Chapter 7
How Should Public Policy Transform the Stock of Buildings Toward Energy Efficiency and Low Emissions? Results from a System Dynamics Modeling Study of Switzerland

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Abstract We report on modeling work that shows how the market, technology, civil society and the state govern the diffusion of energy-efficient renovations in Switzerland's stock of residential, multifamily buildings. The particular focus of this chapter is on the policy implications that we drew from an extensive System Dynamics modeling study. We conclude that energy efficiency is important, yet not sufficient in order to reach ambitious emission reduction goals. In addition to promoting energy efficiency, Switzerland should aim for a widespread decarbonization of heating systems. We discuss what kind of instruments can be used to address various policy levers in order to accelerate the diffusion of energy-efficient renovations. We propose two regulations that could serve as a framework

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This chapter summarizes and further elaborates on research presented in Müller (2012, 2013). Hence, it may include identical wording taken from those publications. Previous versions of this chapter were presented at the 3rd Sustainability Conference in Basel and the 30th System Dynamics conference in St. Gallen.

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for ambitious long-term decarbonization efforts. Finally, we propose a service innovation that could assist building owners in complying with the ambitious regulations required.

Contents

7.1 Introduction

The building sector accounts for about a quarter of global energy-related greenhouse gas emissions and consequently it is a key lever in climate change mitigation efforts (Levine et al. 2007). Such emission reductions may come at a negative price in a substantial share of cases (Ürge-Vorsatz and Metz 2009). Particularly the renovation of old buildings is seen to be among the most cost-effective ways to reduce CO_2 emissions in industrialized countries (Galvin 2010). In the long run this calls for nothing less than a radical transformation of the built environment (Barrett 2009). Currently, however, sustainability in the construction sector is probably just a minor aspect of the design, use, management and maintenance of the built environment (Lovell 2005).

In a recent study, we analyzed the diffusion dynamics of energy-efficient renovations in Switzerland's stock of residential, multifamily buildings (Müller 2012, 2013; Müller and Ulli-Beer 2010, 2008a, b; Ulli-Beer and Müller 2006). The focus of our study was on space heating and hence we abstained from issues such as warm water, appliances or grey energy. We built a System Dynamics model that explains how the market, technology, civil society and the state govern the diffusion of energy-efficient renovations and the CO_2 emissions of the stock of buildings. This enabled us to analyze the following research question: *How can the diffusion of energy-efficient renovations of buildings be accelerated in order to reduce the CO_2 emissions from the stock of buildings?*

In this chapter, we aim to concisely present the most important results from that study. Specifically, we discuss how public policy should transform the stock of buildings toward energy efficiency and low emissions. Beyond the narrow 'use value' of our research we hope to make several exemplary contributions to research in the spirit of ecological economics and sustainability science. For example, our study might be seen as an illustration as to how different fields of society (e.g. the market, technology, civil society and the state) are interrelated in the creation and governance of environmental issues.

This chapter is structured as follows. In Sect. 7.2, we elaborate on methodological aspects of our study. In Sect. 7.3, we describe the context within which the diffusion of energy-efficient renovations occurs as a societal problem situation. In Sect. 7.4.1, we describe the structure of causality that governs the diffusion of energy-efficient renovations. Then, in Sect. 7.4.2, we carry the analysis further by elaborating our building stock model sector. That sector is crucial for understanding the transformation of the stock of buildings. In Sect. 7.7.5, policy levers are identified (Sect. 7.5.1) and analyzed quantitatively (Sects. 7.5.2, 7.5.3, and 7.5.4) in order to understand the policy implications of the model's behavior (Sect. 7.5.5). In Sect. 7.6, we discuss how public policy should transform the stock of buildings. In Sect. 7.7, we answer our research question.

7.2 Research Design and Methods

Before we indulge in the results, we must briefly describe how we proceeded methodologically. The research design[1] that we followed is best described as theory building with System Dynamics (Schwaninger and Groesser 2008; Schwaninger and Pfister 2007). In order to arrive at an empirically grounded simulation model, we followed a research design that relied on five distinct steps. The first step consisted of orienting ourselves in the field and clarifying the relevant research questions. Second, we conducted exploratory (N = 7), systematic (N = 14) and validating (N = 7) interviews. While the interviewees were from heterogeneous backgrounds, most of them can be described as either academic researchers or practitioners (architects, representatives of building owners, representatives of construction companies). We recorded and transcribed the interviews and analyzed them using the MAXQDA software package. We were mostly interested in the content given by the interviewees and did not focus on deep meaning structures as this is done in more hermeneutic methodologies. Hence, we deemed content analysis (Flick 2005: 280) to be sufficiently rigorous and abstained from any analysis methods that strive for deeper analysis. As a third step, we developed four analytical perspectives. Specifically, we analyzed the context, we built a small

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[1] See Müller (2012, 2013) for the complete documentation of the research design and the methods we used.

simulation model of the stock of buildings (Müller and Ulli-Beer 2010), we analyzed actors and we developed an endogenous theory of the causal drivers of the diffusion of energy-efficient renovations. As a fourth step, we integrated insights obtained from the analytical perspectives into a quantitative System Dynamics simulation model, implemented in the VENSIM simulation software. As a fifth step, we conducted policy analysis with the simulation model.

