in the real world (see Sect. 8.5.5). Finally, Sect. 8.6 concludes on the insights developed in this chapter.

8.2 Theoretical Foundation: Elements of the Transformation of Societal Problem Situations

In Chap. 3, I described climate change, energy use, and the stock of buildings as a societal problem situation. However, I did not address the question as to how societal problem situations are resolved. In the following, I argue that societal problem situations are transformed in collaborative ways by societal actors and state actors.

Societal problem situations occur in a "power-shared world" (Crosby and Bryson 2005). They are characterized by high degrees of uncertainty, value conflicts, conflicts of interest and power differentials among advocacy groups; to name just a few aspects. The very nature of societal problem situations precludes simple fixes or easy solutions. A societal problem situation occurs precisely because there is no group of actors which can alleviate it, given current conditions. At heart, societal problem situations are also about power. Because there is no "silver bullet", a policy or instrument that would make the societal problem situation disappear, a gradual process of change should be expected to unfold, possibly over a period of decades.

Because power is shared in societal problem situations, successful interventions aimed at transforming the societal problem situation require the involvement of a broad range of actors. Hence, coordination among important actors involved in the societal problem situation becomes a crucial issue. On the one hand, this may refer to coordination among the different branches and levels of the state. On the other hand, it may refer to the usefulness of involving societal actors. In Switzerland's political system, it is the rule that civil society actors are consulted in the process of legislation (Linder 1999). Yet collaboration with actors involved in the societal problem situation can also be fruitful beyond the legislative process. This is because non-state actors also have the power to intervene in societal problem situations.

The importance of non-state actors in the transformation of societal problem situations is particularly well-known in an environmental context. For example, Kaufmann-Hayoz and Gutscher (2001, p. 21) point out the importance of "instruments that are available not only to public authorities, but to other actors as well". The 'classical' regulatory and economic instruments generally rely on the state. In contrast, co-operative and voluntary instruments may activate the potential for self-regulation (Kaufmann-Hayoz and Gutscher 2001). What is more, voluntary and cooperative action can pave the way for the gradual application of regulatory and economic instruments. In fact, interventions by non-state actors may lead to various beneficial developments. For example, they may lead to successful innovations, they may contribute to technological progress and cost reductions, they may contribute to

the creation of awareness and exert pressure on the state to implement non-voluntary measures. In conclusion, I want to stress the importance of including influential actors into the analysis of societal problem situations and the development of interventions that contribute to their transformation.

The idea that non-state actors are important partners of public policy and organizational strategy has led to several closely related streams of research. For example, a broad literature on governance has emerged in recent years. Governance is seen as a perspective on the interdependencies between states as well as between the state and societal actor groups. Herein, hierarchical coordination is seen as an important, yet by no means the only form of coordination (Benz et al. 2007, p. 13). Somewhat similar, a broad literature on stakeholder management has been developed. Its main insight is that organizations rely on non-state actors in order to achieve their goals. Freeman (1984, p. 46) defined stakeholders as "any group or individual who can affect or is affected by the achievement of the organization's objectives."

Actors in the market can also play a crucial role in the transformation of societal problem situations. This particularly holds when aspects of a societal problem situation are related to production or consumption patterns. For example, issues related to consumption and production have long occupied a central place in environmental discourses. Eventually, innovations such as corporate social responsibility, environmental management, or sustainability marketing emerged out of the recognition of the important role of actors in the market.

Because the decision making of actors in the market is particularly relevant for the diffusion of energy-efficient renovations (and hence for the transformation of the societal problem situation addressed in this study), I propose to review selected concepts of marketing; in particular of sustainability marketing. This will enhance the understanding of the organizational innovation that I propose in Sect. 8.5.3. Insights from this review of key concepts will also contribute to the understanding of other recommendations.

8.2.1 Marketing[2]

The American Marketing Association defines marketing as "the activity, set of institutions, and processes for creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large" (AMA 2007). Sustainability marketing, as described by Belz (2001b, 2004) and others, clearly must be positioned into such an understanding of marketing. Here too, the needs of customers are at the center of marketing. However, sustainability marketing has a somewhat broader perspective and holds that socio-ecological problems need to be considered as a further, important aspect of marketing.

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[2] Most of this section was (often literally) taken from an unpublished seminar paper I wrote in the context of my doctoral studies at University of St. Gallen, see Müller (2007). I would like to thank Frank-Martin Belz for helpful comments concerning that paper.
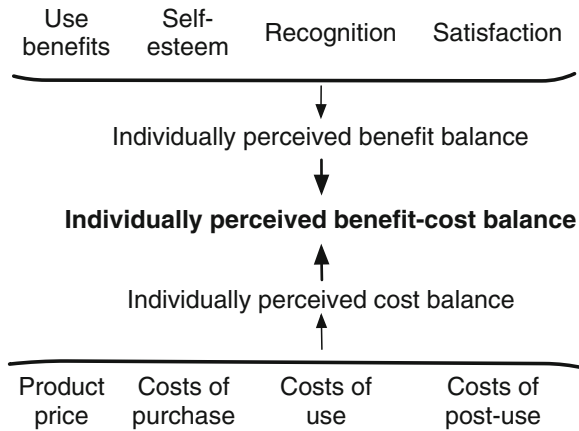
Fig. 8.1 Categories of the customer's evaluation of products and services. Reproduced, translated, and adapted in terms of graphics, from Belz (2001b, p. 78), who in turn drew on Bänsch (1993)

Sustainability marketing proposes to complement the economical goals that guide the management principles and practices of a company with ecological and social goals (normative level). On the strategic level, and on the operative level sustainability marketing employs the whole range of marketing instruments. Often, the market success of social-ecological products and services is hampered by disadvantageous external conditions. Hence, sustainability marketing encourages companies to create an external setting that is favorable to social-ecological products and services (transformative level). This entails efforts that change the political and legal frameworks.

Sustainability marketing has proved to be a useful perspective in the analysis of the construction sector in general and the diffusion of energy-efficient buildings in particular (Koller 1994; Belz 2001a; Belz and Egger 2000; Belz et al. 2003, 2005). In the following, I provide some particularly powerful concepts from both, marketing and sustainability marketing.

According to Belz (2001b, p. 78), the central task of sustainability marketing consists of increasing the net-benefit of social-ecological products or services as perceived by their customers. This can be brought about by increasing individually perceived benefits and by reducing individually perceived costs. Figure 8.1 shows the individually perceived categories underlying the individual's evaluation of the benefit-cost balance:

Belz (2001b, p. 72) proposes a differentiation between the characteristics of a product and the benefits customers draw from these characteristics. Customer benefit then can be seen to be individually constructed based on the characteristics of a product or service. On a general level, the following four categories of benefits can be identified:

- A product's **use benefit** is based on its physical and technical characteristics, such as primary function or performance.

- **Self-Esteem**: Additional benefit can be drawn if a product or service appeals to the customer's individual aesthetic or ethic values. Purchase of an aesthetic or ethically pleasing offer can be seen as an act of participation in the good and beautiful.
- **Satisfaction**: Further additional benefit can be drawn by the individual purchaser, if the offering's characteristics create individual joy beyond the product or service's use benefits.
- If a customer's acquaintances validate the purchase of a particular product or service positively, the customer benefits from **recognition**. While recognition too is an individual benefit, it stems from the social sphere. Increasing the amount of individual benefit drawn from recognition is an important strategy in order to transform social value into individual value.

In regards to costs, Belz (2001b, p. 75) considers all the costs that occur during the life of products and services, such as during the procurement-, use-, or post-use phases. On a general level, the following four categories of costs can be identified:

- The **product price** basically is the price the customer pays in currency.
- The **costs of purchase** consists of the totality of information-, search-, control-, and travel-costs that need to be expended in order to purchase a social-ecological product or service.
- The **costs of use** consist of expenditures that the use of the product induces. Heating costs or phone bills would be a typical example.
- The **post-use costs** basically consist of the cost of proper disposal of the product and its waste.

8.2.2 The Contribution of System Dynamics

System Dynamics has a long record of contributing to the analysis of problems, be they economic, environmental, industrial, or social problems; to name but a few. Its ability to deal with dynamic complexity makes it a useful tool, particularly for the analysis of societal problem situations. Because System Dynamics strives for endogenous explanations, its scope is often rather broad and spans across several academic disciplines. System Dynamics simulation models can be used for several purposes. For example, System Dynamics modeling may help to develop a synthesis of conflicting perspectives of different actors. Further, researchers interested in the question as to how the diffusion of energy-efficient renovations can be started could use the model to analyze how early policies impact on the long-term diffusion process. Models can also be used to evaluate the policies of different states in order to find further policies that could accelerate the diffusion process.

Meadows (1997) argues that there is a wide range of "places to intervene in a system," which might be considered once a simulation model is developed. These are "numbers (subsidies, taxes, standards), material stocks and flows, regulating negative feedback loops, driving positive feedback loops, information flows, the rules of the system (incentives, punishment, constraints), the power of self-organization,

the goals of the system and the mindset or paradigm out of which the goals, rules, feedback structure arise" (Meadows 1997). In the following, I refer to all of these elements as 'intervention levers'.

8.3 Analysis of Single Intervention Levers[3]

8.3.1 Approach

I used the large simulation model presented in Chap. 7 to analyze whether the manipulation of a single intervention lever could increase the TOTAL SHARE OF EEUPGRADINGS close to its maximum value of 0.95. As a first step, I identified the intervention levers by reviewing the large simulation model. I looked for practically relevant intervention levers that could be addressed with policies and instruments (the left column in Tables 8.2–8.7 lists the intervention levers that I found). As a second step, I analyzed each intervention lever in a standardized manner. Specifically, I used VENSIM's STEP function to increase an intervention lever by 50 % in the year 2010.[4] Then, I analyzed how the model behaved relative to the base scenario in the year 2020. I drew on the base scenario that was described throughout Chap. 7. Because this analysis is quite extensive and technical, I provide the full report in the electronic supplement. To illustrate the approach taken in the analysis of intervention levers, the analysis for the first lever is given as an example in Table 8.1.[5] Several issues are noteworthy in that table:

- For each intervention lever I state what **operationalization** I used. Often, the easiest approach involved applying the STEP function to a parameter rather than to the variable representing the intervention lever itself.
- Before I ran the simulation, I stated a **hypothesis** regarding the expected impact of a 50 % increase of the corresponding intervention lever.
- Regarding the **results** of the simulation, I was particularly interested as to how the TOTAL SHARE OF EEUPGRADINGS and the CURRENT CO_2 EMSSIONS behaved. Other variables could have been investigated.

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[3] Due to limitations regarding the possibility of calibrating the model, the results provided in this section must be considered with some caution. The model can be used to roughly compare trends and the direction of impacts. It should not be used for point estimates in the future. Also see Sect. 7.9.

[4] Because the model is highly inert, I decided to use the STEP function rather than the PULSE function. The PULSE function tends to produce weaker impacts. This is because after some time, the shock reverts to its original state. In contrast, the STEP function remains at a higher value for the rest of the time. Consequently, it produces stronger impacts. In addition, the model is affected by only one change, whereas the PULSE function shocks the model twice. One shock occurs when the PULSE function rises and the other occurs when it reverts to its initial stage.

[5] See the electronic supplement for the analysis of the other intervention levers.

Table 8.1 Analysis of the intervention lever BUILDING OWNERS' PERCEPTION OF THE TECHNO-
LOGICAL QUALITY OF ENERGY-EFFICIENT BUILDING DESIGNS

Building owners' perception of the technological quality of eeupgradings

- Operationalization: The variable INTRINSIC PERCEPTION OF TECHNOLOGICAL QUALITY OF
  EEUPGRADING DESIGNS is multiplied by 1.5 after 2010. This corresponds to an increased per-
  ception of eeupgrading technology of 50 %.
- Hypothesis: Increasing the intrinsic perception of the technological quality of eeupgrading
  designs accelerates the diffusion process.
- Test results:

  – The TOTAL SHARE OF EEUPGRADINGS is increased to 0.72 instead of 0.67 by the year 2020.
    This is a 7.5 % increase relative to the base scenario. Such a high absolute value is never reached
    in the base scenario.
  – The impact on the TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS is negligible (below
    0.001).
  – The CO_2 EMISSION RATE is decreased to 4.621 million tons of CO_2 from 4.655. This is
    insignificant.

8.3.2 Results

The results derived from the analysis of intervention levers are given in
Tables 8.2–8.7. I report by how many percent the TOTAL SHARE OF EEUPGRADINGS
and the CURRENT CO_2 EMISSIONS changed relative to the base scenario. Remember
that in the underlying analysis the model was shocked in the year 2010. The reported
results are for the year 2020. I chose this time span because it represents a reasonable,
practical time perspective in terms of the stock of buildings. In the year 2010, the
diffusion process of energy-efficient renovations has already moved to a late stage,
mostly because technology has become quite reliable and cost-effective. This means
that intervention levers that might have accelerated the diffusion in an early phase
now might no longer be identified as effective. This, of course, does not mean that
past policies addressing such intervention levers were in vain. Actually, the contrary
is true. The fact that several intervention levers now turn out to be unimportant simply
means that they have played their role and that the "low-hanging fruits" have already
been picked.

Table 8.2 shows the results of the analysis of intervention levers related to building
owners for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION
RATE. It becomes apparent that the results for the TOTAL SHARE OF EEUPGRADINGS
and the results for the CO_2 EMISSIONS are not linearly related to each other. In other
words, an increase in the TOTAL SHARE OF EEUPGRADINGS does not always lead
to a proportional change in the CO_2 EMISSIONS. The CO_2 EMISSIONS typically react
very insensitively, even when the TOTAL SHARE OF EEUPGRADINGS rises substan-
tially. One reason behind this discrepancy is that the CO_2 EMISSIONS are determined

Table 8.2 Results of the analysis of intervention levers related to building owners for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Building owners' perception of the technological quality of energy-efficient building designs	7.5	−0.1
Building owners' delay in the perception of technological quality	0	−0.3
Financial attractiveness of eeupgradings for BOs	7.4	−0.7
Probability that architects promote energy-efficient building designs	7.5	−0.7
Building owners' preference for energy-efficient building designs	6	−1.3
Increasing the share of professional building owners	0	−0.3
Increasing the share of multi-criteria-oriented building owners	0	0

The values show how much a variable changed relative to its base scenario behavior in the year 2020. Negative values denote decreases

by the whole stock of buildings, whereas the TOTAL SHARE OF EEUPGRADINGS only affects those buildings under renovation in any particular year. Typically, only about 1–2 % of the whole stock of buildings are under renovation. Further, changes in the CO_2 EMISSION RATE are not only brought about by the TOTAL SHARE OF EEUPGRADINGS but also by the LEGAL ENERGY COEFFICIENT OF CONSTRUCTION. Therefore, the CO_2 EMISSION RATE can be reduced even when the TOTAL SHARE OF EEUPGRADINGS remains constant.

Eventually, this means that it is the reduction in the CO_2 EMISSIONS that should be used as a measure of the power of an intervention lever, not the TOTAL SHARE OF EEUPGRADINGS. I deem an intervention lever to be particularly powerful if it leads to a reduction in the CO_2 EMISSIONS of 1 % or more, relative to the base scenario in the year 2020. However, even small reductions in the CO_2 EMISSIONS can make valuable contributions.

Looking at the results reported in Table 8.2, it becomes apparent that the BUILDING OWNERS' PREFERENCE FOR ENERGY-EFFICIENT BUILDING DESIGNS is a particularly powerful intervention lever. With it, the CO_2 EMISSIONS are reduced by 1.3 %. In addition, the PROBABILITY THAT ARCHITECTS PROMOTE ENERGY-EFFICIENT BUILDING DESIGNS and the FINANCIAL ATTRACTIVENESS OF EEUPGRADINGS FOR BUILDING OWNERS prove to be somewhat powerful intervention levers. They both reduce CO_2 emissions by about 0.7 %.

Table 8.3 shows the results of the analysis of intervention levers related to tenants. Similarly, as was the case with building owners, preferences turn out to be the most relevant intervention lever. Specifically, an increase in the TENANTS' UTILITY FROM CO-BENEFITS OF ENERGY EFFICIENCY reduces the CURRENT CO_2 EMISSIONS by 1 %. The other intervention levers turn out to be insignificant.

Table 8.4 shows the results of the analysis of intervention levers related to architects. As can be seen, no intervention lever turned out to be particularly powerful.

Table 8.3 Results of the analysis of intervention levers related to tenants for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Tenants' perception of technological quality of energy-efficient building designs	1.5	−0.1
Tenants' delay in the perception of technological quality of energy-efficient building designs	0	0
Tenants' reaction to energy prices	0	0
Tenants' maximum willingness to pay for rent	0	0
Tenants' utility from co-benefits of energy efficiency	1.5	−1
Increase the share of ecologically oriented tenants	0	0

Table 8.4 Results of the analysis of intervention levers related to architects for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Architects' perception of technological quality of energy-efficient building designs	3	−0.2
Architects' delay in the perception of technological quality of eeupgrading building designs	0	0

Table 8.5 Results of the analysis of intervention levers related to technology for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Effect of public R&D on technological quality	0	0
Effect of learning on the technological quality of eeupgrading designs	0	0
Initial construction costs	N.A.	N.A.
Effect of learning on construction costs of eeupgrading designs	−14.9	1
Effect of stricter standards on construction costs	6	−0.3

Remember though, that the PROBABILITY THAT ARCHITECTS PROMOTE ENERGY-EFFICIENT BUILDING DESIGNS proved fairly powerful above.

Table 8.5 shows the results of the analysis of intervention levers related to technology. Most intervention levers turn out to be unimportant. Remember that in the year 2010 the technological quality of energy-efficient building designs was already very high. Hence, interventions aimed at increasing it are ineffective. However, regarding the costs of implementing energy-efficient building designs, a counter-intuitive behavior is found. These costs are modeled to decrease as experience accumulates. The parameter EFFECT OF LEARNING ON CONSTRUCTION COSTS OF EEUPGRADING DESIGNS controls that relationship. As the EFFECT [...] is increased, the construction costs should be reduced. However, with low construction costs, the subsidies for energy-efficient renovations are low. This actually overcompensates for the effect

Table 8.6 Results of the analysis of intervention levers related to civil society for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Publics' perception of mainstream science's claim	0	0
Publics' perception delay of mainstream science's claim	0	0
Yearly emissions of CO_2 compatible with the 2 degree goal	6	−0.2
Pressure from fossil energy shortage	0	−10.1
Perception of technological quality by civil society actors	3	−1.2
Delay in the perception of technological quality by civil society actors	0	0

of cost reductions from learning. Consequently, the CURRENT CO_2 EMISSIONS are increased by 1 %.

Table 8.6 shows results of the analysis of intervention levers related to civil society. It turns out that PRESSURE FROM FOSSIL ENERGY SHORTAGE reduces the CO_2 EMISSION RATE by a very substantial 10.1 %. What is interesting, is that the TOTAL SHARE OF EEUPGRADINGS remains unchanged. The reason for this behavior is that PRESSURE FROM FOSSIL ENERGY SHORTAGE increases the POWER OF THE ADVOCACY COALITION THAT DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS. This, in turn, leads to an increase in the amount of subsidies for eeupgradings and it leads to a reduction of the legal energy coefficient. State support for R&D is only minimally increased, as the technological quality of eeupgrading building designs is already near its maximum. Further, an increase in the PERCEPTION OF TECHNOLOGICAL QUALITY BY CIVIL SOCIETY ACTORS reduces the CO_2 EMISSION RATE by 1.2 %. That variable also increases the POWER OF THE ADVOCACY COALITION THAT DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS. The other intervention levers turn out to be mostly insignificant.

Table 8.7 shows results of the analysis of intervention levers related to state interventions. REDUCTIONS OF THE LEGAL ENERGY COEFFICIENT turn out to be by far the most powerful intervention lever. It reduces the CO_2 EMISSION RATE by 18.1 %. This intervention lever ensures that once buildings are renovated then high levels of energy efficiency get implemented. It is somewhat counterintuitive that reductions of the legal energy coefficient actually increase the TOTAL SHARE OF EEUPGRADINGS.

Table 8.7 Results of the analysis of intervention levers related to state interventions for the two variables TOTAL SHARE OF EEUPGRADINGS and CO_2 EMISSION RATE

Intervention lever	EEupgradings (%)	CO_2 (%)
Effect of technological quality on the amount of subsidies	−6	0.5
Threshold value until which subsidies are given	25.4	−2.2
Reductions of the legal energy coefficient	13.4	−18.1

The values show how much a variable changed relative to its base scenario behavior in the year 2020. Negative values denote decreases

In the model, the costs of implementing eeupgradings are increased as the LEGAL ENERGY COEFFICIENT is decreased. Higher levels of energy-efficiency cost, *ceteris paribus*, more. The reason why the TOTAL SHARE OF EEUPGRADINGS is increased nevertheless, lies in how the AMOUNT OF SUBSIDIES is determined. The more eeupgradings cost *relative* to paintjob renovations, the larger the AMOUNT OF SUBSIDIES FOR EEUPGRADINGS is (see Fig. 7.28 on p. 240). Further, the THRESHOLD VALUE UNTIL WHICH SUBSIDIES ARE GIVEN reduces the CO_2 EMISSION RATE by 2.2 %. This intervention lever controls the amount of subsidies given. Hence, it is closely related to REDUCTIONS OF THE LEGAL ENERGY COEFFICIENT.

The most important insight from this analysis is that taken in isolation, most intervention levers do not contribute to the transformation of Switzerland's stock of multifamily buildings in an important way over the years 2010–2020. Yet, five interventions emerged as somewhat powerful. Each of them reduces the CO_2 EMISSIONS by 1 % or more. Policies that target these intervention levers should prove to be highly effective. In the following, I discuss each of these intervention levers in greater detail.

Building Owners' Preference for Energy-Efficient Building Designs (−1.3 %)

A wide range of marketing interventions may help to shape building owners' preferences. By communicating the social, economical, and environmental benefits of energy-efficient building designs, marketing may motivate building owners to implement well-planned renovations that balance environmental, economical, and social benefits. This intervention lever may be addressed by a wide range of actors. For example, companies developing and supplying energy-efficient building designs may try to influence building owners toward preferring eeupgradings. Further, agencies such as the Minergie association or governmental ministries may devise campaigns that communicate the beneficial aspects of energy-efficient building designs to building owners.

Perception of Technological Quality by Civil Society Actors (−1.2 %)

This intervention lever is one of two intervention levers that are crucial in the generation of political pressure to implement further public policy interventions. If civil society actors reach the conclusion that the required technologies are available in a sufficient quality, then it is more likely that the state will increase the intensity of intervention. This intervention lever may be addressed by pilot and demonstration projects, and public relations efforts directed especially towards representatives of civil society and the state.

Pressure from Fossil Energy Shortage (-10.1%)

This is the second intervention lever that is crucially related to the generation of political will to implement further policies. If pressure from the availability of fossil energy rises, then the state can implement more ambitious policies. This intervention lever is probably hard to address with direct interventions. However, events such as the great oil spill in the Gulf of Mexico in 2010, the nuclear catastrophe in Fukushima (Japan), periods of high prices, or unexpected revelations about the depletion of conventional reserves probably increase the effect of this lever. Thus they offer a window of opportunity to put more ambitious policies into place.

Threshold Value Until Which Subsidies are Given (-2.2%)

This intervention lever is mostly controlled by the state. As my analysis below shows, the amount of subsidies needs to be carefully balanced with further reductions of the legal energy coefficient (see Sect. 8.4.2 and the next lever below).

Reductions of the Legal Energy Coefficient (-18.1%)

This intervention lever directly relates to the degree of energy efficiency that has to be achieved in energy-efficient renovations. As the energy coefficient is reduced, the energy demand is decreased, while the costs of energy-efficient renovations are increased. This intervention lever is mostly controlled by the state.

8.4 Analysis of Packages of Intervention Levers

The analysis presented in the section above indicates that there is no single "silver bullet" that is capable of accelerating the diffusion of energy-efficient renovations such that the CO_2 emissions are reduced substantially faster compared to the base scenario. However, I identified promising intervention levers, which now will be analyzed together. In particular, I hope to find packages of intervention levers that ideally complement one another. Due to the limitations of the model's calibration, the results provided in this section must be considered with some caution. The model can be used to roughly compare trends and the direction of impacts. It should not be used for point estimates in the future.
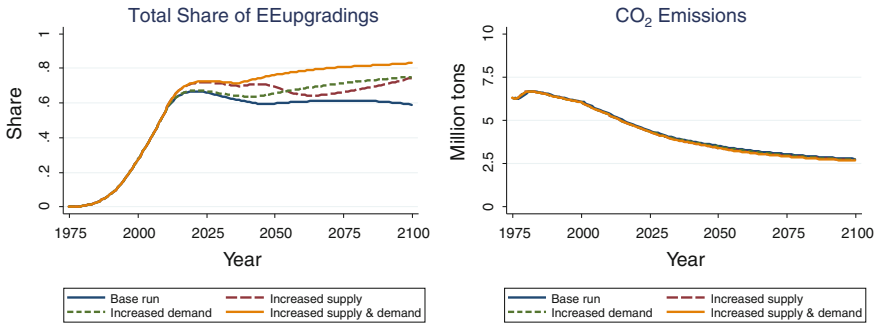
Fig. 8.2 Simulation results for policies related to supply and demand for the TOTAL SHARE OF EEUPGRADINGS (*left* exhibit) and the CO_2 EMISSIONS (*right* figure)

8.4.1 Increase the Supply of and the Demand for Energy-Efficient Housing

Above, the BUILDING OWNERS' PREFERENCE FOR ENERGY- EFFICIENT BUILDING DESIGNS turned out to be a powerful intervention lever that could reduce the CO_2 emission rate by 1.3 %. Similarly, the TENANTS' UTILITY FROM CO- BENEFITS OF ENERGY EFFICIENCY could reduce the CO_2 emission rate by 1.0 %. In order to study how supply and demand react to changes in preferences, I conducted the following three simulations (see Fig. 8.2 for all simulation results).

- First, I simulated an increase in demand by multiplying the variable TENANTS' UTILITY FROM CO-BENEFITS OF ENERGY EFFICIENCY with an auxiliary variable that gradually rises from 1 in the year 2010 to a value of 4 in the year 2100. In that simulation, the TOTAL SHARE OF EEUPGRADINGS increasingly rises above the base scenario. This means that the diffusion of energy-efficient renovations is accelerated when tenants derive greater utility from energy efficiency and its co-benefits in housing.
- Second, I simulated an increase in the supply of energy-efficient buildings. Specifically, I multiplied the variable STRENGTH OF PREFERENCE FOR ENERGY EFFICIENCY with an auxiliary variable, which gradually rises from 1 in the year 2010 to a value of 4 in the year 2100. In consequence, the TOTAL SHARE OF EEUPGRADINGS rises above the base scenario. This means that the diffusion of energy-efficient renovations is also accelerated when building owners have a stronger preference for energy efficiency and its co-benefits.
- Finally, I simulated the effect of a rise in demand and supply by combining the two previous simulations. In consequence, the TOTAL SHARE OF EEUPGRADINGS rises higher than in any of the two previous simulations. This means that increased demand and increased supply reinforce each other.

These findings imply that instruments aiming at influencing preferences and the perception of utility promise to actually accelerate the diffusion of energy-efficient

renovations based on market mechanisms. For example, marketing instruments may be employed to change the preferences of building owners and tenants toward favoring energy-efficient buildings and housing. Further, these results provide some indication that cultural and demographic processes can cause preferences to change and, consequently, affect the stock of buildings. For example, one might speculate that an increase in the share of elderly persons may increase demand for housing with the thermal comfort brought about by energy-efficient building designs.

8.4.2 The Legal Energy Coefficient and Subsidies

Reductions in the legal energy coefficient proved to be a very powerful policy lever taken in isolation. However, the legal energy coefficient should probably not be reduced without considering other aspects. This is because the construction costs of eeupgradings are increased (*ceteris paribus*) when the legal energy coefficient is reduced. Hence, lowering the legal energy coefficient might make eeupgradings less attractive for building owners. However, learning effects and subsidies reduce the construction costs. In order to investigate how the legal energy coefficient and subsidies interact and influence the TOTAL SHARE OF EEUPGRADINGS, I conducted the following three simulations (see Fig. 8.3 for all simulation results).

- **Reduction of energy coefficient** As a first step, I analyzed the effects of a reduction of the legal energy coefficient. Specifically, I multiplied the variable LONGTERM MINIMUM ENERGY COEFFICIENT OF CONSTRUCTION, which was 150 MJ/m^{2}a in the base scenario, with a variable which linearly declines from 1 in the year 2010 to 0.25 in the year 2100. This means that until the year 2100, the ENERGY COEFFICIENT OF CONSTRUCTION reaches a value of 37.5 MJ/m^{2}a. As can be seen in the top-left exhibit of Fig. 8.3, the TOTAL SHARE OF EEUPGRADINGS is substantially increased relative to the base scenario. In principle, this is desirable. Unfortunately, though, the AMOUNT OF SUBSIDIES is very much increased (see bottom left exhibit in Fig. 8.3). While this policy lever indeed reduces the CO$_2$ EMISSIONS, it leads to very high subsidy expenditures, and that is rather undesirable for the state.
- **Reduction of subsidies** As a second step, I investigate the effect of a reduction of subsidies. Specifically, I multiplied the variable AMOUNT OF SUBSIDIES with a factor that had a value of 1 over the years 1975–2010 and after that it linearly declined to 0 by the year 2050. After the year 2050 it remained constant at zero. This simulates the effect of a gradual reduction of subsidies. As can be seen in the top-left exhibit of Fig. 8.3, the reduction of subsidies causes the TOTAL SHARE OF EEUPGRADINGS to be slightly lower compared to the base scenario. However, the AMOUNT OF SUBSIDIES FOR EEUPGRADINGS now also is lower than in the base scenario (bottom-right exhibit). Because the energy coefficient is not affected in this simulation, the CO$_2$ EMISSIONS remain roughly as they were in the base scenario (see top-right exhibit). This second simulation shows that cutting
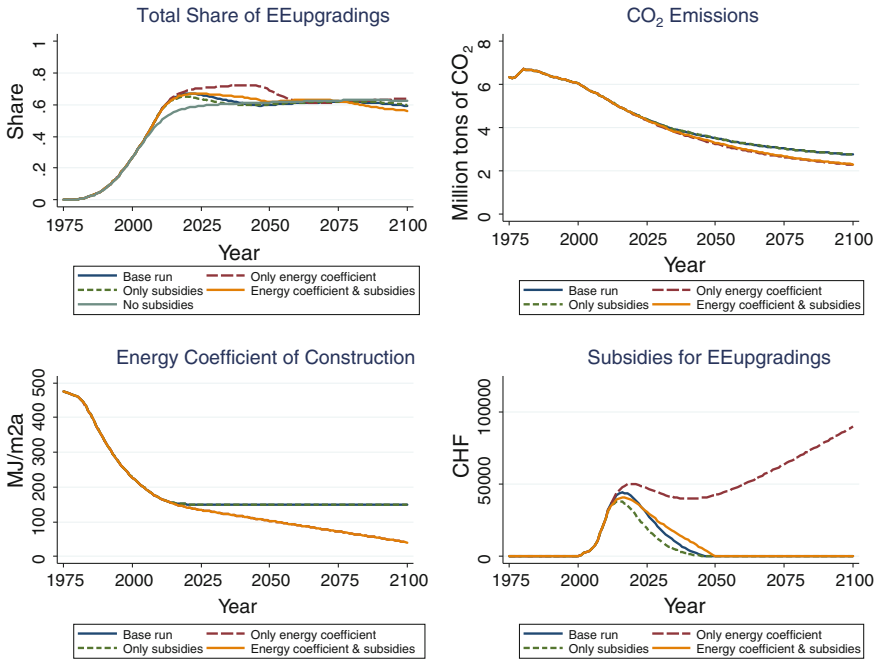
Fig. 8.3 Simulation results for policies related to the legal energy coefficient and subsidies. The four exhibits show the behavior of four variables. In particular, the behavior in the base scenario and the three policy runs discussed above is shown

subsidies (relative to the amount of subsidies used in the base scenario) slightly delays the transformation of the stock of buildings.

- **Reduction of the energy coefficient and subsidies** As a third step, I reduced the energy coefficient and ensured that subsidies too were reduced. Specifically, I combined the two scenarios as described above. On the one hand, now the ENERGY COEFFICIENT OF CONSTRUCTION is decreased over the time period from 2010 to 2100. On the other hand, the SUBSIDIES FOR EEUPGRADINGS are also decreased over the time period from 2010 to 2050. As can be seen in the four exhibits of Fig. 8.3, the TOTAL SHARE OF EEUPGRADINGS does not rise as much as in the first step (when only the energy coefficient was reduced). Yet, the TOTAL SHARE OF EEUPGRADINGS is still somewhat higher than what it was in the base scenario. Further, the AMOUNT OF SUBSIDIES is now slightly higher compared to the base scenario. Yet, the state's expenses for subsidies are still much lower compared to the first scenario (when only the energy coefficient was reduced). Finally, the CO_2 EMISSIONS are substantially reduced relative to the base scenario. The reduction in the CO_2 EMISSIONS is partially caused by the reduction of the ENERGY COEFFICIENT OF CONSTRUCTION. Partially, it is caused by the increase in the TOTAL SHARE OF EEUPGRADINGS.

From these three simulations, we can learn that reducing the ENERGY COEFFICIENT remains a powerful intervention lever that indeed contributes to the reduction of the CO_2 EMISSIONS. Yet, ambitious reductions in the energy coefficient may (*ceteris paribus*) lead to a situation where the state grants far too many subsidies. This would be a waste of scarce resources. Therefore, the state needs to periodically review the subsidy regime and consider how stricter standards, learning effects, and subsidies conjointly affect the cost of renovating. The model can-not be used to elaborate, in a practically relevant way, how this may be achieved. However, with the model I could show in a general manner that it is possible to reduce CO_2 EMISSIONS by reducing the ENERGY COEFFICIENT of new constructions and renovations and simultaneously avoiding too many subsidies being granted.

8.4.3 Broad Series of Interventions

In order to investigate the effect of a broad set of interventions, I increased the following intervention levers by 50 %, starting in the year 2010.

- Building owners' perception of the technological quality of energy-efficient building designs
- Building owners' preference for energy-efficient building designs
- Probability that architects promote energy-efficient building designs
- Tenants' perception of technological quality of energy-efficient building designs
- Tenants' utility from co-benefits of energy efficiency
- Pressure from fossil energy shortage
- Longterm minimum energy coefficient of construction (decreased by 50 %).

The left exhibit in Fig. 8.4 shows that the TOTAL SHARE OF EEUPGRADINGS is increased to near to unity by this set of interventions. The exhibit on the right shows that the CO_2 EMISSIONS is substantially reduced by this set of interventions. In fact, both the TOTAL SHARE OF EEUPGRADINGS and the CO_2 EMISSIONS roughly
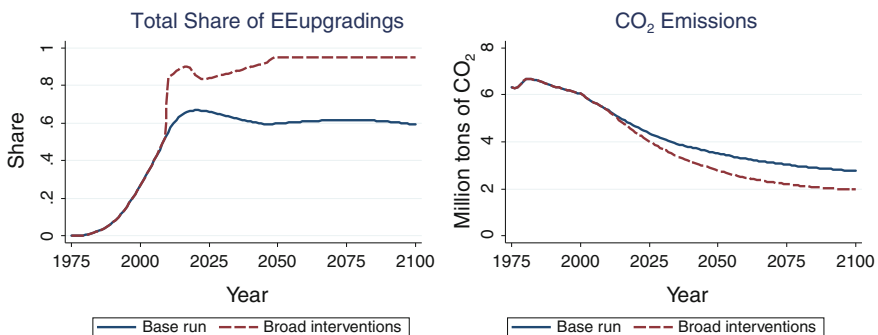
Fig. 8.4 Simulation results of a broad range of intervention levers on the TOTAL SHARE OF EEUPGRADINGS (*left* exhibit) and the CO_2 EMISSIONS (*right* exhibit)

reproduce the *Efficiency* scenario that I described in the analysis of the small model presented in Chap. 4 (see Sect. 4.5, on p. 132).

In Chap. 4, I set the share of energy-efficient renovations to rise exogenously from 0 (prior to the year 1995) to 0.95 in the year 2010 and then remain constant at a value of 0.95 until the year 2100. Now I find that the large simulation model can reproduce this scenario endogenously. This happens when a set of intervention levers such as the ones described above is increased. Increasing the TOTAL SHARE OF EEUPGRADINGS near to unity would constitute an enormous success for Switzerland's energy policy as well as for its environmental policy. Yet even in the case of such an overwhelming success, the stock of multifamily buildings does not achieve emission-reductions that are better than those described in the *Efficiency* scenario in Chap. 4. The implications of this finding are further discussed in the following section, particularly in Sect. 8.5.1.