However, these five steps were not followed in a strictly linear fashion. Instead, we iterated as we deemed fit. Throughout the research process, we conducted desktop research and we routinely tested and verified our results. In particular, model testing entailed evaluating the simulation model against many of the standard tests described in the literature (Barlas 1996; Sterman 2000; Schwaninger and Groesser 2009). Because behavioral data against which the model behavior could be tested against was mostly not available, we strongly relied on model structure tests.

7.3 Context

Analyzing the context within which the diffusion of energy-efficient renovations takes place helped us to determine the adequate boundary in our modeling efforts. Further, it provided us with an important opportunity to learn about the issue under study. On the most general level, we found that climate change and energy security concerns should be considered to be the most important drivers of the diffusion of energy-efficient renovations. The emergence of a distinct energy policy in Switzerland can be traced to the first oil crisis in 1973, when the country's strong dependence on energy imports became evident. Since then, promoting energy efficiency has been a crucial part of Switzerland's energy policy (Linder 1999; Jegen 2003). Scientists recognized anthropogenic climate change as a dangerous possibility as early as in 1977 (Weart 2008). However, only over the last decade has climate change emerged as a publically influential discourse. As this discourse became ubiquitous, it profoundly re-shaped the way energy policy was debated (Reddy and Assenza 2009) and led to an additional problematization of current energy use patterns (Jasanoff 2010). Mitigating greenhouse-gas emissions now is a key aspect of many public policy efforts.

Climate change concerns and energy supply security concerns can be considered to be general drivers that exert pressure on the stock of buildings and the various societal fields associated with it. Eventually, this has created a societal problem situation that involves actors in the market, actors in civil society and the state. In the wake of the emergence of a societal problem situation, established practices are destabilized and change processes are put into motion. Such change processes are typically highly unstructured, uncertain and rife with conflicts of interest among different actors (Geels 2005).

We found that analyzing societal actors was particularly important in understanding the diffusion of energy-efficient renovations. This is because this diffusion process is not primarily driven by markets and prices. Instead, it is a diffusion process that is substantially driven by societal actors who want to influence public policy according to their interests. In particular, it was mostly societal actors (e.g., environmental pressure groups) who began to call for the transformation of the stock of buildings. These claims were generally intended as a contribution to the public good, undertaken with the intention of reducing energy security risks and reducing the risks of global climate change. Eventually, such environmental discourses and the prospects of strong state regulations cause other societal actors (e.g., industrial associations) to voice opposed views and participate in a competition for the publics' endorsement.

In the political science literature, the effect of societal actors on the policy process has been described in the context of the advocacy coalition framework (Sabatier 2007; Weible et al. 2009). That framework has been used to understand the policy process, particularly policy change over long time periods lasting a decade or longer. Several contributions empirically analyzed the effect of advocacy coalitions in various policy domains in Switzerland. For example, in the domain of energy policy (Kriesi and Jegen 2000, 2001; Jegen 2003), climate policy (Lehmann and Rieder 2002; Ingold 2007, 2010) or environmental policy in general (Bornstein 2007). From that literature, we were able to confidently derive the existence of an advocacy coalition that generally demands further public policy interventions into the stock of buildings ("pro ecology") and an advocacy coalition that generally opposes further interventions ("pro growth").

As societal actors influence public policy to initiate and promote energy efficiency technology and low-emission energy systems, actors in the market too play an important role. Based on a series of interviews, we identified building owners, architects and tenants to be the most important actors in the market. In contrast, we found that construction companies hardly influence the decisions-making related to energy efficient renovations. Based on our interviews, we proposed to further categorize building owners according to the amount of professional know-how they have. We found that building owners without professional know-how may be a crucial group, because they own about 70 % of multifamily buildings. Unfortunately, they frequently face greater obstacles in implementing energy-efficient renovations.

We found two barriers to a low-emission stock of buildings to be particularly powerful. First, building owners implement energy-efficient renovations only if and only when they deem fit. There are no regulations forcing them to increase the energy efficiency of their building. Building owners, for example, may choose to do nothing at all or simply paint their façade instead of insulating it. Energetically relevant regulations only become relevant once substantial renovation is actually undertaken. Then, pre-defined levels of energy efficiency have to be achieved in the elements under renovation. The second barrier refers to the "investor-user dilemma". This occurs when a building owner carries the costs of an investment into energy efficiency and the tenants obtain the benefits. In such a situation, the building owner has an incentive to chose the investment with the lowest cost, regardless of cost-benefit considerations (Golubchikov and Deda 2012; Schleich 2009; OECD/IEA, AFD 2008).

It is noteworthy that the state of technology and the economics of energy-efficiency now no longer are substantial barriers in Switzerland. The last decade has brought about spectacular technological and economical progress in energy-efficient construction (Erhorn-Kluttig and Erhorn 2007). In fact, CEPE and HBT (2002: 314) recall that the rapid technological progress achieved over the last decades would have been called a super-efficient development in the early 1980s. In the future, the potential for technological and economical breakthroughs is rather limited. Instead, incremental cost reductions, further improved performance and the integration of various technologies should be expected (IEA 2008: 183).