8.5 Discussion: Transformation of the Societal Problem Situation

In this section I present a series of closely related recommendations for the transformation of the societal problem situation. I substantially draw on the insights obtained from working with the two simulation models. Ultimately, however, this section goes beyond model-based policy analysis and uses the full range of insights developed in this study to propose recommendations.

8.5.1 Review of Results

As a preliminary step, I review the main results and discuss their implications for policy-making. They can be summarized as follows.

- Although the stock of buildings is highly inert, several trends have caused the reduction of emissions in the stock of residential, multifamily buildings over the last three to four decades. Particularly noteworthy are the gradually declining diffusion of fossil-based heating systems across the stock of buildings (see Fig. 4.8 on p. 131), the gradually rising diffusion of energy-efficient renovations, the gradual reduction of the legal energy coefficient, and autonomous efficiency improvements. Most likely, these trends will continue into the future.
- Using the large simulation model, I showed how the share of energy-efficient renovations could be increased close to unity. As the TOTAL SHARE OF ENERGY-EFFICIENT RENOVATIONS moved toward its maximum value, the large simulation model endogenously converged toward the behavior of the small model in the *Efficiency* scenario described in Sect. 4.5. There, all buildings under renovation implemented an energy-efficient building design (95 % of the renovations

implemented eeupgradings and the remaining 5 % implemented energy-efficient reconstructions).

- Implementing the *Efficiency* scenario in Switzerland's stock of buildings would constitute an unprecedented policy success. In fact, the *Efficiency* scenario can be conceived of as the best possible case.
- In Sect. 4.6, I concluded that "even in the rather optimistic *Efficiency* scenario, 0.49 tons of the total allowance of 2 tons CO2 per capita in the year 2050 would account for the heating of Switzerland's residential multifamily buildings. Said differently, a quarter of every Swiss resident's yearly emission quota is being spent for the heating of residential multifamily buildings. Consider that the 0.49 per-capita tons of CO_2 only contain the emissions used for the heating of multifamily buildings. Those emissions do not include the per-capita emissions from single- or two-family buildings or commercial buildings. Warm water and appliances are also not included in the per-capita emissions given above". Therefore, it seems rather unlikely that the implementation of the *Efficiency* scenario would actually lead to emission-reductions that are compatible with the vision of the 2-ton-CO_2 society by 2050 and the 1-ton-CO_2 society by 2100.
- In sectors such as transportation or production, emissions appear to be on the rise, and technological abatement potentials appear to be smaller than in the building sector. For example, Switzerland's emissions from fuels used for motor vehicles rose from about 15 million tons of CO_2 in the year 1990 to about 17.5 million tons in the year 2010. Over the same time, emissions from fuels used for heating buildings and making warm water decreased from 25 million tons of CO_2 to 22.3 million tons of CO_2 (BAFU 2010, p. 4).[6]

What implications do these findings have for interventions into the societal problem situation? I arrived at the following main conclusions. These conclusions will then guide the development of recommendations.

- Ultimately, it is the total reduction of CO_2 emissions that matters for climate policy. This means that there is some maneuvering space regarding where emission-reductions are to be achieved. Public policy should decide to implement emission-reductions where there is both, a substantial technological reduction potential and where there is substantial economical reduction potential.
- It is my understanding that a track record of actual emissions in the building sector and a track record of rising emissions in the transportation sector favors emission-reductions in the building sector relative to other sectors, in particular the mobility sector.[7] Explanations for this may be that energy efficiency in buildings leads to increased comfort and is frequently cost-effective. In contrast, energy efficiency in motor vehicles requires lighter drive trains, smaller and less powerful motors, and perhaps non-standard fuels, as the technical efficiency potential of conventional

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[6] Note that these figures refer to the whole stock of buildings and also include single-family buildings.

[7] Other sectors too have economical and technological reduction potentials. However, I maintain that emission-reductions in the stock of buildings are comparatively favorable. Also see the study of Switzerland's greenhouse-gas abatement costs by McKinsey and Company (2009).

combustion engines is increasingly tapped. All this may reduce the utility drivers get from their vehicles. Further, in motor vehicles, the weight of the energy system and the energy density of the fuels are directly correlated with the overall energy efficiency of the vehicles. In contrast, bulky or heavy energy systems in buildings do not affect the energy efficiency of the building.

- The arguments outlined above lead me to conclude that the stock of buildings will eventually have to implement emission-reductions beyond its share of energy demanded and compensate for rising emissions in other sectors in the next decades.
- Based on the discussion of the *Efficiency* scenario above, I find it rather unlikely that an efficiency-oriented energy policy can achieve the emission-reductions that will be required by the stock of buildings. Instead, the decarbonization of the stock of buildings should be considered to be a crucial element of Switzerland's energy policy.
- If Switzerland wants to achieve the goals of a 1-ton-CO_2 society by the year 2100, then this probably means that buildings in general should not emit greenhouse-gases. Exceptions should be made for the special situation of heritage buildings. For the bulk of buildings, however, very ambitious renovations will need to be implemented. In Sect. 4.6 (see p. 132), I showed that a widespread decarbonization of the heating systems would lead to such a situation.

Yet how might a decarbonization of the stock of buildings by the year 2050 be achieved? In the following, I propose two regulations that might achieve the decarbonization of Switzerland's heating systems by 2050 (Sect. 8.5.2) and I propose an organizational innovation that should support building owners to comply with these regulations (Sect. 8.5.3). Eventually, I elaborate on interventions into the renovation process (Sect. 8.5.4) and further measures that might contribute to the transformation of Switzerland's stock of buildings (Sect. 8.5.5).

8.5.2 Regulations for the Transformation of the Stock of Buildings

In order to contribute to the development of a political strategy for the transformation of the stock of buildings, I propose the following set of regulations for discussion. I am very well aware that several difficult and crucial questions regarding political approval and practical implementation are omitted from this discussion. However, I wish to stress that I intend to propose a complement rather than an alternative to current policies.

Regulation 1

Until the year 2050, zero- or low-CO_2 emission heating technology has to be implemented in every building built before the year 2000.

Regulating the emissions from heating systems should prove much easier than mandating energy-efficient renovations. Because the service life of a heating system is much shorter compared to the service life of a building, almost all heating systems should be expected to exceed their service life by 2050. Because the emissions from heating systems are regulated, building owners are free to select the mix of insulation and energy technology (insulation, windows, energy source, etc.) that is best suited to their building and their individual preferences. I propose a command-and-control approach rather than high tax on greenhouse-gases because in rented apartments the tenants pay the costs of heating, whereas the building owner invests in the heating system. Therefore, a tax on fossil-fuels might not create the same pressure for action as would mandatory regulations. However, as a complement, an environmental tax on fossil-fuels could support the transformation of the stock of buildings. This particularly holds when the earnings of the environmental tax are used to subsidize renovations.

If it is possible to create the strong expectation that in the next 40 years the stock of buildings will indeed be transformed to a situation of low or zero emission, then entrepreneurs and companies can expect a large future market. This should lead to the development of technologies and business models that become increasingly better and cheaper. Therefore, I expect the implementation of such a long-term policy to alter the costs and quality of energy-efficient building designs beyond current practices. This is because actors in the construction industry would anticipate a big market and develop technologies and business models that implement low-emission heating and building designs at competitive prices, thus unlocking the innovativeness of entrepreneurs.

Regulation 2

Until the year 2020 building owners have to submit a roadmap that details how low-emission energy systems will be implemented in their building and how they intend to finance their road to a zero-emission building.

This second regulation is to encourage building owners to think about the implementation of measures long before the actual deadline arises. The development of a long-term plan should allow building owners to plan and coordinate investment decisions for their buildings. By planning a series of consecutive measures, inefficiencies should be substantially reduced. For example, a lack of coordination and long term planning might lead a building owner to first exchange windows and heating systems and only several years later to insulate the façade. Yet in order to insulate, the windows have to be unmounted and repositioned, so it would have been cheaper to replace the windows during insulation. And after insulation, the heating system might be over-dimensioned for a now efficient building. Thus, a smaller and cheaper heating system could have been bought after insulation.

Generally, such a regulation would particularly benefit non-professional building owners, who often lack a coherent long-term strategy for their buildings and are more likely to suffer from such inefficiencies. They rather decide in a step-by-step fashion,

frequently based on events in their personal lives. A further benefit of having a set of measures awaiting implementation is that it could encourage building owners to order construction during times of recession, when prices for construction are relatively low.

This proposal is complementary to current energy policies because it explicitly states a long-term goal and a date for achieving it without prescribing how building owners achieve these goals. Its temporal specification is such that building owners, construction companies, and technology developers have plenty of time to adapt. The two regulations could nevertheless achieve a very ambitious policy goal; namely, the far-reaching decarbonization of the stock of buildings by the year 2050. This is a crucial difference to current policies addressing emissions by buildings. Implementation of the two regulations presented here would basically guarantee a far-reaching decarbonization of Switzerland's stock of buildings.

Of course, implementation of these regulations would require careful further analysis. Issues such as the conservation of heritage buildings or the question as to how non-complying building owners would be sanctioned pose special difficulties. Also, current energy and climate policy regulations as well as building standards would need to be scrutinized regarding their consistency in terms of these regulations.

A brief glance at the literature (see Chap. 3) reveals that the technologies and the policy instruments necessary to achieve a low-or-zero-emission stock of buildings are mostly available. Energy systems for warm water in winter may still pose a problem. Ultimately, however, the crucial question now is how the necessary political will could be marshaled.

These regulations aim for an ambitious target. They could create a strong incentive to move the stock of buildings toward nearly complete decarbonization. However, these regulations should be complemented by further instruments that enable and facilitate compliance by the involved actors. In the following subsection, I propose an innovative organization that could help building owners to implement these two regulations and I discuss interventions addressing the renovation process.

8.5.3 Immobility: An Innovation in Support of Building Owners[8,9]

Starting Point: Building Owners Without Professional Know-How are a Crucial Bottleneck

Over the last decade, give or take a few years, the renovation of buildings has become increasingly complex. This is due to technological progress and the tightening of mandatory regulations. However, in the last five years or so, advanced energy-efficient renovations (such as those implementing the Minergie passive-house standard) have lost their pioneering character and are now entering the mainstream in the construction industry. However, implementing no-emission buildings in renovations, as implied by the two regulations introduced above, will make renovations more challenging. Hence, the construction sector will continue to experience rapid technological change. What is more, several other aspects of the construction sectors are in flux, such as the market situation, the cost of energy, and governmental policies.

Professionals in the construction industry are gradually getting acquainted with the challenges of advanced energy-efficient renovations. They will be able to participate in, or adapt to future technological change and any other changes touching upon their core practices. In contrast, non-professional building owners are mostly overwhelmed by the challenges brought about by energy-efficient renovations. They can-not be expected to adapt to, or participate in technological change and they often find it challenging to adequately consider the current state of the construction sector when faced with the need for decisions.

Should a widespread decarbonization of Switzerland's heating systems actually be attempted, then the technical and economical complexity of renovations should be expected to rise even more. This all means that most non-professional building owners will face very substantial challenges, which will impede the decarbonization of the stock of buildings. This situation may be conceived of as a problem, yet it also constitutes a major entrepreneurial opportunity for "(…) creating, communicating and delivering value (…)" AMA (2007) to non-professional building owners. If it were possible to develop and actually implement a business model that solves the challenges that non-professional building owners face, then it may be expected that the transformation of Switzerland's stock of buildings toward low-emission, and perhaps even more generally toward sustainable housing, can be accelerated.

In the following, I propose a cooperative society that assists building owners without professional know-how by offering them solutions for their most pressing

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[8] Trademark pending.

[9] The inspiration to propose a marketing-based intervention came partially from my involvement with the Competence Centre for Energy and Mobility's research network "Advanced Retrofit" and from a doctoral course and the exchange with fellow students. I would like to thank the members of the CCEM research network and the participants of the sustainability marketing seminar at HSG, taught by Prof. Dr. F. Belz in spring 2007. I would like to thank Heidi Hoffmann, Ruth Kaufmann-Hayoz, Silvia Ulli-Beer, and Mark Zimmermann for valuable comments.

challenges. I hope that such a new type of actor may work as a catalyst in the alleviation of the societal problem situation.

This organization, which I call "Immobility," does not yet exist. However, it promises to be an important instrument as the majority of buildings are owned by building persons who lack profound knowledge and experience (see Sect. 5.4.1).

Business Model

I propose a business model for an organization that assists building owners with all issues surrounding the renovation of buildings. The guiding idea is that most buildings are owned by individuals who do not have the professional knowledge and routine required to implement energy-efficient building designs in renovations. The cooperative society I propose, would assist building owners in dealing with technical, financial, and procedural complexities associated with renovations, such that the outcome is adequate for the specific building: technically well built and cost-effective. Such a business model probably would need to address the following issues.[10]

- **Long-term planning** The various elements of a building have different service lives. However, they should not be replaced without consideration of possible path dependencies,[11] or else renovations may become overly expensive. Long-term planning should help to avoid path dependencies in sequential renovations. Further, the business model should assist building owners in long-term financial planning for renovations.
- **Value creation** Planning should ensure that the building is renovated in a way that maximizes the utility that tenants draw from the building. This should increase the rent potential, reduce the risk of vacancy, and eventually increase the value of the building. Further, the business model should ensure that social and environmental values[12] are considered adequately.
- **Assistance with technology choice** For most building owners, even those with a background in technology, searching for information on technical components such as heating systems is a time-consuming and therefore costly process. Further, a substantial share of information on technical systems comes from the producers themselves, who are primarily interested in promoting their products. Hence, the business model should provide neutral and up-to-date information regarding

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[10] In order to substantiate this business model, further input will be required from practitioners, such as from the construction industry and marketing.

[11] Imagine, for example, that the heating system in a building is replaced. One year later, energy-efficient windows are installed, and two years later the building is insulated. In such a case, the heating system would eventually be over-dimensioned. Further, the in order to insulate the façade, the windows may have to be taken out and fitted again.

[12] The creation of social value in buildings may refer to the provision of communal space that facilitates interaction among the tenants. Environmental values may refer to the creation of opportunities for the biosphere; for example, the provision of nesting boxes for birds.

current technologies and their cost. In order to be perceived as credible, the cooperative society should seek endorsement from other actors, such as the federal office of energy or the Minergie Association.

- **Assistance with financial matters** The business model should assist building owners with organizing finance if sufficient reserves have not yet been and cannot be accumulated before the renovation. This entails advising building owners on what subsidies to apply for and how to optimize taxes. Further, by bundling the demand of several building owners, it may be possible to negotiate discounts.
- **Reduction of complexity** Building owners should not have to deal with several companies. Instead, the business model should coordinate among the companies involved and act as the single representative toward building owners, so that they can concentrate on the important decisions.
- **Managed care for buildings** As an important aspect, the business model should provide managed care (or commissioning, Mills 2011) for buildings. This means that buildings should be evaluated at regular intervals in order to find optimization potential in the domains of energy and other domains (see p. 96 for a brief description of commissioning). Such a service would encourage long-term relationships with building owners. As a part of commissioning, tenants should be taught how to use the technologies in their building in an optimal manner.
- **Strategic focus** The business model should not provide solutions for every type of building. Instead, the focus should be on buildings of a more usual type. Strategic focus should be on high volume of relatively similar buildings and cost reductions through economies of scale and scope and learning effects.

Technology: The CCEM Advanced Retrofit Concept[13]

The CCEMARC is a technological innovation that entails product- and process innovations in the exterior renovation of buildings. It consists of a set of technologies and concepts that allow one to quickly measure a building, plan elements for the façade and roof, prefabricate the elements in an industrial process, and finally mount the prefabricated elements on a building. Measurements are obtained by 3D-laser scanning, which allows one to obtain precise measurements in an efficient manner. The measurement allows an architect or planner to specify prefabricated elements such that they exactly fit the specifications of the buildings (e.g., spacings for windows, height, etc.). The elements consist of insulation material and encasement. Further, they contain channels for ventilation, electricity, and supply lines for solar panels. By

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[13] This technology was conceived and developed in the context of Switzerland's Competence Center for Energy and Mobility (CCEM), specifically in the research network "Advanced Low Energy Renovation of Buildings". While the project Diffusion Dynamics of Energy-Efficient Renovations formed part of that research network, I claim no authorship regarding the CCEM advanced retrofit concept. See http://www.empa-ren.ch/ren/uebersicht.htm, accessed 20 Jul 2011, for further information. See http://www.videoportal.sf.tv/video?id=02991afc-2957-40b6-8b8a-15d73500d6d4, accessed 20 Jul 2011, for a report on Switzerland's national television about an application of the CCEMARC (in German).

putting such channels into the façade and roof elements, such channels can be efficiently placed between the façade and the currently existing building. This is much more efficient than having to break walls inside the building to install ventilation systems. The elements are prefabricated off-site and eventually installed in one or two days. Prefabrication allows higher quality and higher degrees of industrialization compared to the conventional on-site construction work. This approach allows tenants to remain in the building instead of being evicted. In consequence, building owners continue to get revenues from rental payments

Organizational Form: Cooperative Society

The business model I outlined above is probably best implemented by a cooperative society. In Switzerland, cooperative societies have a long history of providing a wide range of important services. Cooperative societies can potentially be very cost-effective. In fact, Kissling (2008, p. 93) argues that cooperative societies have been successful because they favor long-term success over short-term success. Further, they have a track record of contributing social and cultural values (Kissling 2008, p. 93).

Prominent examples in Switzerland are Migros and Coop, the two largest retailers in Switzerland,[14] Mobility,[15] a cooperative society offering innovative solutions for car-sharing or Minergie,[16] a cooperative society offering certification for energy-efficient building designs. In the housing sector, building cooperative societies have been very successful in providing inexpensive housing to their members. In particular, large and highly professional building cooperative societies have been among the early adopters of the Minergie labels and implement a disproportionate share of solar collectors in the city of Zürich (see quote on p. 160).

Example

In order to illustrate and further substantiate the envisioned business model, I developed a (fictitious) example. It is provided in Appendix D.

Considerations for Implementation[17]

Obviously, the idea outlined in this section needs to be further substantiated if an implementation should be attempted. In particular, the following issues would need to

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[14] See http://www.migros.ch. and http://www.coop.ch. Accessed 21 Jul 2011.