7.4 Modeling the Diffusion Dynamics of Energy-Efficient Renovations

7.4.1 Governance Structure of the Diffusion Process

Figure 7.1 shows a causal loop diagram (CLD) of the governance structure that controls the transformation of the stock of buildings toward energy efficiency and low emissions.[2] While the actual simulation model consists of variables and equations, we chose to present a causal loop diagram (Sterman 2000). This enables us to focus on the main structure of causality and abstain from technical details. Specifically, the CLD consists of variables that are linked with an arrow according to the direction of causality: A positive causal relationship (marked with a "+") is postulated to exist between the *Number of NEE buildings* and the *Number of renovations implementing EE building designs*. Both variables move in the same direction. An inverse causal relationship (marked with a "–") is postulated to exist between the *Number of renovations implementing EE building designs* and the *Number of NEE buildings*. When the *Number of renovations implementing EE building designs* rises then the *Number of NEE buildings* falls.

As can be seen, several interrelated feedback loops were conceived. Loop A shows how energy-efficient renovations transform the stock of buildings. Loops B and C represent the two sides of the housing market that control the stock of buildings. Specifically, loop B describes the demand for and loop C describes the supply of energy-efficient housing. Loops D and E represent technological and

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[2] Due to limitations in space, the following description is substantially abbreviated. A complete account of the feedback loop perspective is available in Müller (2012, 2013).

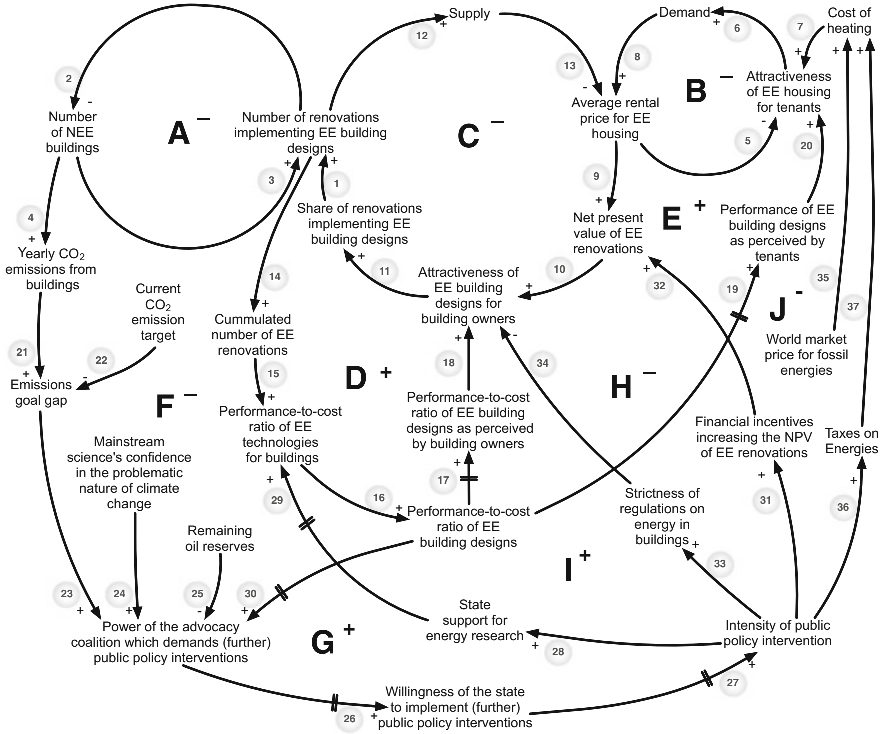

Fig. 7.1 Causal loop diagram of the main structures of causality in the simulation model. Note that loop *A* represents the building stock model sector described below. Note that loops *B–J* govern the transformation of the stock of buildings by way of the variable share of renovations implementing EE building designs

economical progress. Due to learning effects, economies of scale and scope, energy-efficient building designs in renovations improve and become cheaper. Loop D shows that technological and economical progress makes energy-efficient building designs more attractive for building owners. Loop E shows that technological progress makes energy-efficient housing more attractive for tenants. Loop F shows how public policy reacts to the emergence of energy security concerns and climate change and supports research and development of technology. Loop G shows that the availability of adequate technology intensifies adaptive pressure on public policy. Consequently, public policy accelerates the diffusion of energy-efficient building designs by creating financial incentives (loop H). Eventually, public policy also tightens mandatory standards (loop I) and increases the cost of fossil fuels (loop J).

Together, these feedback loops provide an "endogenous point of view" (Richardson 2011) on the diffusion of energy-efficient renovations. In fact, this representation of the structure of causality may be considered as an interdisciplinary synthesis of various individual pieces of empirical and theoretical research.