[15] See http://mobility.ch. Accessed 21 Jul 2011.

[16] See http://minergie.ch. Accessed 21 Jul 2011.

[17] I am grateful to Mark Zimmermann who communicated several issues to me by Email on September 21, 2011.

be considered in collaboration with experts in the construction sector and marketing practitioners.

First, the positioning of Immobility among banks, planners, construction companies, and technology suppliers needs to be clarified. It is crucial that Immobility can provide a clearly visible value-added aspect to building owners. Second, a comprehensive business model needs to be developed that explains how the founding phase and the subsequent establishment are to be attempted.

8.5.4 Interventions into the Renovation Process

In Sect. 5.2, I described how a typical renovation process might unfold. Based on the sequence of steps described there, several interventions into the renovation process can be identified. In particular, I found that the following intervention levers could be addressed by different actors. Note that I do not propose interventions for each renovation step identified on p. 144. The reason is that I did not find any reasonable interventions. However, practitioners and other persons with more knowledge regarding the renovation process may find further interventions. The numbers following the steps of the renovation process indicate what step that was in Chap. 5.

- **Initiation of the renovation process (1)** The renovation of a building is very seldom of urgency. This means that the renovation of a building might be timed such that it falls into a period of slow economic growth or a recession. By starting the renovation of buildings in times of recession, construction costs might be relatively low and macro-economic stability may be increased. In recent years, Switzerland has supported energy-efficient renovations as part of its macro-economic stabilization program. However, because it may take nearly one year to initiate and conduct a conventional energy-efficient renovation, public policy should ensure that there is always a sufficiently big stock of renovation projects that can be carried out at short notice.
- **Detailed analysis (3)** In this step, building owners, architects, and specialized companies should be motivated to adapt their standards and practices such that increased emphasis is given to potentials for the creation of value. This specifically means identifying attributes that would increase the willingness to pay by tenants. I would expect that particularly for non-professional building owners attributes could be identified that could help to increase the rent potential, and hence may make energy-efficient renovations more economical. It might be helpful if building owners consult tenants regarding their preferences.
- **Development and evaluation of renovation strategies (4)** Building owners might benefit from tools that help them to evaluate different dimensions of different renovation projects. In fact, several guidelines and standards on various aspects of sustainable construction have been developed over the last years (Siegl 2008). However, I doubt that more than just a few building owners actually rely on such guidelines when developing and evaluating renovation strategies. Therefore, public

policy should find ways to influence building owners to adopt such guidelines and standards.

- **Organization of finance (5)** This step provides an opportunity to tie the economic evaluation of a renovation project to an evaluation of benefits of energy-efficient or even sustainable building designs. Banks and other financiers should insist that building owners actually evaluate the economics of energy efficiency in their renovation projects. This should entail not only a comparison of investment costs and energy savings. It should also consider the co-benefits of energy efficiency (Ott et al. 2006; Belz and Egger 2000) and include two or three scenarios regarding future energy price developments. Public policy should identify and implement measures to ensure that such a systematic evaluation becomes standard practice among financiers.

- **Informing tenants (8)** When informing tenants about impending renovations, building owners should actively communicate the benefits of the renovated housing. Probably only a minority of tenants are aware of the various co-benefits that energy efficiency brings. By actively communicating these benefits, the tenants' acceptance of energy-efficient housing and their willingness to pay might be increased.

- **Obtaining offers from construction companies (9)** Building owners should actively communicate to construction companies that they value experience with energy-efficient building designs. Public construction projects should play a clearly visible role in demanding this.

- **Selection of construction companies (10)** Building owners should not only focus on the financial dimension of the offers of construction companies. Instead, they should consider experienced construction companies, particularly in technological sensitive areas such as ventilation systems.

- **Handing over the apartments to tenants (14)** At the moment of handing over the apartment, tenants should be briefed regarding the use of the various technical systems and issues related to energy use. A successful intervention addressing this issue might consist of both, the communication knowledge and the communication of attitudes and norms. Such an intervention might be initiated by building owners. Yet in order to have a broad impact, governments should devise measures to ensure that tenants of energy-efficient buildings are instructed as to how to use the respective technologies.

8.5.5 Instruments for Intervention Levers

With the analysis of intervention levers in Sects. 8.3 and 8.4, I succeeded in identifying intervention levers that proved to be particularly powerful in the year 2020. I consciously choose that time frame for practical reasons. Such an approach, however, has its limitations. First, the results from the quantitative analysis should be considered with some caution, as there remain uncertainties related to the calibration of the simulation model. Second, in the long run, for example, until the year 2050,

even small effects may make important contributions. Third, the quantitative analysis did not consider with what type of instruments an intervention lever might actually be influenced.

In the following, I provide a typology of instruments that can be used to influence important policy levers in a desirable direction. This typology draws on Sect. 3.7 where I reviewed a wide range of policies and instruments. Further, the typology draws on the intervention levers that I identified in Sect. 8.3. In addition, it uses variables related to the stock of buildings that were presented in Chap. 4. The resulting typology is of a conceptual nature. It could be used to analyze a country's policy related to buildings or for systematically searching for further interventions.

Types of Interventions

This list contains descriptions of instruments as well as actions that could influence an intervention lever.

- **Change institutional framework** This refers to efforts by civil society actors and the state to change the institutional framework within which the diffusion of energy-efficient renovations occurs. By changing laws to be consistent with energy-efficient construction practices, energy-efficient building designs become part of the mainstream.
- **Continuous training** By offering chances for training, actors in the construction and real-estate sector can obtain the know-how required to implement energy-efficient building designs.
- **Energy counseling** This is a service, wherein an expert reviews built structures and user patterns and gives advice regarding how the energy demand may be reduced. Increasing the availability and accessibility of energy counseling services should improve the quality of decisions made by actors.
- **Emission regulations for heating systems** Emission regulations can refer to any regulation that sets emission limits for various gases. By regulating the emissions of heating systems, the application of current technology can be enforced and technological progress may be induced.
- **Establish standards** The establishment of standards, such as the Minergie standard, reduces information and transaction costs. For example, building owners might have to negotiate various technical details with architects prior to the Minergie standard. By referring to the Minergie standard, building owners can now easily demand an energy-efficient building design without having to discuss technical details.
- **Facilitate exchange among practitioners** By supporting the sharing of experiences among practitioners in the construction and real-estate sector, the diffusion of energy-efficient building designs and key technologies is accelerated.
- **Information campaigns** This refers to the communication of knowledge and the creation of awareness to a specific group. For example, Switzerland's federal office for energy distributes newsletters to all building owners. While information

campaigns usually are an element of marketing campaigns, they generally do not entail the offering of products and services.

- **Labeling** Labels communicate and certify the existence of certain attributes of a product. They are particularly useful to communicate attributes that are difficult to observe.
- **Marketing campaigns** This is an endeavor to inform and convince potential customers of a product or service. By marketing energy-efficient building designs and selected components, such as ventilation systems, the chance is increased that potential customers become actual costumers.
- **Participate in the political process** Participation in the political process may be a highly effective intervention if the institutional framework can be shaped to support energy-efficient building designs.
- **Pilot and demonstration initiatives** Such initiatives allow us to learn from early applications and demonstrate key aspects of new technologies and building designs. By implementing pilot and demonstration initiatives, actors in the construction and real-estate sector can become acquainted with innovations. This, in turn, accelerates the diffusion process.
- **Relaxation of regulations** Several regulations restrict the economic profitability of construction projects. For example, there are regulations governing the maximum floor space that may be built on lots. Further, there are regulations that impose minimum distances between built structures and the borders of the lot. By slightly relaxing such regulations for energy-efficient renovations, the economic attractiveness of such renovations is increased.
- **Research and development initiatives** This includes the initialization and support of research and development that leads to better or more cost-effective technologies and processes.
- **Subsidies for energy efficiency** This entails the partial funding of investments into energy efficiency by actors other than the owners of such investments.
- **Subsidies for low-emission heating systems** This entails the partial funding of investments into low-emission heating systems by actors other than the owners of such investments.
- **Taxation of fossil-fuels** This entails the taxation of fossil-fuels. A tax on fossil-fuels is seen to lead individuals to use less fossil-fuels. Further, alternative heating systems may become more attractive.
- **Taxation of fossil heating systems** This entails the taxation of heating systems that use fossil-fuels. A tax on such heating systems would increase the attractiveness of alternative heating systems.
- **Word of mouth** Word of mouth refers to the attitudes and expectations that are communicated about a product or service among its potential or actual customers. For example, an architect owner may informally ask colleagues about their experiences with energy-efficient building designs. While the spreading of positive word of mouth might generally happen coincidentally, it could actually be an intervention that is at the disposal of actors in the construction and real-estate sectors.

Table 8.8 Interventions addressing the stock of buildings

Intervention lever	Interventions and actors that could implement them
Energy-efficiency of heating systems	Continuous training (I, S), energy counseling (C, G, I), emission regulations for heating systems (G), establish standards (C, G, I, S), facilitate exchange among practitioners (C, G, I), information campaigns (C, G, I), labeling (C, G, I), marketing campaigns (I), research and development initiatives (G, I, S), subsidies for energy efficiency (C, G), taxation of fossil-fuels (G)
Diffusion of fossil-based heating systems	Change institutional framework (C, G, I), energy counseling (C, G, I), establish standards (C, G, I), information campaigns (C, G, I), marketing campaigns (I), Participate in the political process (C, G, I), relaxation of regulations (G), subsidies for low-emission heating systems (C, G), taxation of fossil-fuels (G), taxation of fossil heating systems (G)

Abbreviations B building owners, *C* civil society actors, *G* governments of various levels, *I* industry actors (such as construction companies and architects), *S* scientists and actors from academia, *T* tenants

Intervention Levers

Instruments from the general typology listed above can be used to address selected intervention levers. Tables 8.8–8.12 list the interventions levers to which such instruments can be applied. For each intervention lever (shown in the left column) I state what type of instrument might be used to influence it (shown in the right column). Further, for each type of instruments I state what kind of actor might be able to implement it (abbreviations in brackets).

Table 8.8 shows selected intervention levers related to the stock of buildings. Recall that I already provided a brief discussion of the most important levers related to the stock of buildings in Sect. 4.7 (see Table 4.3). Now, I complete that analysis by proposing types of instruments that can address those intervention levers.

On the next page, Table 8.9 shows interventions addressing building owners and Table 8.10 shows interventions addressing tenants. On the page following that, Table 8.11 shows interventions addressing technology and Table 8.12 shows interventions addressing civil society.

8.6 Conclusions

In this chapter, I addressed my final, and probably most important, research question: "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?" As a first, preliminary step, I discussed elements of the transformation of the societal problem

Table 8.9 Interventions addressing building owners

Intervention lever	Interventions and actors that could implement them
Building owners' perception of the technological quality of energy-efficient building designs	Information campaigns (G, I), pilot and demonstration initiatives (G, I, S), word of mouth (B, T)
Building owners' delay in the perception of technological quality	Information campaigns (C, G, I), pilot and demonstration initiatives (B, C, G, I), word of mouth (B, T)
Financial attractiveness of eeupgradings for BOs	Relaxation of regulations (G), research and development initiatives (C, G, I), subsidies for energy efficiency (G), subsidies for low-emission heating systems (G), taxation of fossil-fuels (G), taxation of fossil heating systems (G), word of mouth (B, T)
Probability that architects promote energy-efficient building designs	Continuous training (C, G, I, S), establish standards (G, I), facilitate exchange among practitioners (C, G, I), information campaigns (C, G, I), marketing campaigns (C, G, I), relaxation of regulations (G)
Building owners' preference for energy-efficient building designs	Energy counseling (C, G, I), emission regulations for heating systems (G, I), establish standards (G, I), information campaigns (C, G, I), labeling (C, G, I), marketing campaigns (C, G, I), pilot and demonstration initiatives (B, C, G, I), relaxation of regulations (G), subsidies for energy efficiency (G), subsidies for low-emission heating systems (G), taxation of fossil-fuels (G), taxation of fossil heating systems (G), word of mouth (B, T)
Increasing the share of professional building owners	Implement "Immobility" cooperative society (C, G, I)

Abbreviations B building owners, C civil society actors, G governments of various levels, I industry actors (such as construction companies and architects) S scientists and actors from academia, T tenants

Table 8.10 Interventions addressing tenants

Intervention lever	Interventions and actors that could implement them
Tenants' perception of technological quality of energy-efficient building designs	Information campaigns (C, G, I), labeling (C, G, I), marketing campaigns (C, G, I), pilot and demonstration initiatives (B, C, G, I), word of mouth (B, T)
Tenants' utility from co-benefits of energy efficiency	Information campaigns (C, G, I), labeling (C, G, I), marketing campaigns (C, G, I)

Abbreviations B building owners, C civil society actors, G governments of various levels I industry actors (such as construction companies and architects), S scientists and actors from academia, T tenants

Table 8.11 Interventions addressing technology levers

Intervention lever	Interventions and actors that could implement them
Effect of learning on construction costs of eeupgrading designs	Continuous training (C, G, I, S), facilitate exchange among practitioners (C, G, I), research and development initiatives (C, G, I)
Effect of stricter standards on construction costs	Facilitate exchange among practitioners (C, G, I), research and development initiatives (C, G, I), relaxation of regulations (G), subsidies for energy efficiency (G)
Architects' perception of technological quality of energy-efficient building designs	Continuous training (C, G, I, S), establish standards (G, I), marketing campaigns (C, G, I), pilot and demonstration initiatives (B, C, G, I), research and development initiatives (C, G, I), word of mouth (B, T)

Abbreviations B building owners, *C* civil society actors, *G* governments of various levels, *I* industry actors (such as construction companies and architects), *S* scientists and actors from academia, *T* tenants

Table 8.12 Interventions addressing civil society levers

Intervention lever	Interventions and actors that could implement them
Yearly emissions of CO_2 compatible with the 2 degree goal	Participate in the political process (B, C, I, S, T)
Pressure from fossil energy shortage	Marketing campaigns (C, G, I), participate in the political process (B, C, I, S, T), taxation of fossil-fuels (G), taxation of fossil heating systems (G)
Perception of technological quality by civil society actors	Establish standards (G, I), information campaigns (C, G, I), pilot and demonstration initiatives (B, C, G, I), word of mouth (B, T)
Threshold value until which subsidies are given	Change institutional framework (G), participate in the political process (B, C, I, S, T)
Reductions of the legal energy coefficient	Change institutional framework (G), emission regulations for heating systems (G, I), establish standards (G, I), participate in the political process (B, C, I, S, T), research and development initiatives (C, G, I), subsidies for low-emission heating systems (G), taxation of fossil-fuels (G), taxation of fossil heating systems (G)

Abbreviations B building owners, *C* civil society actors, *G* governments of various levels, *I* industry actors (such as construction companies and architects), *S* scientists and actors from academia, *T* tenants

situation. In that theoretical foundation, I argued that societal problem situations can-not be 'fixed' or 'solved'. Instead, I emphasized that societal problem situations are transformed collaboratively, involving several actors. As a second step, I used the large simulation model to systematically analyze intervention levers. I analyzed intervention levers in isolation as well as in packages containing several intervention levers. Eventually, I summarized the main findings of my work and discussed the implications for the development of recommendations. I argued that the transformation process of the stock of buildings should be expected to unfold over several

decades. Further, I argued that such a transformation would not be achieved by only relying on energy-efficiency policies. Instead, the stock of buildings should generally not emit greenhouse-gases. I presented two regulations that could achieve such a goal. I proposed a collaborative society that solves the building owners' problem and has the potential to enhance compliance with these regulations. Further, I discussed how different actors might influence the renovation process, such that renovations are more likely to implement energy efficiency solutions. Finally, I developed a typology of instruments and elaborated what type of actors might use what type of instrument to influence what intervention lever.

Concluding this chapter, I realize the important role the state will have to play in the transformation of this societal problem situation. However, the state does not act independently from civil society actors or actors in the market. Instead, the state must also be conceived of as the object of a power struggle between actors with differences in power and interests. Rather than 'solving' a problem situation, the state must consider to what degree other actors enable state regulations. This is in line with the notion of a "collaborative transformation" of societal problem situations.

Recognizing that non-state actors contribute to the governance of societal problem situations yields a broader perspective as to what 'instruments' can be used in its transformation. Specifically, it allows one to not only consider 'classical' policy instruments such as taxes, regulations, or incentive schemes. Now, conscious actions by non-state actors can be understood as an act of governance. While co-ordination among different actors probably would enhance the effect of such interventions, it allows for some degree of autonomy in actors' actions. Yet at the same time it demands that non-state actors act responsibly and consider what they can contribute in their realm of influence.

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Part IV
Discussion and Conclusions

Chapter 9
Discussion and Conclusions

9.1 Introduction

In this study, I analyzed how the diffusion of energy-efficient renovations might be accelerated, such that the CO_2 emissions might be reduced. The study focussed on multifamily buildings in Switzerland and proceeded as follows. As a first step, four analytical perspectives were developed (Chaps. 3–6). As a second step, the insights from these four perspectives were synthesized into a rich System Dynamics simulation model of the diffusion of energy-efficient renovations (see Chap. 7). As a third step, the simulation model as well as other insights from the study were used to analyze how the diffusion might be accelerated (see Chap. 8).

In this final chapter, I reflect on the results of the study. All the other chapters (except the introduction) provided some form of discussion and conclusion, where I reflected on the results obtained in the corresponding chapter. Instead of repeating the conclusions provided in the individual chapters, I now attempt to develop a more general discussion. Hence, this chapter proceeds as follows. In Sect. 9.2, I discuss the specific research questions that guided the study. Then, I address the general research questions in order generate the main conclusions to the study (see Sect. 9.3). In Sect. 9.4, I summarize the contributions the study makes to various fields of research and practice. In Sect. 9.5, I discuss strengths and limitations of the study and suggest further research that I think would be valuable. In Sect. 9.6 I discuss generalizations that can be drawn from the study.

9.2 The Specific Research Questions Revisited

This study was guided by five specific research questions as well as a general one. In the following, I discuss these specific research questions. In addition, I discuss how the insights gained from one chapter's results contributed toward the argument of the whole study.

Research question 1: how should the context, within which the diffusion of energy-efficient renovations takes place, be described in order to guide subsequent system modeling?