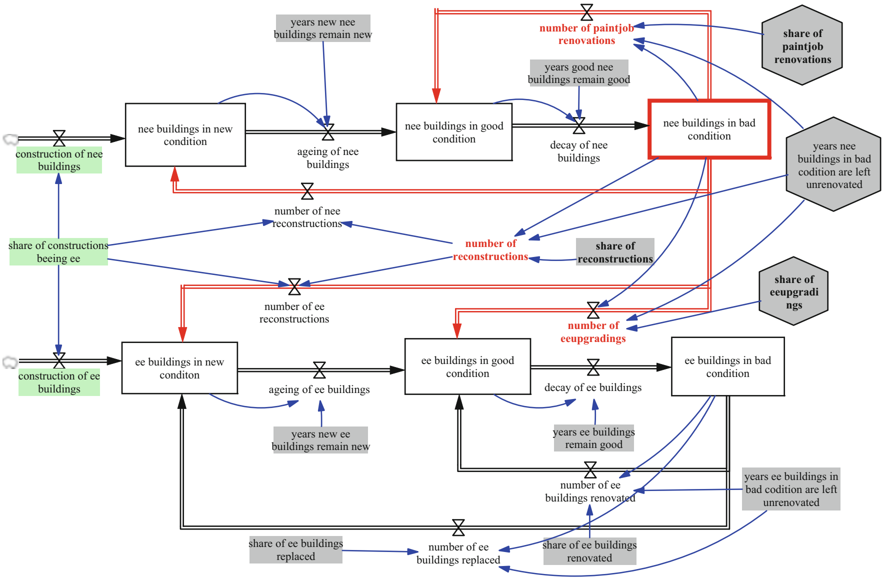

Fig. 7.2 Stock-and-flow-diagram of the building sector

However, causal loop diagrams have limitations. They are less detailed compared to actual simulation models and they can not be simulated by themselves (Sterman 2000). In particular, they do not allow eliciting behavioral aspects such as CO_2 emission trajectories. Therefore, we implemented this structure of causality into a full-fledged simulation model. In the following section, we describe how loop A was implemented as our building stock model sector.

7.4.2 The Building Stock Model Sector

Figure 7.2 shows the stock-and-flow diagram of the building sector of our model[3, 4]. Stock-and-flow-diagrams are used to represent the structures of a system in close relation to the equations that are actually simulated.

We consider buildings to be either in a new condition, in a good condition or in a bad condition. The number of buildings in each condition is accounted for by a stock. Over time, as buildings age, new buildings flow into the stock of buildings in good

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[3] In order to produce computer simulations, equations have to be specified in a computer simulation software such as VENSIM.

[4] Due to limitations in space, the following description is substantially abbreviated. A complete account of the building stock model sector is available in Müller and Ulli-Beer (2010) and Müller (2012, 2013).

condition and eventually they flow into the stock of buildings in bad condition. Only buildings in bad condition are renovated. We assume that it in average takes 55 years for a building to pass through all three stages and eventually be renovated. By combining these three stocks and the aging rates, an aging chain was formed.

Buildings are further differentiated according to their energy efficiency into non-energy-efficient (nee) or energy-efficient (ee) buildings.[5] Nee buildings in bad condition can be renovated with one of the following three basic renovation strategies. When a paintjob renovation is implemented, then a nee building in bad condition becomes a nee building in good condition. The energy efficiency remains unaltered. When an eeupgrading is implemented, then a building is moved into the energy-efficient aging chain and is also seen to be in good condition. Buildings can be torn down and reconstructed. In such a case, a building in new condition is built. Depending on the construction code, the building is reconstructed as a nee or an ee building.

Crucial in this building stock model are the variables *share of eeupgradings* and *share of paintjob renovations*. In the simulation model, they are calculated dynamically, based on the governance structure. Consequently, these two variables control what share of buildings is renovated according to the corresponding renovation strategy. The *share of reconstructions* is set constant at 5 %. The number of buildings under renovation in any year is calculated by dividing the *nee buildings in bad condition* trough the *years nee buildings in bad condition are left unrenovated*.

By underlying the diagram shown in Fig. 7.2 with equations and parameters we were able to simulate the evolution of the stock of buildings over time. In addition to the building sector shown in Fig. 7.2, we relied on further sectors to track energy coefficients, floor spaces and CO_2 emissions. Further, we relied on a series of exogenous inputs, such as past and projected data for the diffusion rates of oil and gas heating systems, the efficiency of heating systems, heated floor spaces and energy coefficients to simulate the model.

7.5 Model Behavior and Implications for Public Policy

7.5.1 Identification of Policy Levers from the Model Structure

Public policy intervenes into the stock of buildings by influencing policy levers with policies and instruments. Table 7.1 shows an evaluation of policy levers

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[5] Specifically, buildings are seen to be non-energy-efficient (nee) if the energy coefficient for heating is 193 MJ/m^{2}a or higher and they are considered to be energy-efficient (ee) if the energy coefficient for heating is below 193 MJ/m^{2}a. These values correspond to the Swiss Minergie label after 2003 and the mandatory governmental regulations after 2008 as defined by the Swiss conference of the cantonal energy directors (EDK 2008: 13).

Table 7.1 Evaluation of policy levers directly influencing the transformation of the stock of buildings

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

directly related to the stock of buildings. By simulating the model, we found that the *share of eeupgradings* and the *CO_2 emission rate* are particularly powerful policy levers. Using the other policy levers turned out to be unrealistic, of questionable value or unpractical because substantial success has already been achieved. For example, the construction of additional non-energy-efficient buildings has been eliminated by past changes to the building code (Jakob 2008) and hence it no longer is a usefull policy lever. Scenario analysis reported in Müller (2012) showed that accelerating the renovation cycle by 5 years does not substantially impact on the CO_2 emission rate in the long term and hence is of questionable importance.

In addition to the policy levers directly influencing the transformation of the stock of buildings, indirect policy levers could be identified. By reviewing the simulation model, policy levers capable of increasing the *share of eeupgradings* were found. These were listed in the left column of Table 7.4. The next section reports on results from quantitatively analyzing such indirect policy levers.

7.5.2 Analysis of Policy Levers by Themselves

In order to analyze indirect policy levers in a standardized manner, we increased each lever by 50 % in the year 2010. Then, we compared the model behavior relative to the base scenario in the year 2020. Our guiding question was whether the manipulation of a single policy lever could increase the *total share of eeupgradings* near unity. We found that there is no single policy lever that is capable of increasing the *share of eeupgradings* such that the CO_2 emissions are reduced substantially relative to the base scenario. Nevertheless, we found that the following policy levers influence the *share of eeupgradings* quite sensitively by themselves:

- Building owners’ perception of the technological quality of energy-efficient building designs

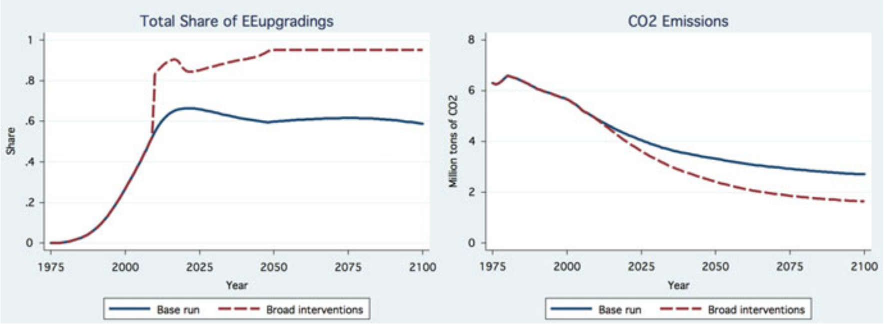

Fig. 7.3 Behavior of the simulation model in the base run (*straight line*) and after implementing a broad series of interventions (*dotted line*)

- 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[6]

7.5.3 Analysis of a "Broad Interventions" Package of Policy Levers

In a next step, we simulated the effect of a broad package of interventions. This was simulated by conjointly increasing the sensitive policy levers by 50 % after the year 2010. We found that this almost instantly increases the *total share of eeupgradings* near to unity (see left exhibit of Fig. 7.3). In reality, such an increase would constitute an enormous policy success. The right exhibit of Fig. 7.3 shows the resulting behavior of the *CO_2 emissions*. In both scenarios, *CO_2 emissions* are reduced substantially over time, indicating the important contributions made by energy-efficient renovations to emission mitigation. The emission trajectory obtained in the base run scenario would already be a quite successful policy-outcome. It seems unlikely that a more ambitious emission trajectory could be obtained based on energy-efficiency alone than the trajectory obtained in the "broad interventions" scenario. A crucial question is whether the

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[6] The variable *longterm minimum energy coefficient of construction* was decreased by 50 %.

Table 7.2 Emissions and emission reductions in the "base run" and the "broad interventions" scenarios. Gives the emissions of the stock of buildings in the two scenarios in million tons of CO_2 per year (Mio.t.p.a.) and the emission reductions as percent changes relative to the years 1990 and 2010

	Base run			Broad interventions		
	Mio.t.p.a.	*Δ 1990*	*Δ 2010*	Mio.t.p.a.	*Δ 1990*	*Δ 2010*
1990	6.1			6.1		
2010	4.9	*−20 %*		4.9	*−20 %*	
2050	3.3	*−46 %*	*−33 %*	2.4	*−61 %*	*−51 %*
2100	2.7	*−56 %*	*−45 %*	1.6	*−74 %*	*−67 %*

emission reductions obtained in these two scenarios are sufficient in light of public policy goals.

Several approaches have been taken to deriving long-term policy goals in energy and climate policy. In the Swiss context, visions such as the 2,000-W-society or the 1-t-CO_2-society are frequently used to derive long-term policy goals. For example, the implementation of a 1-t-CO_2-society would require the average Swiss resident to reduce emissions to 2 t CO_2 per capita in the year 2050 and to 1 t CO_2 per capita in the year 2100 (Novatlantis 2007). In order to evaluate the implications of our simulation results, the visions of the 2,000-W-society or the 1-t-CO_2-society are not very practical. We found it more practical to compare emission reductions in percent rather than discussing what share of the 1-t-CO_2-allowance should be spent on the heating of multifamily buildings. Siller et al. (2007), for example, call for greenhouse gas emission reductions of around 80 % by 2050 (with 1990 as the base year) in order to limit global warming to 2 °C. More recently, the European Union communicated long-term emission reduction goals in the contexts of its "roadmap for moving to a competitive low carbon economy in 2050" (EU 2011). For the residential and service sector the roadmap calls for CO_2 emission reductions of around 90 % by 2050 (relative to 1990 emission rates). Concluding this discussion, we propose to set emission reductions of 90 % by 2050 (relative to 1990) as the long-term policy goal against which the emission trajectories of Switzerland's stock of buildings should be evaluated against. While Switzerland is not member of the EU, EU policies do influence Switzerland's policy-making, as the country typically strives to roughly align with the EU.