In Chap. 3, I argued that the emergence of energy security issues and later concerns about the dangerous effects of rapid climate change led to adaptive pressure on the stock of buildings. Such external pressures, however, eventually caused various developments within Switzerland's construction and real-estate industry. Technological innovations led to an increased quality of energy-efficient technologies such as insulation, windows, or ventilation systems, and eventually this led to improved energy-efficient building designs in general. Learning effects, economies of scale and scope, as well as state subsidies led to decreasing costs. Communication, standardization, labeling, as well as further training increased awareness of energy-efficient building designs among various actors. As a result, the share of energy-efficient building designs implemented in new constructions and renovations rose.

However, housing and construction were important aspects of Switzerland's society long before the energy efficiency of the stock of buildings became an issue. Issues such as the investor-user dilemma, regulations in tenancy and tax laws, the lack of qualified craftsmen, and various other issues act as barriers to the rapid diffusion of energy-efficient building designs. Throughout the various stages of the diffusion process, the state implemented several instruments aimed at promoting the diffusion of energy-efficient building designs.

In conclusion, I found that it is mostly developments that are external to the stock of buildings which exert adaptive pressures on the stock of buildings. The stock of buildings and the various fields of practice related to it then gradually adapt to these pressures. Ultimately, the whole situation is complex, fragmented, and appears to be rapidly changing in many aspects. Hence, I found that the context is best described as a societal problem situation. Specifically, I found that various actors took issue with aspects of Switzerland's energy, emission, and housing patterns. Scientists, having discovered the link between anthropogenic greenhouse-gas emissions and the risks of rapid climate-change, were the first actors to demand emission-reductions. As evidence piled up and the belief in the dangerous effects of anthropogenic greenhouse-gas emissions spread among scientists, other actors became involved. Civil society actors, initially related to the environmental movement, translated the scientists' claim into political action. Eventually, emission-reduction entered the mainstream and became part of the political and economical agenda.

Throughout this process, however, actors with interests in the current fossil-based energy system were compelled to engage in this discourse and compete for the general public's endorsement. For example, representatives of fuel interests insisted on a lack of alternatives, pointed to technological progress in fossil-fuel-based technologies, and generally upheld the view that in a liberal market economy choices should remain mostly with consumers. In recent years, some parts of the fossil-fuel industry aligned with the new political mainstream by proposing "eco heating oil" or by promoting more efficient burners for fossil-based heating systems.

A strength of my work regarding this research question is that it provides a very broad description of the context. It shows that the whole diffusion process is ultimately governed by external developments of a global scale. Further, the resulting description is theoretically guided by a preliminary theory of societal problem situations, by theories of the diffusion of innovations, and by a typology of tools for sustainable development. A potential limitation is that the resulting description may be perceived to be too broad. In fact, this chapter can-not address all of the potentially relevant issues with rigor and detail. I am very well aware that issues such as global energy policies, climate-change, the rebound effect, and many more could be treated much more extensively. However, I am confident that I identified and described those issues which are most important for the purpose of this specific study. Hence, the research conducted in order to answer this first research question contributed various theoretical concepts as well as empirical findings. However, in order to adequately guide subsequent modeling work, it proved important to reduce the empirical richness of the real world. For example, I ultimately drew on rather aggregated operationalizations such as "energy-efficient building designs" instead of modeling the many different types of windows, ventilation systems, and insulation technologies.

Research question 2: 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?

In Chap. 4, I proposed to use a small model to analyze how the stock of buildings develops under different assumptions. With the first three scenarios, the boundaries were set within which Switzerland's stock of residential multifamily buildings will probably evolve. Specifically, the *baserun scenario* can be seen to set the limit of a rather sluggish development whereas the *efficiency scenario* sets the limit of the best possible development.

From the analysis of the small model, I concluded that it is unlikely that Switzerland's stock of multifamily buildings reaches emission rates that are consistent with a 2-ton-CO_2-society by the year 2050 and a 1-ton-CO_2-society by the year 2100, based solely on energy efficiency on the demand side. This finding led me to analyze a fourth scenario, where I simulated the effects of a gradual decarbonization of the heating systems. As it turned out, decoupling greenhouse-gas emissions from increases in energy use can lead to a very low-emitting stock of buildings. This insight into the importance of decarbonization would subsequently inspire the two regulations I proposed in Chap. 8. Further, the small model developed in Chap. 4 served (with minor adjustments) as the building-stock module in the large model.

Research question 3: 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?

In Chap. 5, I proceeded along different routes in order to investigate which actors were involved in the societal problem situation. In doing so, I drew substantially from expert interviews. As a first step, I described the renovation process as a series of

distinct steps. This idealtypical description gave me insight as to which actors were closely involved with the actual construction process. As a second step, I developed a long list of potentially relevant actors that included actors in the market, civil society actors, and actors in the state. As a third step, I identified four actors (building owners, architects, tenants, and advocacy coalitions) to be included into the large simulation model. I then analyzed them in greater detail, developed an empirically grounded typology of each actor, and finally explained what drives changes in the actors' decision making. As a last step, I analyzed the power each actor type has toward accelerating the diffusion of energy-efficient renovations and I analyzed each actor type regarding their interest in an energy-efficient stock of buildings.

Addressing this third research question led to a detailed understanding of the actors in the societal problem situation. It allowed me to base the modeling of actors on the description of the empirical reality provided by my interviewees. Further, it allowed me to explain changes in the decision making of actors in an empirically rigorous way. A strength of this chapter is that it starts with a rather broad perspective and *prima facie* allows for any kind of actor to be considered as important. Then, those actors which are identified as actually being the most important are rigorously analyzed. The sections on building owners and architects should be considered to be rather representative as they are well grounded in the interview data. Further, the section on the advocacy coalitions is well grounded in the empirical literature. A potential limitation is that the section on the tenants is not actually based on interview data from tenants (see Sect. 9.5.1 for a more detailed discussion of this issue).

Research question 4: what are the most important processes causing the diffusion of energy-efficient renovations?

In Chap. 6, I developed a causal loop diagram which explains the diffusion of energy-efficient renovations by way of a series of interrelated, causal feedback loops. As a first step, I showed how building owners and tenants interact on the housing market. By coupling the decision-functions of building owners and tenants, supply and demand for housing are shown to be mutually dependent. As a next step, I explained that technological progress occurs as a function of the cumulated number of energy-efficient renovations and I showed how technology influences the decision making of building owners and tenants. In fact, technology and the market can be seen to represent the key decision making structure in the societal problem situation, which determines a market-clearing equilibrium. Initially, low energy prices and a very low performance-to-cost ratio of energy-efficient technologies impede the diffusion of energy-efficient renovations. With the emergence of energy security issues and climate-change concerns, civil society actors begun to demand policies which would promote energy efficiency and low emissions. Gradually, the state begun to implement instruments and policies that increased energy efficiency. Three types of instruments proved particularly important. These were the support of research and development of technology, the financial support of applications of energy-efficient technology, and the implementation of command-and-control type instruments. As a result of state policies, energy-efficient renovations gradually became more attractive

for building owners and tenants. Consequently, the housing market gradually shifted, and the share of renovations which implemented energy-efficient renovations started to rise.

This chapter contributed a dynamic theory of the diffusion of energy-efficient renovations. It sketched the most important dynamics of the subsequently developed large simulation model. A strength of this chapter is that the most important structures of causality can be communicated in a very clear way. However, a limitation is that qualitative models are constrained in the precision that they can provide. They do not detail in what direction feedback loops actually work, what equilibrium they attain, or how they interfere with each other. In order to obtain more precision, a quantitative simulation model was required.

Research question 5: 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?

In Chap. 7, I developed a large System Dynamics model of the diffusion process of energy-efficient buildings. In order to do so, I relied on insights from the four analytical chapters. The small model of the stock of buildings (see Chap. 4) served as a starting point. I advanced the analysis by using the dynamic theory represented in the causal loop diagrams (see Chap. 6). Specifically, I operationalized that qualitative explanation into a stock-and-flow diagram and I specified equations and parameters such that a reasonable behavior was produced. Further, I also drew on the description of building owners, tenants, architects, and the advocacy coalitions, and operationalized these insights into the model structure. The analysis of the context of the diffusion of energy-efficient renovations in Chap. 3 proved instrumental in considering the available literature. Further, the broad analysis of the context conducted therein was crucial when considering the boundaries of the large simulation model.

In order to strengthen the quality of the model, I performed a series of tests. Throughout the modeling process, I iteratively cycled between model testing and model adaptation (see Sect. 9.5.2 below for a more detailed discussion of the strengths and limitations of the simulation models). Eventually, I obtained a formal, conceptually rich, empirically well-grounded, and theoretically informed dynamic theory of the diffusion process, in the form of a System Dynamics simulation model. That model was used to analyze selected aspects of the diffusion process:

- The effect of a massively rising energy price. That analysis led me to caution against overly optimistic expectations regarding the effect of a two- or three-fold rise in the energy price. Even with such substantial increases in the energy price, the effect on the diffusion of energy-efficient renovations would be minimal.
- The start-up difficulties of energy-efficient technology. I found that a lack of state support for research and development substantially delayed the diffusion of energy-efficient renovations.
- The role of external drivers. I found that the diffusion of energy-efficient renovations was substantially delayed without external drivers. Regarding the CO_2-emission rate, I found that a lack of external drivers led to massively higher CO_2 emissions.

First, I proposed two regulations that could actually lead to the decarbonization of the stock of buildings. Specifically, I called for mandatory regulations banning fossil-based heating systems by 2050 and I proposed that building owners submit a plan for the renovation of their building by 2020. Second, I proposed a cooperative society called "Immobility" that would contribute to solving several of the building owners' challenges. This cooperative society would enable building owners to make their buildings environmentally and economically sustainable and comply with the two regulations that I proposed. Third, I discussed how various actors might intervene in the renovation process in order to increase the likelihood of renovations implementing energy-efficient building designs. Finally, I provided a typology of instruments and explained how they might be used to influence intervention levers, such that the diffusion of energy-efficient renovations is accelerated. I concluded that chapter by pointing out that the societal problem situation could only be transformed in a collaborative manner, involving various actors.

The work conducted in response to the fifth specific research question makes a series of crucial contributions to the argument of the study. The most important is that it selects important insights from the analytical perspectives and synthesizes them into a simulation model. Model testing and subsequent improvement also contribute toward that goal. Eventually, the resulting simulation model should be seen to be an "epistemic device" that supports the analysis of the material issue of the study.

Research question 6: 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?

In Chap. 8, I provided a preliminary discussion of the transformation of societal problem situations. This served as a theoretical foundation for the subsequent development of recommendations as to how the diffusion of energy-efficient renovations can be accelerated. I proceeded along several different routes to find such recommendations. First, I used the large simulation model to conduct a systematic analysis of intervention levers. I analyzed how an increase of 50 % in the year 2010 would affect the share of energy-efficient renovations and the CO_2 emission rate in the year 2020. I found that most intervention levers hardly accelerate the diffusion process over this time. A small number of intervention levers, however, can increase the share of energy-efficient renovations up to about 25 % and reduce the CO_2 emission rate by up to 18 % by the year 2020. When the most effective policies are applied together, then the share of energy-efficient renovations can be brought near to unity. However, even if all renovations were to implement energy-efficient building designs, the reduction of the CO_2 emission rate would still not be consistent with the goals of a 2-ton-CO_2-society by the year 2050 and a 1-ton-CO_2-society by the year 2050. Eventually, I concluded from the analysis of the two simulation models that the heating systems for floor heating need to be completely decarbonized (see Sect. 8.5.1 for an extensive review of results). Based on the insights from the models, I developed four closely related sets of recommendations.

The work conducted for answering research question 6 provided several crucial contributions to the argument of this study. In fact, it might be seen as the most

practically relevant chapter of this study. This is achieved by showing the importance of decarbonization as a complement to efficiency-oriented policies and by proposing a series of interventions that can enforce and support such a decarbonization strategy. Finally, Chap. 8 yields insights that allow for the general research question to be answered (see the section below).

9.3   Conclusions

Based on the discussion of the specific research questions, above, I now provide several conclusions in relation to the general research question. In the introduction, I formulated the general research question as follows: **How can the diffusion of energy-efficient renovations of (residential multifamily) buildings be accelerated in order to reduce Switzerland's emission of CO_2?** Before I directly address the general research questions, the following insights need to be considered as a preliminary step. These insights are partially derived from the literature and partially derived from my work, as presented throughout the study.

- Over the last few decades, energy security issues and the emergence of a discourse on climate-change have created adaptive pressure on Switzerland's stock of buildings. The stock of buildings has mostly been reacting to these pressures. The large simulation model may be seen as a description of the governance structure that controls the adaptation of the stock of buildings to these external pressures.
- Over the last three to four decades, several trends have caused the reduction of emissions in the stock of residential, multifamily buildings. Particularly noteworthy are the gradually declining diffusion of fossil-based heating systems across the stock of buildings, the gradually rising diffusion of energy-efficient renovations, the gradual reduction of the legal energy coefficient, and autonomous efficiency improvements. Most likely, these trends will continue to lead to emission-reductions. However, the literature, as well as my research, indicate that those trends will not lead to the achievement of the vision of the 2-ton-CO_2-society by 2050 and the 1-ton-CO_2-society by 2100.
- The literature that I reviewed, as well as the interviews that I conducted, led me to conclude that the implementation of energy-efficient building designs in the renovation of multifamily buildings is generally technologically feasible and frequently economically viable. However, the literature also confirmed the existence of a multitude of barriers to the diffusion of energy-efficient renovations.
- Because of the long service life of buildings, the stock of buildings is highly inert. In fact, only about 1–2 % of Switzerland's buildings are insulated or otherwise made more energy-efficient each year. This means that any transition toward a low-emission stock of buildings based on energy-efficient renovations should be expected to unfold over several decades. On the other hand, an acceleration of the diffusion of energy-efficient renovations promises to make an important contribution to the achievement of the vision of a 1-ton-CO_2-society.

Against the background of these insights, the relevancy of the general research question easily becomes evident. I attempted to provide answers to these questions by way of the large simulation model. Based on a systematic analysis, I was able to find a whole series of intervention levers that actually increased the share of energy-efficient renovations and decreased the CO_2 emission rate (see Sects. 8.3 and 8.4). However, in the analysis of the small model presented in Chap. 4, it had already become clear that energy-efficiency-oriented policies are not sufficient. In addition to an accelerated diffusion of energy-efficient renovations, the need for a widespread decarbonization of the stock of buildings' heating systems became evident. I reached the following conclusions.

- If Switzerland wants to achieve the emission-reduction goals given by the vision of a 1-ton-CO_2 society, then the stock of buildings will probably have to implement emission-reductions beyond its share of energy demanded in order to compensate for rising emissions in other sectors.
- This entails that buildings in general should not emit greenhouse-gases. While exceptions should be made for special situations, such as heritage buildings, the bulk of buildings will need to implement decarbonization renovations.

Eventually, these findings caused me to slightly expand the focus of the study and also include the role of heating systems in a very general way. Based on the simulation model and on the analytical perspectives, I propose to accelerate the diffusion of energy-efficient renovations and the decarbonization of the heating systems as follows:

- **Implement the two regulations in order to provide a long-term policy framework.** In Sect. 8.5.2, I proposed that until the year 2050, zero- or low-CO_2 emission heating technology has to be implemented in every building built before the year 2000. What is more, until the year 2020, building owners would have to submit a roadmap that details how low-emission energy systems will be implemented in their building and how they intend to finance their road to a zero-emission building.
- **Implement a cooperative society that assists building owners with solving their major challenges.** In Sect. 8.5.3, I described an organization that could assist building owners with various challenges in energy-efficient renovations.
- **Implement interventions that increase the likelihood that renovations implement a high level of energy efficiency.** In Sect. 8.5.4, I described how various actors could intervene in the renovation process in order to increase the likelihood that energy efficiency becomes the standard rather than an extra option in renovations.
- **Increase the intensity of the intervention levers identified as powerful.** In Sect. 8.3, I analyzed what intervention levers are powerful. In Sect. 8.5.5, I provided a typology of instruments for each intervention lever and I showed what type of actor could implement these instruments. I concluded that a wide range of actors, state as well as non-state actors, can contribute to the intensification of these intervention levers, in order to participate in the collaborative transformation of the societal problem situation.

9.4 Contributions of the Study

The study contributed to several disciplines and fields of research as well as to policy-making. In the following, I list several contributions that I think are the theoretically and practically most interesting ones.

To the Field of System Dynamics

This study contributes a further application to the field. Applying the System Dynamics methodology to issues of great societal significance has always been the goal of its founders. This study follows this tradition. Beyond this, I think that the following aspects of my work may be of special interest to fellow System Dynamicists.

- This study illustrates the power of small models. In Sect. 4.1, I argued that small models should be seen as an approach that is particularly well suited to communicated complex situations to decision-makers. In doing so, it may complement group model building and model simplification.
- My work may be of special interest to System Dynamicists who search for inspiration as to how to elicit decision-functions of actors from interview data. In Sect. 5.4.1, I used my interview data to describe the situation building owners are in, to elucidate the different types of building owners and analyze their behavioral characteristics, and to explain changes in the decision making of building owners. In addition to the interview data, I used contributions from the literature and from publicly available statistics.
- The idea of developing analytical chapters as a first step and then synthesizing them into a large simulation model as a second step proved very useful. I think that most System Dynamics research into societal problem situations would benefit from proceeding in this manner. This refers not only to using analytical chapters in general. I actually think that it is always useful to analyze the context and the actors involved. Further, it probably always is useful to develop a small model of the basic stocks and flows and then develop a causal theory on the processes which control that basic structure.

To General Ecology and Sustainability Science

General ecology (as it is understood by the University of Berne) is a scientific perspective that has "the relationship between humans (as individuals and as societies) and their natural environment" (Kaufmann-Hayoz 2007, p. 3) as its object of study and aims to be a "comprehensive and integrative approach to the phenomena of human-nature interrelations, including material-energetic as well as socio-cultural aspects" (Kaufmann-Hayoz 2007, p. 3). It corresponds to sustainability science (Komiyama et al. 2006).

- The study shows how Switzerland's society, its built environment, and its natural environment are related to each other. This is most clearly seen in the case of Switzerland's CO_2 emission rate. Demands for CO_2 mitigation emerged in science and then later diffused into politics. CO_2 emissions, as well as any attempt to reduce CO_2 emissions, are essentially human–environment interactions.
- Further, the study shows in an exemplary manner that the analysis of environmental issues should not be conducted from a single disciplinary perspective. While technical, economical, or political issues all play a role, an adequate analysis of environmental issues should pursue a broad and integrative perspective. This study does so, by showing how economics, technology, public opinion, and policy change are interrelated, and how they bring about the governance of the stock of buildings' CO_2 emission rate.

To the Social Sciences

This study makes several contributions to the social sciences, both methodological and theoretical.

- To the study of the diffusion of innovations, the study contributes a review of drivers of and barriers to the diffusion of energy-efficient investments in the building sector. Further, it systematically describes the key elements of this diffusion process (see Sect. 3.6).
- The study identifies the most important actors who are involved with the diffusion of energy-efficient renovations. In doing so, the study accounts for the many different perspectives that actors hold.
- The study provides an analysis of the effect of different types of actors on the diffusion of energy-efficient renovations (see Sect. 5.5). More specifically, the study evaluates the different types of building owners, tenants, architects, and advocacy coalitions regarding their interest in energy efficiency and its co-benefits and the influence on the energy efficiency of the stock of buildings.
- The study illustrates the methodological power of System Dynamics in the analysis of societal processes. In particular, the study shows how System Dynamics simulation models can integrate empirical findings and theoretical concepts in a much more powerful way than the verbal or statistical approaches that are typically used. On the one hand, theories in the form of quantitative models are generally more explicit than purely verbal theories. On the other hand, System Dynamics facilitates the building of 'richer' models, which aim for an empirically more adequate description of societal processes than the reductionist approaches that are often used. Research that applies the System Dynamics methodology typically uses data from a broad range of sources. Numerical, as well as verbal and observational data, can be used to guide the development of the model structure and its subsequent calibration. This is particularly important when social science research is problem focussed and also less-than-perfect data need to be used. Finally, theory building with System Dynamics has the potential to inspire further empirical research in

the social sciences. Using a model to direct empirical research may help to guide the contribution of the academic 'hypothesis testing industry'.

- This study contributes a preliminary theory of societal problem situations and illustrates that the concept of societal problem situations is useful for framing complex societal constellations. In doing so, this study complements preliminary work by my colleagues and myself. In Müller et al. (2011), a method for the identification of experts capable of representing actors involved in a societal problem situations was introduced. What is more, this study shows how conceptual representations of actors might be implemented into a System Dynamics simulation model.
- The study also addresses the question as to how societal problem situations may be alleviated. I argued that societal problem situations can-not be "solved" by any particular actor. Instead, societal problem situations may be alleviated by collaborative transformation efforts conducted by societal actors. Such actors will have to implement changes in their specific fields. Further, the collaborative transformation of societal problem situations entails changes in societal structures (e.g., infrastructures, regulations) as well as in social structures (e.g. lifestyles, preferences).

To Political Science

- This study contributes an extensive review of the literature on policy change in the domains of energy and climate policy in Switzerland (see Chap. 3 and Sect. 5.4.4.1). Closely related to this, the study implemented the first operationalization of the advocacy coalition framework into a System Dynamics simulation model. By doing so, the study illustrates the potential of System Dynamics modeling in the analysis of policy change. In particular, System Dynamics modeling would offer political scientists a tool for developing causal theories of change processes. The value added from modeling lies in the way modeling facilitates theory building. For example, it allows for the visual representation of complex change processes and it facilitates the development of causal explanation. The ability to conduct behavioral analysis enhances the quality of the resulting theory. Finally, by comparing models of different cases, System Dynamics modeling could facilitate the development of higher level theories.
- The large simulation model may be considered as a contribution to the analysis and to the governance of environmental problems. This is because the large simulation model explains an environmentally relevant variable (the CO_2 emission rate) and relates it to human activities. The large simulation model endogenously explains how changes in the economic sector, in technology, in science, in civil society, and in the state control the behavior of the environmentally relevant variable.

To Economics

- The study summarizes key findings from the literature on the economics of investments into energy-efficient building designs. Further, the study shows how different kinds of uncertainty impede optimal ex-ante investment decisions in the context of the discounted cash-flow framework (see Sect. 3.6.6). Instead, the study argues, actors are substantially guided by expectations regarding future developments.
- The study explicitly shows how market-mechanisms impact on the built environment. Further, the study shows how market mechanisms are framed by civil society and the state.

To Policy Makers and Practitioners

- In Chap. 6, I explained the diffusion of energy-efficient renovations by way of a causal loop diagram. That diagram may prove insightful for policy makers and practitioners because it can serve as a framework for a broad yet rigorous understanding of the diffusion process. Most practically relevant issues and concepts can be positioned within that causal loop diagram. Further, it can be used to qualitatively reflect on the effects of interventions. Finally, when the large simulation model is used for policy analysis, the causal loop diagram can be used to explain the main dynamics of the large simulation model.
- The study provides a review of the literature on the dynamic behavior of Switzerland's building-stock (see Sect. 4.2).
- The study describes a typical renovation process (see Sect. 5.2). Describing the renovation process as containing 16 distinct elements is a prerequisite for subsequent intervention. In addition, I propose several interventions into the renovation process that can support the transformation of the stock of buildings toward higher levels of energy efficiency. Policy makers and practitioners can use that description in order to develop further interventions into the renovation process.
- With the two regulations in support of the decarbonization of the stock of buildings, the study provides a new and powerful framework for the long-term management of the stock of buildings. policy-makers can further substantiate these regulations in order to actually make them part of a country's energy policy.
- The cooperative "Immobility" society should be conceived of as a market-based policy instrument, with which public policy can enhance building owners' capacity to comply with energy and climate policy goals.
- The study provides a typology of instruments that can be used to affect intervention levers in the real world. That typology can be used to systematically review a country's current energy and climate policies.
- Finally, the study shows by way of example that a societal problem situation cannot just be alleviated with a "silver bullet" so to speak. Instead, societal problem situations should be expected to unfold through a gradual process of change, possibly over a period of decades.

9.5 Strengths, Limitations, and Suggestions for Further Research

9.5.1 Research Design

The research design of the study consisted of developing a System Dynamics simulation model of the diffusion of energy-efficient renovations and using it to analyze how the diffusion of energy-efficient renovations might be accelerated. In order to develop the simulation model, I drew on a wide range of empirical and theoretical contributions found in the literature, and I also conducted my own empirical research. In order to proceed in a structured manner, I decided to develop four preliminary analytical chapters. Proceeding in this manner proved highly useful, as it allowed for light to be shed on the different perspectives on the issue under study before a synthesis was attempted. The research design proved to be a clear strength of this study.

Based on the experience with this study, I would recommend the following research design to any research project analyzing a societal problem situation. A first analytical perspective should provide a literature review of what are thought to be key elements of the societal problem situation. Based on that, a small model of the "physical structure" that is at heart of the societal problem situation should be developed. As a next step, I recommend identifying the important actors and analyzing how changes in their decision making can be modeled. Such an analysis might entail describing important actions and analyzing what interest actors have and how powerful they are. Finally, a theory of the mechanisms that cause changes in the "physical structure" needs to be developed. By developing these analytical perspectives, the elements that need to be considered for integration into a large simulation model are elucidated. The resulting simulation model can then be used to analyze intervention levers and conduct policy analysis. It would be very valuable to eventually obtain an evaluation of the usefulness of this approach that is based on several applications.

Differentiating the expert interviews into exploratory, systematic, and validating interviews proved very beneficial. The exploratory interviews facilitated the orientation and the development of a questionnaire for the systematic interviews. The systematic interviews allowed for broad and systematic insights to be gained. Finally, the validating interviews contributed to the testing of preliminary versions of the two models. What is more, the way experts were selected for the interviews led to a high degree of theoretical representativeness. However, statistical representativeness could not be attained with the qualitative methods that I used. The experts that I interviewed were individuals for whom the topics discussed in the interview formed part of their daily practices. This allows for confidence regarding the validity of the insights obtained from the interviews. However, there is one important exception that requires some further explanation. This concerns the lack of interviews with tenants. Tenants were not interviewed because I anticipated serious methodological problems that would render such interviews useless. Because energy efficiency is only one among many factors affecting housing choices, I doubt whether the average

tenant could elaborate on energy efficiency in housing. Instead, I asked architects and building owners how they perceived the behavior of tenants in the context of energy-efficient renovations. In addition, I interviewed a representative of the Swiss Tenants' Association. That expert turned out to have a profound understanding of the situation of tenants during renovations. The insights obtained from asking those interviewees about the tenants' behavior proved sufficient for the purpose of my study. Nevertheless, further research should conduct an empirical analysis of tenants' decision making, based on a statistically representative sample of actual decisions. This would allow for the analysis of empirical preferences rather than stated preferences. The insights obtained from such a study may support marketing efforts in support of energy-efficient renovations.

9.5.2 Quality of the Simulation Models

In Sect. 7.9, where I reported on contextual, structural, and behavioral model testing procedures, I reached the conclusion that "the model structure should be considered to be rather well established. Regarding the behavior of the model, the picture is slightly less clear. The problem is that there are no numerical data for most variables. This seriously restrains any attempt to rigorously base the model on data without conducting extensive empirical work (...). Therefore, the most interesting and most powerful behavioral tests, such as correlation coefficients or goodness of fit, could not be applied".

   I am well aware that many parameters and time series that I put into the model require further empirical grounding. However, there are good reasons to have confidence also in the behavioral aspects of the simulation model. The following points explain why I have reached this conclusion.

- It is crucial to understand what kinds of statements may be produced with the simulation model. I find it crucial that the simulation model is not used for formulating point estimates or 'predictions'. Absolute statements such as "the variable X will obtain a value of Y in the year Z" are not permitted. However, the simulation model can be used to analyze whether an intervention accelerates or delays the diffusion process. This implies statements such as "when the variable X1 is increased relative to its reference behavior, then the variable X2 is decreased relative to its reference behavior". With due caution, the model can even be used to quantify the magnitude of such effects. This would imply statements such as "when the variable X1 is increased by 50 % relative to its reference behavior, then the variable X2 is decreased by 5 % relative to its reference behavior". However, such quantitative effects should be considered only to indicate the magnitude of an effect; they are not precise measures of the strength of an effect.
- System Dynamicists generally agree that it is crucial to include all the important structures into a dynamic model, also when no numerical data on a particular aspect are available. The reason for this is that System Dynamics modeling aims to

describe systems from an "endogenous point of view" (Richardson 2011). Broad boundaries enable the development of an endogenous perspective. This means that the form of the available data is secondary to the need for comprehensiveness. Further, often there is non-numerical data that can educate modelers as to how a model behaves and what assumptions are to be used. Alternatively, theories from a near field may inform the modeling of a specific system. General reasoning may contribute to locating reasonable values for parameters and time series. The following example shows how I proceeded with setting assumptions. For the variable SHARE OF ARCHITECTS PROMOTING ENERGY EFFICIENCY, I was not able to find numerical data, as it happened frequently with other variables. Yet, it is known from the literature that diffusion processes typically exhibit an s-shaped behavior. Therefore, I assumed that the diffusion of energy efficiency among architects would also follow such an s-shaped pattern. General reasoning was used to further specify the behavior of that variable. I assumed it to be unlikely that all architects would become promoters of energy efficiency. Further, I assumed that the largest rise in the SHARE OF ARCHITECTS PROMOTING ENERGY EFFICIENCY would occur between 1995 and 2020. Considering all this information, an educated assumption for the behavior of the SHARE OF ARCHITECTS PROMOTING ENERGY EFFICIENCY could be set (see Fig. 7.20 on p. 232). This example illustrates that even with a lack of numerical data, very reasonable assumptions can be set.

- Finally, I found that the high inertia of the stock of buildings reduces the risk of producing wrong insights due to imprecise operationalizations. As documented in the electronic supplement, I conducted extensive sensitivity analyses for all intervention levers. For each intervention lever, the simulation model was calculated 200 times, with the intervention lever drawn by chance on each iteration from a uniform distribution from 50 to 150 % of the variable's normal value. With that sensitivity analysis, I was able to show that such variations in parameter values have a small impact on the TOTAL SHARE OF EEUPGRADINGS and hardly affect the CURRENT CO$_2$ EMISSIONS at all.

These considerations support the conclusion that the large simulation model captures the essential dynamics of the diffusion process of energy-efficient renovations. Nevertheless, the simulation model has some limitations. I find the following issues noteworthy:

- The large simulation can-not explain the non-diffusion of energy-efficient renovations. This is due to the way that technological progress was "hard-wired" into the model. While public policy support for research and development proved instrumental in accelerating the rise of the technological quality of energy-efficient renovations, the model can-not produce a non-diffusion over its time period. Ultimately, the fact that the model can-not explain a non-diffusion of energy-efficient renovations is not relevant for the purpose that the model was built for.
- In retrospect, the variance in behavior between the four building owner types, respectively between the three tenant types, seems surprisingly small. Future research should investigate whether the model under-estimates variance in behavior between the different types of these two actors.

- The construction costs of the two renovation strategies were modeled as absolute values. In retrospect, it would have been better to use a construction cost index. Absolute values may suggest a level of precision that the model can-not achieve.
- Both simulation models have a very high level of aggregation in the way buildings and flats are treated. This means that market processes are not considered with detail. Future research might work to represent buildings and flats with more detail attributes.

9.5.3 Further Issues

In addition to the discussion of the research design and the quality of the simulation models, the following issues strike me as noteworthy. Perhaps future research may find this interesting.

- Future research should analyze to what degree strategic delay acts as a barrier to the diffusion of energy-efficient renovations. Strategic delay is a side-effect from rapid technological progress, in a situation where the next year's offerings are either substantially cheaper or substantially better. In such a situation buyers have a potentially strong incentive to delay the purchasing of the technology. This reduces the adoption rate of the technology as well as the technology's opportunities in terms of technological progress.
- In future research, the large simulation model could be used as a framework to analyze the energy and climate policies of other countries. Such an endeavor could yield an evaluation of the current policies and it could potentially lead to substantial policy progress. What is more, by comparing evaluations of current energy and climate policies across several countries, a better framework might be established.
- In this study, I mostly ignored the implications of an accelerated diffusion of energy-efficient renovations on social-justice issues. In fact, a too fast diffusion of energy-efficient renovations might substantially reduce the supply of affordable housing for households in the lower income tiers. Such a development would not be in line with the vision of a sustainable development. Hence, future research should empirically assess the opportunities and threats brought about by an accelerated diffusion of energy-efficient renovations as well as renovations that lead to the decarbonization of heating systems.
- Future research should analyze different discourses (e.g., environmental discourses, public discourses) as to whether energy efficiency is conceptualized more as an investment or more as consumption. This is not only of academic interest. Marketing and communication strategies that emphasize the consumptive aspects of energy efficiency (e.g., benefits such as thermal comfort, better indoor air quality) would have to be very different from strategies that conceptualize energy efficiency as an investment.
- Finally, I call for future research in the Field of System Dynamics on the issue of model structure visualization. Valuable contributions could be made by addressing

the question "how can the communication of System Dynamics models be facilitate based on tools and instruments from graphic design?" Future research should devise recommendations that guide System Dynamicists in the graphic enhancement of stock-and-flow diagrams and causal loop diagrams. Results from such research could perhaps come in the form of a manual or a collection of templates.

9.6 Generalization: Toward a Generic Model of the Diffusion of Sustainability Technologies

In addition to its primary contribution toward the general research question, this study also makes contributions to more general issues. In Sect. 9.4, I mentioned several such contributions. For example, the preliminary theory of societal problem situations and the reflections on the research design may be considered as such general contributions. In the following, I discuss a particularly interesting generalization. Specifically, I will outline a generic theory of the diffusion of sustainability technologies. Due to constraints in space and time, this final discussion is brief and serves as an exemplar rather than as an extensive approach.

For the purpose of this section, I propose to define the term "sustainability technology" simply as any technology or equipment that leads to more sustainable practices than can current technologies or equipment. Examples for sustainability technologies are energy-efficient renovations, solar panels, hybrid cars, low-emission heating systems, and so on. I assume that sustainability technologies are innovations. Further, I assume that they must diffuse through market mechanisms in order to contribute to a sustainable development.

Let us first recall the basic structures of causality that drive the diffusion of energy-efficient renovations. Initially, no energy-efficient renovations were conducted at all. This was because the performance of energy-efficient technology was poor and the costs of implementation were high. The core decision making structures, the feedback loops which control supply, demand, and technology, endogenously kept the system in an equilibrium without energy-efficient renovations. The diffusion of energy-efficient renovations started when external drivers begun to exert pressure and initiated policy change. Specifically, government support for research and development contributed to the improvement of energy-efficient technology and energy-efficient building designs. Consequently, the start-up problem of the reinforcing feedback loop controlling technological progress was overcome. As technology became better, the cumulative number of energy-efficient renovations increased. By way of learning effects, and economies of scale and scope, this increased the performance-to-cost ratio of energy-efficient renovations, thus increasing the attractiveness of such renovations, and eventually again increasing the cumulative number of energy-efficient renovations.

This structure of causality can be applied to explain the diffusion of sustainability technologies in general. Figure 9.1 shows the generic model of the diffusion of
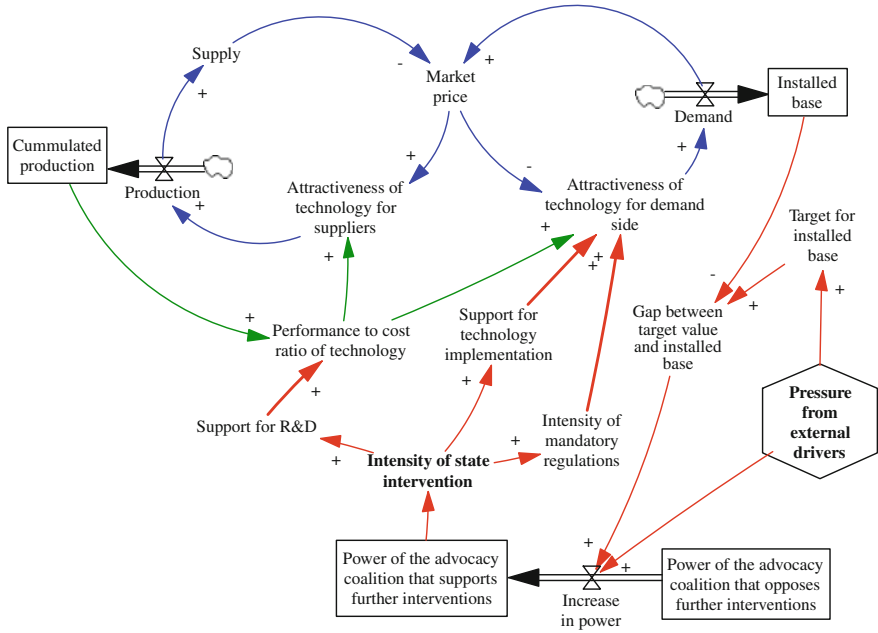
Fig. 9.1 Toward a generic model of the diffusion of sustainability technologies. *Arrows in blue* show structures related to the market, *arrows in green* show structures related to technology, *arrows in red* show structures related to the state

sustainability technologies that I propose as a generalization of this study.[1] At its core are two loops that represent the supply and the demand side of the market (shown in blue). The two loops interact primarily trough the MARKET PRICE. In fact, the MARKET PRICE balances the two loops in such a way that SUPPLY and DEMAND become equal. The ATTRACTIVENESS OF THE TECHNOLOGY FOR SUPPLIERS depends on the MARKET PRICE and on the PERFORMANCE-TO-COST RATIO OF THE TECHNOLOGY. As either variable is increased, the ATTRACTIVENESS [...] rises. This leads to an increase in SUPPLY and a decrease in the MARKET PRICE. The ATTRACTIVENESS OF THE TECHNOLOGY FOR DEMANDERS also depends on the market price and on the PERFORMANCE-TO-COST RATIO OF THE TECHNOLOGY. However, as the MARKET PRICE rises, the ATTRACTIVENESS [...] is reduced, thus reducing DEMAND. As DEMAND falls, the MARKET PRICE also falls, eventually increasing the ATTRACTIVENESS OF THE TECHNOLOGY FOR DEMANDERS. I find that both market loops are balancing.