Table 7.2 shows the absolute CO_2 emissions and the emission reductions relative to the year 1990 that were obtained by simulating the two scenarios above. In the most optimistic "broad interventions" scenario, the CO_2 emissions are reduced by about 61 % by 2050 and by about 74 % by 2100. In the base scenario, emission reductions by about 46 % by 2050 and by about 56 % by 2100 were attained. Comparing these emission reductions against the long-term policy goal of a 90 % reduction by 2050, we find that even the emission reductions attained in the most ambitious "broad interventions" scenario appear not to be sufficient.

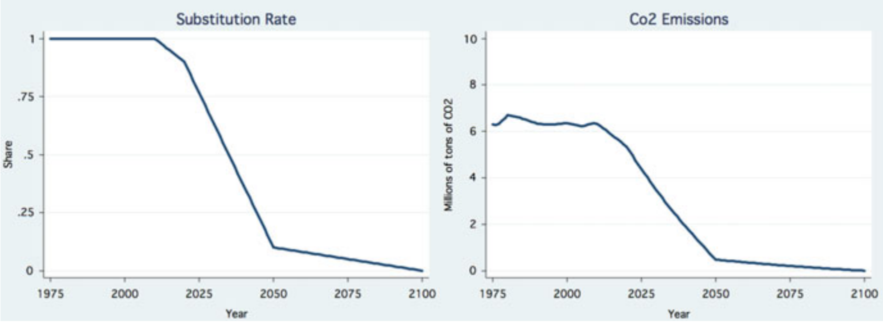

Fig. 7.4 Gradual substitution of fossil heating systems until 2050. The exhibit on the left shows the assumed substitution rate. The exhibit on the right shows the resulting emission trajectory

7.5.4 *Analysis of a Forced Outphasing of CO_2 -Emitting Heating Systems*

The emission reductions achieved in the 'broad interventions' scenario, based primarily on energy efficiency, are not sufficient to reach the long-term policy goal of 90 % reductions. This finding leads us to argue that further measures, in addition to energy efficiency, are needed. In particular, we call for a far-reaching decarbonization of Switzerland's stock of buildings.

In order to show how the decarbonization of Switzerland's heating systems would impact on the CO_2 emission rate, we conducted a further simulation. Specifically, we simulated the effect of reducing the diffusion rate of oil and gas heating systems. Technically, this was implemented by multiplying the diffusion rates of oil and gas heating systems with the variable *substitution rate* shown in the left hand exhibit in Fig. 7.4. The exhibit on the right hand in Fig. 7.4 shows the resulting CO_2 emissions. It becomes evident that the CO_2 emissions could indeed be reduced nearly to zero if an ambitious substitution program aimed at reducing the diffusion rate of oil and gas heating systems were implemented.

7.5.5 *Discussion*

In a nutshell, the findings obtained from analyzing the model's behavior can be summarized as follows. We found that by conjointly using highly sensitive policy levers, the *share of eeupgradings* can be increased near to unity. However, the emission reductions obtained from this proved insufficient. By out-phasing oil and gas heating systems, the *CO_2 emissions* could be reduced near to zero.

We find that our results fit the findings of other authors in the literature reasonable well. Siller et al. (2007), in a study of Switzerland's residential building sector, find that emission reductions of around 80 % (by 2050, relative to 1990) can be achieved based on a very strong combination of energy efficiency and renewables. TEP and ETH (2009) provide a model of the whole stock of residential buildings in Switzerland and consider space heating as well as warm water generation and appliances. They find that greenhouse-gases emissions can be reduced by 28–65 % by 2050, depending on what assumptions are made. Schulz (2007: 118) 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 40 % 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 reduce the CO_2 emissions of residential buildings by about 80 %.

In conclusion, we find that public policy should attempt to reduce emissions by around 90 % by 2050, by increasing the share of eeupgradings near to unity and promoting the out-phasing of fossil-based heating systems. In the following section, we elaborate on the instruments and regulations that public policy should employ toward that goal.

7.6 Transformation of the Stock of Buildings

7.6.1 *Instruments in Support of the Diffusion of Energy-Efficient Renovations*

Inspired and guided by a "typology of tools for building sustainability strategies" (Kaufmann-Hayoz et al. 2001), we conducted a literature review of policies and instruments typically used in environmental policy (Müller 2012, 2013). Our goal was to find instruments that can be used to influence the wide range of policy levers listed on the left-hand side of Table 7.4. Table 7.3 shows the instruments that we found particularly promising.

For each policy lever shown in Table 7.4, we list the instruments that we deem adequate for influencing that policy levers. What is more, we list the group of actors that we deem capable of using an instrument to influence the specific policy lever. While we devised this typology for the case of Switzerland, we expect it to be a useful tool for analyzing energy and climate policy in other northern, industrialized countries. In particular, it could be used to systematically search for further public policy interventions. On a more general level, Table 7.4 illustrates that transformation processes are brought about by applying a wealth of instruments to many different policy levers.