As PRODUCTION is increased, the CUMULATED PRODUCTION also rises. By way of economies of scale and scope, and learning effect, the PERFORMANCE-TO-COST RATIO OF TECHNOLOGY is increased. This increases the ATTRACTIVENESS OF THE TECHNOLOGY for the supply side as well as for the demand side, eventually result-

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[1] I hope to further elaborate on this generic model of the diffusion of sustainability technologies in future research.

ing in an even greater CUMULATED PRODUCTION and a rising INSTALLED BASE. I conclude that technological progress works as a reinforcing feedback loop. However, in the initial stage no technological progress can occur, as there is a start-up problem. From the perspective of the state, the diffusion of the sustainability technology is a solution to a policy challenge. Generally, I postulate that it is PRESSURE FROM EXTERNAL DRIVERS that eventually increases the POWER OF THE ADVOCACY COALITION THAT SUPPORTS FURTHER INTERVENTIONS. Also, the bigger the GAP BETWEEN THE TARGET VALUE AND THE INSTALLED BASE is, the faster the POWER OF THE ADVOCACY COALITION THAT SUPPORTS FURTHER INTERVENTIONS is increased. As the POWER [...] rises, the INTENSITY OF STATE INTERVENTION eventually also rises. The state implements three distinct policy instruments. First, the state provides SUPPORT FOR R&D in order to overcome this start-up problem related to technological progress. Second, the state provides SUPPORT FOR TECHNOLOGY IMPLEMENTATION. Finally, the state increases the INTENSITY OF MANDATORY REGULATIONS. These three policy instruments all support the diffusion of the sustainability technology and eventually lead to a large INSTALLED BASE.

This logic can be applied to a wide class of specific sustainability technologies. This generic model of the diffusion of sustainability technologies could also be expanded to include network effects as a further positive feedback loop that drives the attractiveness of a technology. Such network effects may be appropriate for an explanation of the diffusion of hydrogen vehicles, where the density of refueling stations, and the attractiveness of the technology are mutually dependent.

Further, less obvious generalizations could be derived from this study. Perhaps it would be possible to derive a generic model of the transformation of the energy system toward higher sustainability. Most certainly such an endeavor would have to consider the market, technology, external drivers of policy change and a particular logic of state interventions. Full-scale simulation should also consider behavioral differences among different actors.

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Appendix A
Materials Published in the Electronic Supplements

Several materials were used in this study, which are either to voluminous to print or are only available in electronic form. The following materials are provided via an electronic supplement.[1]

- Documentation of the Interviews
- Codes used in the analysis of the interviews
- Testing intervention levers

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[1] Additional material is available online from http://extras.springer.com

Appendix B
Most Important Variables of the Large Simulation Model

In this appendix, the names of the main variables of the large simulation model are listed.[2] Further, I define what units it is measured in and I state over what rage the variable varies in the model. Finally, I state what kind of subscripts were used to further differentiate the variable. In particular, the following subscripts were used (also see Sect. 7.2 starting on p. 211):

- **by BO type** refers to the four subscripts used for building owners, namely *profit-professional*, *profit-non-professional*, *multicriteria-professional* and *multicriteria-non-professional*.
- **by tenant type** refers to the three subscripts used for tenant types, namely *cost-minimizers*, *evaluators* and *ecological*.
- **by strategy** refers to the two subscripts used for renovation strategies, namely *paintjob renovations* and *eeupgradings*.
- **by housing type** refers to the two subscripts used for *paintjob housing* and *eeupgraded housing*.

In this appendix, the main variables are grouped according to the four modules of the model and can be found as follows:

- Module 1: The Stock of Buildings Revisited (see p. 208)
- Module 2: Demand and Supply on the Housing Market (see p. 209)
- Module 3: Technology (see p. 209)
- Module 4: Civil Society and State Interventions (see p. 209)

Note that within the four modules, the variables are ordered according to the main sectors, as given in Fig. 7.1 on p. 209. Within the sectors, the variables are not ordered alphabetically. Instead, they are ordered in a way that is oriented toward when a variable is required to advance the understanding of the model's structure.

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[2] Remember that the large model uses the small model as its first module. Alterations are only made in order to subscript the stock of buildings for the four types of building owners. Hence, module 1 of the large model contains basically the whole small model.

B.1 Module 1: The Stock of Buildings

Table B.1 Key variables of module 1: The stock of buildings

Variable	Meaning	Unit [Range]	Subscripts
Buildings owned by BO type			
SHARE OF BUILDINGS OWNED BY BO TYPE	Gives the share of buildings that is owned by any of the four building owner types	dmnl [0–1]	BO
Building sector			
HEATED FLOOR SPACE	Gives the past empirical and future projected heated floor space of Switzerland's multifamily buildings	dmnl [0–1]	BO
Building stock state variables (e.g. EE BUILDINGS IN NEW CONDITION)	Contain the number of buildings in any of the 6 possible states shown in Fig. 4.2	buildings [0–∞]	BO
Building stock flow variables (e.g. AGEING OF EE BUILDINGS)	Give the number of buildings moving in and or out of any of the 6 possible states shown in Fig. 4.2	buildings/year [0–∞]	BO
YEARS NEE BUILDINGS IN BAD CONDITION ARE LEFT UNRENOVATED	Gives the number of years that buildings in non-energy-efficient buildings in bad condition are in average left unrenovated	year [0–∞]	BO
TOTAL SHARE OF EEUPGRADINGS	This variable aggregates the SHARE OF EEUPGRADINGS from the four building owner types into the total share of renovations that are renovated into an energy-efficient building design (see Fig. 4.2)	dmnl [0–1]	–
Floor space and energy coefficients			
ENERGY COEFFICIENT OF CONSTRUCTIONS	Gives the energy coefficient that constructions have to implement by law	MJ/m^{2}a [0-∞]	–
ENERGY COEFFICIENT OF EEUPGRADINGS	Gives the energy coefficient that eeupgradings have to implement by law	MJ/m^{2}a [0–∞]	–
AVERAGE ENERGY COEFFICIENT OF STOCK OF [NEE / EE / TOTAL] BUILDINGS	Gives the average empirical energy coefficient of the nee buildings, of the ee buildings or of all the buildings	MJ/m^{2}a [0–∞]	–
CO$_2$ emissions			
Diffusion rates of [oil / gas] heating systems in [construction, eeupgrading]	Give the share of energy provided by different heating systems, either in construction or in renovations	dmnl [0–1]	–

Table B.1 (continued)

Variable	Meaning	Unit [Range]	Subscripts
Efficiency of [oil / gas] heating systems	Gives the share of energy that is converted from useful energy to final energy for oil and gas heating systems	dmnl [0–1]	–
CURRENT CO$_2$ EMISSIONS	Amount of CO$_2$ released each year as a consequence of heating with oil and gas heating systems	tons CO$_2$/year [0–∞]	–

B.2 Module 2: Demand and Supply on the Housing Market

Table B.2 Key variables of module 2: Supply and demand on the housing market

Variable	Meaning	Unit [Range]	Subscripts
Building owners' decision-making			
SHARE OF EEUPGRADINGS	Gives the share of buildings under renovation that are renovated into an energy-efficient building design for each type of building owner (see Figs. 4.2 and 7.6) Note that this variable only applies to the buildings that are under renovation in the current year. Hence, even with a very high share of eeupgradings, only a very small percent of the total stock of buildings is transformed every year	dmnl [0–1]	BO
Tenants' decision-making			
SHARE OF TENANTS DEMANDING EEUPGRADED HOUSING	Gives the share of tenants that demand eeupgraded housing	dmnl [0–∞]	tenants
Demand, supply and cumulated renovations			
CUMULATED NUMBER OF EEUPGRADINGS	This variable accumulates the eeupgradings of each year into a stock, and could also be called "installed base". This variable allows to derive learning effects as a function of the installed base	buildings [0–∞]	–

(continued)

Table B.2 (continued)

Variable	Meaning	Unit [Range]	Subscripts
Calculating market price component			
MARKET PRICE COMPONENT OF THE RENT OF HOUSING	Part of the rent that is not related to construction costs. Is used to calculate mark-ups for housing types that are in high demand and calculate discounts for housing types that are in low demand	CHF [−∞–∞]	housing type
Calculating heating costs			
AVERAGE HEATING COST	Gives the average heating costs of the two housing types	CHF [0–∞]	housing type
Calculation of rental prices			
YEARLY COST OF RENTING HOUSING	Gives the cost that tenants must pay in order to use and heat a flat	CHF [0–∞]	tenants
Share of Tenant Types			
DISTRIBUTION OF TENANTS	Gives the share of tenants that belong to any of the three tenant types	dmnl [0–1]	tenants

B.3 Module 3: Technology

Table B.3 Key variables of module 3: Technology

Variable	Meaning	Unit [Range]	Subscripts
Technological quality			
TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS	Measures the technological quality of the eeupgrading renovation strategy	quality units [0–1]	–
Construction costs			
CURRENT REAL CONSTRUCTION COST FOR PAINTJOB RENOVATIONS	Gives the cost of implementing the paintjob renovation strategy	CHF [0–∞]	–
CURRENT REAL UNSUBSIDIZED CONSTRUCTION COST FOR EEUPGRADINGS	Gives the cost of actually implementing the eeupgrading renovation strategy, without considering subsidies	CHF [0–∞]	–
Architects' reaction to technological change			
PROBABILITY THAT ARCHITECTS PROMOTE ENERGY EFFICIENCY	Gives the likelihood that a building owner encounters an architect who promotes energy efficiency	dmnl [0–1]	–

B.4 Module 4: Civil Society and State Interventions

Table B.4 Key variables of module 4: Civil society and state interventions

Variable	Meaning	Unit [Range]	Subscripts
Civil society			
POWER OF THE ADVOCACY COALITION WHICH DEMANDS FURTHER PUBLIC POLICY INTERVENTIONS	Measures the share of members of parliament who in principle support further interventions in support of energy efficiency in the stock of buildings	power units [0–1]	–
Reactions of the state			
INTENSITY OF PUBLIC POLICY INTERVENTION INTO THE STOCK OF BUILDINGS	Measures the actual level of state intervention	Intensity units [0–1]	–
EFFECT OF PUBLIC R&D EXPENDITURES ON THE TECHNOLOGICAL QUALITY OF EEUPGRADING DESIGNS	Measures the contributions public R&D expenditures have on the technological quality of eeupgrading designs	quality units [0–1]	–
AMOUNT OF SUBSIDY FOR EEUPGRADINGS	Measures the financial support given to buildings owners who implement energy-efficient building designs	CHF [0–∞]	–

Appendix C
Model Testing

Model testing is a crucial element in research based on System Dynamics. In this appendix, I provide more detail on this topic than I could in the main text. Due to space limitations, only the main results from model testing could be reported there (see Sect. 7.9). In this appendix, I provide greater detail on the work that was done to increase and document the quality of the two models.

By applying a wide range of tests to the model and its behavior, the validity of the model is increased. However, validity in an absolute sense can not be achieved—certainly not in the social sciences. Nevertheless, the iterative process of model testing, model adaptation and retesting somewhat mirrors the evolutionary mechanism, and it is thought to yield a robuster model compared to an untested model. The tests reported here were selected from the literature (Schwaninger and Groesser 2009; Sterman 2000).

The structure of this appendix is as follows: First, I discuss tests that apply to both models (see Sect. C.1). Second, I report on the testing of the small model (see Sect. C.2). Finally, I report on the testing of the large model (see Sect. C.3). I only reported on tests I deem applicable to my models.

C.1 Tests Applying to Both Models

Issue Identification Test

Schwaninger and Groesser (2009, p. 9004) demand that System Dynamics models be applied to "the right problem". In the introduction (see Chap. 1) and the analytical chapters (particularly in Chaps. 3, 4 and 5), I very clearly showed thats energy-efficient renovations are indeed a very important problem. What is more, once the limitations of the role of energy efficiency in buildings became clearer, I slightly expanded the focus and investigated the role of heating systems. Hence, I conclude that this study indeed addresses the right problem.

Adequacy of Methodology Test

Schwaninger and Groesser (2009, p. 9004) argue that System Dynamics is suited best
for dealing with issues characterized by "dynamic complexity, feedback mechanisms,
nonlinear interdependency of structural elements and delays between causes and
effects". Throughout this study I have shown that System Dynamics is an adequate
methodology for the specific issue under study.

Structure Examination Test

This test refers to whether a model contradicts knowledge or evidence about the
situation under study (Schwaninger and Groesser 2009, p. 9005). Sterman (2000,
p. 859) points to several questions regarding the structure of models. I can respond
to them as follows:

- The structure of both models is consistent with current knowledge about the system. I tried to describe the model as explicitly as possible and I labored hard to
  show how the model is grounded in the empirical and the theoretical literature.
- The level of aggregation is in my opinion the correct one. The current state of
  knowledge favors an aggregate perspective. However, further research might lead
  to more disaggregated modeling. Yet the work reported here can serve as a framework within which disaggregated work can take place.
- As far as I can see, both models conform to basic physical laws, such as the
  conservation of mass.
- As far as I can see, the decision rules of actors adequately explain *changes*. In
  Chap. 5, specifically in Sect. 5.4, I extensively justify the decision rules implemented into the model.

I conclude that the simulation models used in this study are exceptionally rigorously
grounded in the theoretical and empirical knowledge currently available.

Parameter Examination Test

This aim of this test is to "evaluate a model's parameter against evidence or knowledge
about the real system" Schwaninger and Groesser (2009, p. 9006). This test showed
that there is probably some uncertainty about the correct value of parameters. Most
parameter in the model were set so that they produced a behavior which—in light
of theoretical and empirical knowledge—seemed the most reasonable. However,
future research could aim to empirically estimate parameter and contribute to further
reduction of uncertainty.

Boundary Adequacy

Sterman (2000, p. 859) points to the importance of the boundary adequacy. Regarding my models, I think that the boundary adequacy has been thoroughly established. Chap. 3 clearly sets the context. The small model described in Chap. 4 showed the need to develop a endogenous explanation, as presented in Chaps. 5 and 6. In this study, a building stock model, the market, technology, drivers of policy change and state interventions were brought together in order to provide an interdisciplinary account of the diffusion of energy-efficient renovations.

However, there is one aspect, where the boundary could be criticized as too narrow. This concerns the question of heating systems. However, the focus of this study was from the begin on the role of efficiency in the hull rather than the question of low energy use and low emission heating systems. I therefore refer to future work to integrate an endogenous explanation of the diffusion of low energy use and low emission heating systems.

Testing the Integration Time Step

I found that both models are stable for both, a time step of one and the smallest time step proposed by Vensim, set to 0.007812. Between the two runs only absolutely minor differences exist. Due to the widespread lack of precise data put into the model, minor computing errors from integration can be ignored as not meaningful. I therefore conclude that both models show nearly the same behavior and that they are stable also when the integration time step is changed.

Dimensional Consistency

Dimensional consistency refers to a situation, where the units in an equation are consistent to each other. In order to check dimensional consistency, I used Vensim's *units check* function. Initially, the software showed that several unit errors existed. However, by manually inspecting equations where Vensim found unit errors, the number of unit errors could be reduced to zero.

Testing the Time Horizon

In order to ensure that the models do not show unrealistic behavior or fluctuations outside the time horizon, I set the model time from 1975 to 3000 and ran the baserun scenario for that long time period.

In the small model, the nee stream of buildings continues to deplete and begins to fall below 1000 buildings in bad condition after the year 2336. This long duration

is because in the baserun scenario, 45 % of nee buildings in bad condition are reno-
vated with paintjob renovations. Similarly, the yearly CO_2 emission rate stabilizes to
2.9 million tons of CO_2 in the year 2200 and 2.7 million tons in the year 3000. This
behavior is within what was expected. I therefore conclude that the model is stable
and converges to a long-term steady state.

In the large model, the same dynamic pattern can be seen. The non-energy-efficient
aging chain is depleted in the long run. And the CO_2 emission rate stabilizes at around
2.5 million tons of CO_2. Both, the building owners' SHARE OF EEUPGRADINGS and
the SHARE OF TENANTS SEARCHING EEUPGRADED HOUSINGS converge towards a
stable value. Both, the TECHNOLOGICAL QUALITY OF EEUPGRADINGS as well as the
construction costs for both renovation strategies converge towards a stable long term
value.

Testing the Time Horizon of the Large Model

In order to ensure that the model did not begin to show unrealistic behavior outside
the time horizon, I set the model time from 1975 to 3000 and ran the baserun scenario
for that long time period. All the drivers of policy change as well as the POWER OF
THE ADVOCACY COALITION DEMANDING (FURTHER) PUBLIC POLICY INTERVEN-
TIONS converge to a stable value. The fact that the EMISSION GOAL GAP does not
converge towards zero is a sensible result. It represents the fact that energy-efficiency
measures are not capable of bringing down the emission rate towards the goal rate.
Further, all three public policy interventions (public R&D, subsidies, energy coeffi-
cient) converge towards a stable limit. I therefore conclude that both models show
stability also in the long run.

Family Member Test

Often, simulation models can be described as belonging to a typical class of mod-
els (Schwaninger and Groesser (2009, p. 9010). My models probably best are
described as diffusion models, which are generally characterized by s-shaped diffu-
sion processes.

C.2 Testing the Small Model

The following work was carried out in order to increase the trust in the small model
presented in Chap. 4 and used as the basis for the large model's building stock module
(see Sect. 7.4).

C.2.1 Model Structure

In the validating interviews, one of my interviewees suggested that I use a fixed delay function in order to calculate the aging behavior of the stock of buildings. In such a case, the number of buildings constructed in the year 1 would become buildings in good condition in t+10 years. I experimented with several operationalizations (including Vensim's DELAY FIXED function) and a combination of the operationalization described above with fixed delays. I found that it proved impossible to find a satisfactory operationalization. In order to have a well calibrated aging chain, the initial year of the model would have to be postponed by the number of years a building needs to be renovated (55 years in my case). Starting the model at the year 1920 would pose the problem of data availability, and extending the time horizon of the model would carry a series of further implications for my study. However, experimenting with fixed time delays made me aware of the fact, that my operationalization probably underestimates the speed of transformation. Because the number of buildings under renovations is calculated as NUMBER OF NEE BUILDINGS IN BAD CONDITION divided through YEARS A BUILDING IN BAD CONDITION IS LEFT UNRENOVATED, it may take more time until the non-energy-efficient aging chain is drained.

C.2.2 Parameter and Numerical Assumptions

Testing the Number of Buildings

As described above, the past and projected total heated floor space for residential multifamily buildings (rather than the actual number of buildings) are put into the model as exogenous inputs. The number of buildings is then calculated by dividing the current total floor space through the average floor space per building ($=1000 \, \text{m}^2$). Table C.1 shows, that the empirical data on the number of buildings and the number of buildings given by the simulation model are not identical. The reason might be that the average heated floor space of multifamily buildings changed over time. Also, different data sources use slightly different definitions of multifamily

Table C.1 Comparison of empirical data and model values, for the number of buildings with at least 3 apartments

Year	Empirical data	Simulation model
1970	138 637	n.a.
1975	154 682	137 784
1980	170 727	155 654
1990	197 666	191 392
2000	220 426	227 130

The value for 1975 was interpolated from the years 1970 and 1980. All data was retrieved from Switzerland's federal office for statistics STAT-TAB database (BFS 2010)

buildings. In conclusion, I deem the deviation acceptable. This particularly holds, because all energy-related calculations are anyway based on the total heated floor space rather than the number of buildings.

C.2.3 Model Behavior

CO_2 Emissions

Since the CO_2 emissions are the reference mode of this model, I carefully tested the fit of the model with the empirical data. This proved to be less straightforward than expected as I found the data not to be available in the desired specifications. For example, (Schulz 2007, p. 46) only provide values for the total stock of residential buildings, whereas I need values for the stock of multifamily buildings only. Nevertheless, I found two approaches to obtain approximate values for the yearly emission rates.

BAFU (2010) reports Switzerland's emissions from motor and heating fuels.[3] Obviously, the heating fuels include all building types. Therefore, in a first step the share of multifamily buildings in the total emissions needs to be approximated. According to BFE (2004, A8), multifamily buildings account for roughly 30 % of total heated floor space. However, I assume that multifamily buildings only account for 20 % of the emissions. This is because also process heat for industry is in the data and because multifamily buildings have a smaller surface to volume coefficient than one- or two-family homes, which makes them more energy-efficient.

The second approach relies on data from Switzerland's energy statistics (BFS 2010). There, time series for final energy demand from fossil heating fuels (heating oil) and gas are available from 1910 to 2009. By multiplying the final demand with the corresponding emission factors, the emissions can be approximated. By attributing 20 % of those emissions to multifamily buildings, the corresponding emissions can be approximated.

Figure C.1 shows the two time series obtained from official statistics and the model behavior in the baserun scenario. Comparing the model output with the data, it becomes evident that the model reproduces the empirical data sufficiently well. This can be also demonstrated quantitatively, by regressing the baserun time series onto any of the two empirical data series. As a result, an adjusted R^2 of more than 0.99 is obtained in both cases (ordinary least squares, no constant estimated). Pearson's correlation coefficient for the baserun time series and the BAFU data is 0.12. For the baserun time series and the BFE data it is –0.29.

Some caution however must be given, as the empirical data was calculated on the assumptions made above. In addition, I find it important to state clearly that the model was specifically calibrated to approximately reproduce the empirical data by including the flow variable INCREMENTAL EFFICIENCY GAINS IN THE STOCK OF

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[3] The corresponding terms in German are "Treibstoffe" and "Brennstoffe".
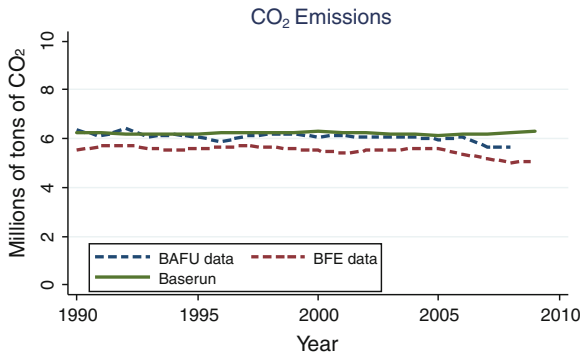
Fig. C.1 Comparison of emission data and model output in the baserun scenario
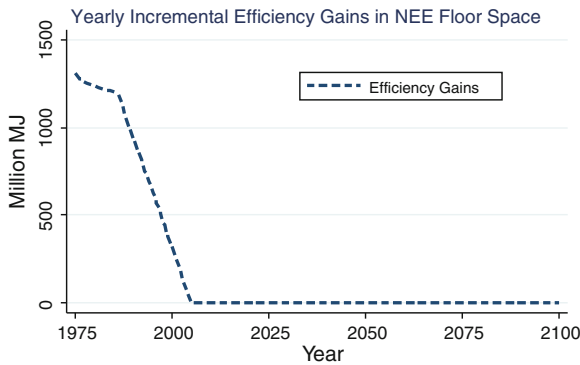
Fig. C.2 Incremental efficiency gains of nee floor space in millions of MJ per year

NEE BUILDINGS (also see Fig. 4.6 on p. 128) to reduce the energy demanded by the stock of nee buildings. Figure C.2 shows how this outflow was set in order to calibrate the model.

C.2.4 Sensitivity Analysis

All the sensitivity analysis was carried out with Vensim's standard sensitivity simulation setup. I set the number of simulations to 200. I used multivariate sampling with a random uniform distribution unless stated otherwise. The reason for using a uniform distribution (rather than a normal one) is that it is easier to identify sensitive behavior with this distribution. Normal distributions could be used to analyze the stability of the model under various normally distributed errors.

Fig. C.3 Sensitivity analysis
of the initial distribution of
buildings over the three quality
categories
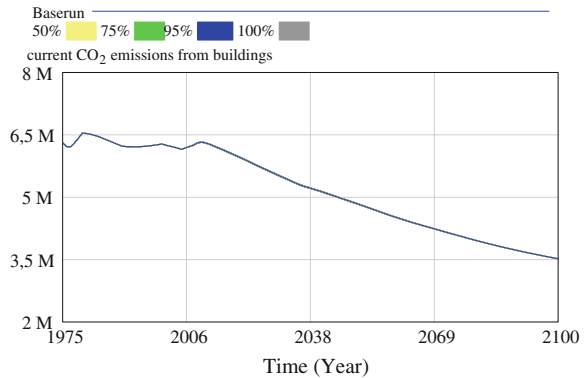
Initial Distribution of Buildings Over the Three Quality Conditions

In the model, I assigned the initial total number of buildings to three states. Now,
I want to test whether variations in the initial distribution of buildings influence the
CO_2 emission rate. Ideally, the outcome of this test should be that the CO_2 emission
rate is robust to variations in the initial distribution.

It set the permissible range of SHARE OF BUILDINGS INITIALLY IN NEW CON-
DITION between 0 and 0.2 and the permissible range of SHARE OF BUILDINGS INI-
TIALLY IN GOOD CONDITION to 0.2 to 0.6. The SHARE OF BUILDINGS INITIALLY
IN BAD CONDITION is ten calculated as the difference to 1. I found that the the CO_2
emission rate is almost completely insensitive to variations in the initial distribu-
tion of buildings (see Fig. C.3). In fact, only when one zooms heavily into Vensim's
sensitivity graph do the differently colored surfaces become visible (not shown in
figure). I therefore conclude that this initial values are sufficiently well set when used
as explained above.

Aging Parameters

The aging parameters used to calculate after how many years a building moves down
to the next condition were set in accordance to expert judgment rather than hard
data. In order to test how sensitive the CO_2 emission rate is to changes in those aging
parameters, I performed the following sensitivity analysis. For each of the three
aging parameter which control the stream of nee buildings, I allowed a variation
of plus or minus 10 years around the model value. Figure C.4 shows the resulting
sensitivity graph. According to that figure, 95 % of the 200 runs Vensim calculated
remained reasonably close to the baserun line (expressed as the green surface and
further encapsulated surfaces. Obviously, simulation runs where all aging parameters
take a high value transform the stock of buildings slower to energy-efficiency than

Baserun
50% [75%] [95%] [100%]
current CO2 emissions from buildings
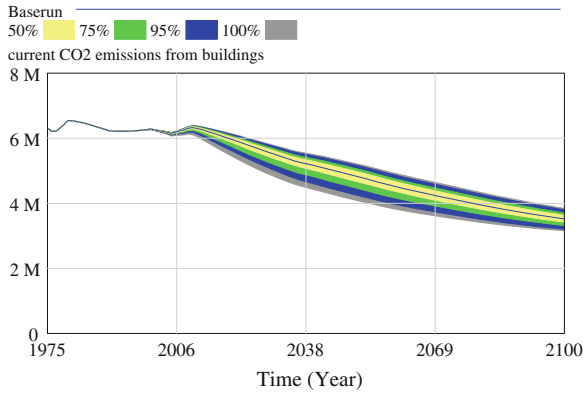
Fig. C.4 Sensitivity analysis of aging parameter

simulation runs where buildings have a comparatively short service life. In the long run, however, all the runs seem to converge. This is, because eventually all non-energy-efficient buildings are moved to the stream of energy-efficient buildings. I interpret the result of this analysis to strengthen the credibility of my model.

C.3 Testing the Large Model

C.3.1 Model Structure, Parameter and Behavior

With some minor exceptions, module 1 of the large model (the stock of buildings revisited) corresponds to the small model. See above for testing issues of this module. No formal model tests can be carried out, due to a lack of data beyond what was presented in Chap. 7.

C.3.2 Sensitivity Analysis

Extensive sensitivity analysis of all intervention levers was performed (the electronic supplement). There, I concluded that the large model is remarkably stable.

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Appendix D
A Fictitious Example of the Immobility Business Model

In Sect. 8.5.3, I developed the idea of an association, that would support non-professional building owners to overcome the challenges of energy-efficient renovations. In order to illustrate and further substantiate the envisioned business model, I developed a (fictitious) example. Due to limitations, I provide this example in the appendix instead in the main text.

Imagine that a brother and a sister inherit a multifamily building from their parents, in the outskirts of a medium-sized city in Switzerland. The building was built in the year 1971 according to the construction standards of the time. It has 5 cm of insulation, which is not very much compared to the 25–30 cm of insulation materials used in current new buildings. Since its construction, the façade has been painted once, but no further insulation has been added. The windows were never replaced and neither the roof nor the basement were ever insulated. Currently, the building is starting to show wear and tear in several elements. The windows will need to be replaced sooner or later. Generally, maintenance was minimal during the last decades and the reserves set aside for future renovations were negligible. This was because most of the income from the tenants' rent went to interest payments for the mortgage, and whatever remained was drawn as income by the previous owners of the building.

The new owners were unsure how to proceed regarding their building and contacted the Immobility association to request an analysis of their building. Eventually, a specialist came to analyze the state of the building and produce a report. In addition to the results of the analysis of the building, the specialist compiled a report on the current housing market situation and reported on trends that might influence demand for housings at the specific location. Specifically, the report stated that the building's main structures had aged well. The report also stated that the size of the rooms was still big enough given current market trends. Further, while the bathrooms and kitchens were several years old, they still were functional and could be used for a further decade. However, important elements such as the heating system, the windows, the blinds, the tiles on the roofing and the pipings for the water supply were near or already past their service life. Further, the report identified a lack of balconies, too small windows and the awkward and sparse placement of electrical sockets as attributes that reduced the utility tenants drew from their housing.

In contrast, addressing these attributes could increase the rent potential of housings. The report further identified the lack of financial reserves as a key impediment to a major renovation.

Based on that report, the specialist offered the building owners to become member of the association. Further, he proposed that in the next few years the building should be left as it is with just minimal repair and maintenance. However, instead of drawing the proceeds of the rent as income, the building owners should use what is left after interest payments and maintenance to accumulated some capital. They were given the choice to put the accumulated capital either into a bank account or into an account at the Immobility association. Comparing bank rates and rates from Immobility, the building owners found that Immobility offers better rates. This is because the association gives preferential mortgages to other members. In consequence, Immobility can offer higher interest rates for saving accounts compared to banks and it can offer lower interest rates for mortgages than banks.[4] The expert further proposed to apply the CCEMARC in about five to ten years to the building. This would ensure that an advanced energy-efficient building design would be implemented at comparatively low cost. This would allow to obtain the Minergie certificate. The expert further recommended to replace the roof with a prefabricated maisonette apartment and to install balconies for each flat. This would increase the value of the flats on the rental market. Through the façade, a ventilation system, power lines and new pipings could be brought to each flat. This would allow to replace the pipings and install a ventilation system without disturbing the tenants more than a few days. Further, solar panels will be installed for warm water generation, and the heating system will then rely on a new system that combines heat pumps that take heat from the air and a heat pump that accesses an insulated, warm water tank in the ground. The warm water tank will be heated during warm days in spring, summer and falls. It will be used conjointly with neighboring buildings, so that investment costs can reduced and the thermal efficiency increased. This would allow to implement carbon-free[5] systems for heating and warm water.

Seven years later, the building owners decided to initiate the renovation process. They met twice with the project manager at Immobility, updated information in the files and outlined the renovation strategy that would be implemented. It was found that the market situation at the building's location remained largely unchanged and that current market conditions would allow an increase of up to 30 % compared to current rents. Over the last few years, about 100,000 Swiss francs were accumulated in a fund for future renovation work. In addition, some 400,000 Swiss francs could be obtained as a long-term loan from the Immobility association. The association drew on savings from other members and hence could offer favorable conditions. Further,

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[4] I compared interest rates for saving accounts at Comparis for a capital of 100,000 CHF I found a variance from 0.100 to 1.150 %. Interest rates for mortgages were not readily available at Comparis. Therefore, I checked the cantonal bank of Zürich (ZKB). I found a variance from 1.190 % for a 2 year mortgage and 2.530 % for a 10 year mortgage. This warrants the conclusion that banks generally pay less interest for savings than they take for mortgages.

[5] Switzerland's electricity mix is generated without any signifiant emissions of CO_2, this may be different in other countries, particularly when coal is used to generate electricity.

some funds were obtained from banks at favorable rates. Due to the large volumes of renovations and the fact that Immobility professionally manages renovations, banks considered the buildings of Immobility members to carry a smaller risk compared to the average market. Therefore, they demanded lower interest rates.

Based on the former report and in close consultation with the building owners, the project manager initiated the required steps. He charged a specialized company to obtain the required three-dimensional measurements, based on which an architect at Immobility developed a project and specified the elements for prefabrication. The project manager obtained a construction permit, informed the tenants and handled all the paper work. After getting confirmation from the building owners he charged a specialized construction company to build the elements.

Two months later, prefabrication of the façade modules and the maisonette apartment that will replace the roof was completed. In the meantime, preparatory work was carried out. One window in each apartment was taken out and replaced by a balcony door. Further, a staircase was built into the roof, such that the future maisonette apartment would be accessible. The day before the installation, a crane was brought to the building and mounted. Eventually, the installation was begun by removing the whole roof from the building. Next, the façade elements were mounted around the building, at the exact place they were foreseen for. Where necessary, the old windows were unmounted. The façade elements already contained the new windows were necessary. As the façade elements were mounted, the crane lifted the prefabricated elements of the maisonette apartment on top of the building, where they were mounted. Subsequent work consisted of connecting various elements to each other. For example, the solar panels on top of the roof had to be connected and the new heating system had to be put in. Finally, external balconies were mounted in front of the building and connected. Finally, inspection for quality control was carried out. Later that year, a team of experts came by to commission the building and give tenants some instructions regarding how to use the ventilation system. Throughout the renovation work would be supervised by a project manager at Immobility.

Glossary

Actor Real individuals or groups of individuals which act in the real world.

Agent A representation of actors in the System Dynamics model. Used to represent the most important behavioral differences between actors within a typology.

Energy coefficient (legal) This is a measure of the amount of energy one square meter of heated floor space may use in a building. This is defined in the building code. A building only gets a construction permit if it adheres to the legal energy coefficient.

Energy coefficient (empirical) This is an empirical measure of the amount of energy one square meter heated floor space actually uses. It is typically given as an average value for the stock of buildings.

Energy efficiency Energy efficiency improvements are "a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity. The reduction in the energy consumption is usually associated with technological changes, but not always since it can also result from better organisation and management or improved economic conditions in the sector ('non-technical factors')" (WEC 2008, 11).

Energy index The energy index is the total of the final energy (in MJ) used for heating a building during 1 year, divided by the heated floor space (in m^2). It is defined as MJ/m^2a. The corresponding term in german is *Energiekennzahl* (Econcept and Amstein+Walthert 2007, A-110).

Minergie Minergie is the name of a label for buildings in Switzerland. In addition to higher levels of comfort, Minergie-certified buildings implement a level of energy-efficiency which is significantly above the legal standard.

Renovation Upgrading of a building by implementing construction work, such that the building changes its state as described in Sect. 4.4.1.2.

Renovation practices Activities, rules, norms, attitudes, knowledge, competencies and dispositions that accompany the renovation of buildings.

Renovation strategy A particular approach to the renovation of a building. In Sect. 4.4.1.2, I define three different renovation strategies (reconstruction, energy-efficient upgrading and paintjob renovation) which summarize the different approaches that can be applied to non energy-efficient buildings in bad condition.

References

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