Table 7.3 Typology of instruments that can be used to influence the wide range of policy levers listed on the left-hand side of Table 7.4

	Instrument	Description
Command and control instruments	Emission regulations for heating systems	By regulating the emissions of heating systems, the application of current technology can be enforced and technological progress may be induced
	Relaxation of regulations	By relaxing limiting regulations (e.g. maximum floor space allowed by the building code), the economic viability of energy-efficient renovations may be increased
Economic instruments	Subsidies for energy efficiency and low-emission heating systems	By partially funding such investments, their attractiveness is increased. Subsidies are particularly interesting when combined with taxes on energy use and emissions
	Taxation of fossil-fuels	As the price of fossil fuels is increased, consumers substitute away from fossil-fuels
	Taxation of fossil heating systems	As fossil heating systems become more expensive, the attractiveness of alternative heating systems is increased. In contrast to taxing fuels, the taxation of (new) heating systems does not affect previous owners of fossil heating systems
Communication and diffusion instruments	Relying on 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
	Continuous training	Promoting continuous training enables actors in the construction and real-estate sector to obtain the know-how required to implement energy-efficient building designs
	Energy counseling	Promoting energy counseling would increase the knowledge base of decision-makers and nudge them toward more professional decision-making

(continued)

Table 7.3 (continued)

	Instrument	Description
	Establish standards	The establishment of standards, such as Minergie in Switzerland or the LEED standard in the US, reduces information and transaction costs. By referring to an established standard, building owners can now easily demand an energy-efficient building design without having to discuss technical details with architects
	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 specific groups
	Labeling	Labels can be used to communicate and certify difficult to observe attributes of a building, such as energy efficiency
	Marketing campaigns	Marketing energy-efficient building designs and their components aims to inform and convince potential customers
	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	Pilot- and demonstration initiatives acquaint actors in the construction and real-estate sector with technical innovations, thus accelerating the diffusion process
	Relying on 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
	Research and development initiatives	Initiating and supporting research and development leads to better and more cost-effective technologies

Table 7.4 Policy levers, instruments applicable to them and actors capable of implementing the instruments. 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

	Policy lever	Instruments
Building owners	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)
Tenants	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)

(continued)

Table 7.4 (continued)

	Policy lever	Instruments
Technology	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)
Civil society and the state	Yearly emissions of CO_2 compatible with the 2° 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	Participate in the political process (B, C, I, S, T)
	Reductions of the legal energy coefficient	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)

7.6.2 *Regulations in Support of the Decarbonization of the Stock of Buildings*

In the following, we discuss how a far-reaching decarbonization of Switzerland's heating systems could be achieved. In particular, we propose two regulations for discussion. In doing so, we are very well aware that several questions regarding political approval and practical implementation will remain open. Note that we propose these regulations as a complementary framework within which current efficiency-oriented energy policies would remain effective. We do not propose to replace current energy policies with the two regulations.

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 have exceeded their service life by 2050. With this regulation, fossil-based CO_2 emissions from heating systems would be banned. However, building owners would remain free to select the mix of insulation technology (façade insulation, efficient windows, etc.) and emission-free heating system that is best suited to their situation. The reason why we propose a command-and-control-type approach rather than market-based instruments (Kaufmann-Hayoz et al. 2001), such as a high tax on greenhouse-gases, is the prevalence of the investor-user dilemma (see above in Sect. 7.2). A tax on fossil CO_2 emissions might not prove an effective signal to the owners of rented buildings, because the tenants bear the cost of the tax. However, as a complement, an environmental tax on fossil-fuels could support the transformation of the stock of buildings and it might encourage renovations in owner-occupied 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, we expect the implementation of such a long-term policy to alter the costs and the 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.

The purpose of this second regulation is to encourage building owners to consider the implementation of decarbonized building designs 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 would have enough 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. In addition, these two regulations might prove effective in other northern, industrialized countries.

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.

7.6.3 A Business Model in Support of Non-professional Building Owners

Implementing near-zero-emission building designs in renovations, as implied by the two regulations introduced above, would increase the challenge of renovating. In such a situation, non-professional building owners should be considered to be a bottleneck, as they hardly have any chance to accumulate experience. In order to overcome this bottleneck, we propose to develop and actually implement a business model that solves several of the challenges that non-professional building owners face. By doing so, the transformation of Switzerland's stock of buildings toward low-emission, and perhaps even more generally toward sustainable housing, could be accelerated. Specifically, we propose the founding of a cooperative society that would work as a catalyst.

The cooperative society would assist building owners in dealing with various technical, financial, and procedural obstacles associated with renovations. It would ensure that the outcome of a renovation is adequate for the specific building in its specific situation; technically well built and cost-effective. 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. Its business model probably would need to address the following issues[7]:

- **Long-term planning**: The various elements of a building have different service lives and they should be replaced with consideration of possible path dependencies. Else, renovations may become overly expensive and ineffective. Long-term planning could avoid the risks of path dependency in sequential renovations. What is more, the cooperative society should assist building owners in long-term financial planning for renovations.
- **Value creation:** Buildings should be renovated in a way that maximizes the utility that tenants draw from it. This means that planning should raise 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 are considered adequately.
- **Assistance with technology choice:** For most building owners, searching for technical information is a time-consuming and costly process. Further, a substantial share of information on technical systems comes from vendors themselves. Hence, such information is not necessarily neutral or adequate. In order to respond to this, the cooperative society should provide neutral and up-to-date information on current technologies and cost.
- **Assistance with financial matters:** The cooperative society should assist building owners with organizing finance if sufficient reserves have not yet been accumulated before the renovation. This entails advising building owners on

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[7] Thanks to Mark Zimmerman (EMPA) for helpful comments by Email (September 21, 2011).

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 from vendors and construction companies.

- **Reduction of complexity:** Building owners should not have to deal with several companies. Instead, the cooperative society 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 cooperative society 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 occupational health. Such a service would encourage long-term relationships with building owners. As a part of commissioning efforts, tenants should be taught as to how to use the technologies in their building in an optimal manner.
- **Strategic focus**: The cooperative society should not provide solutions for each type of building. Instead, the focus should be on buildings of frequent types. Its strategic focus should be on high volume of relatively similar buildings and cost reductions through economies of scale and scope and learning effects.

7.7 Conclusions

In this chapter, we addressed the question, how public policy could transform the stock of buildings toward energy efficiency and low emissions. Based on the arguments elaborated above, we propose the following condensed answer. Public policy should increase the share of renovations implementing energy-efficient building designs near to unity and prevent paintjob renovations. In order to do so, public policy should attempt to address all policy levers available and use a wide arsenal of instruments that influence those policy levers. However, it seems rather unlikely that energy efficiency alone will suffice to reduce emissions by 90 % by 2050 (taking 1990 as a base year). Therefore, public policy should promote the wide-spread decarbonization of fossil heating systems. In order to accelerate the diffusion of energy-efficient renovations and achieve a wide-spread decarbonization of the stock of buildings by 2050, public policy should implement the two regulations described in Sect. 7.6.2. The first regulation, prohibiting the emission of CO_2 from heating systems by 2050, would create adaptive pressure decades before the year 2050 and would serve as a framework within which all other public policy interventions can be placed in. The second regulation, mandating the development of a roadmap for the renovation of buildings by 2020, would ensure that building owners pursue a long-term perspective in their decision-making. In order to support the majority of non-professional building owners in dealing with the rising complexity of renovations, we propose that public policy plan, implement and support service innovations such as the cooperative society described in this chapter. We expect that such service innovations reduce policy resistance and enhance the economical, ecological and social value of the built environment.

References

Barlas Y (1996) Formal aspects of model validity and validation in system dynamics. Syst Dyn Rev 12(3):183–210

Barrett M (2009) Policy challenges for building stocks. Build Res Inf 37(2):201–205

Bornstein N (2007) Three essays on the acceptability of environmental policy in Switzerland. Ph. D. thesis, Ecole Politechnique Féderale de Lausanne, Lausanne

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

EDK (2008) Mustervorschriften der Kantone im Energiebereich (MuKEn). Ausgabe 2008, Konferenz Kantonaler Energiedirektoren (EDK). http://www.endk.ch/muken.html?file=tl_files/documents/MuKEn2008_di.pdf, 25 Aug 2009

Erhorn-Kluttig H, Erhorn H (2007) Ecobuildings: towards an energy- efficient european building stock beyond national requirements. In: Proceedings of 2nd PALENC conference and 28th conference on building low energy cooling and advanced ventilation technologies in the 21st century, September, Crete Island

EU (2011) A roadmap for moving to a competitive low carbon economy in 2050, communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF. 13 Mar 2012

Flick U (2005) Qualitative Sozialforschung. Eine Einführung., Rowohlts Enzyklopädie, Rowohlt Taschenbuch Verlag, Reinbeck bei Hamburg

Galvin R (2010) Thermal upgrades of existing homes in germany: the building code, subsidies, and economic efficiency. Energy Build 42:834–844

Geels FW (2005) Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective. Technol Forecast Soc Change 72:681–696

Golubchikov O, Deda P (2012) Governance, technology, and equity: an integrated policy framework for energy efficient housing. Energy Policy 41:733–741

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

Ingold K (2007) The influence of actors coalition on policy choice: the case of the Swiss climate policy. In: Friemel T (ed) Applications of social network analysis: proceedings of the 3rd conference on applications of social network analysis 2006, UVK Medien, Konstanz

Ingold K (2010) Apprendre pour le futur: Une analyse de la politique climatique suisse. Swiss Pol Sci Rev 16(1):43–76

Jakob M (2008) Grundlagen zur Wirkungsabschätzung der Energiepolitik der Kantone im Gebäudebereich. Centre for Energy Policy and Economics (CEPE)

Jasanoff S (2010) A new climate for society. Theory Cult Soc 27(2–3):233–253

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

Kaufmann-Hayoz R, Bättig C, Bruppacher S, Defila R, Di Giulio A, Flury-Kleubler P, Friederich U, Garbely M, Gutscher H, Jäggi C, Jegen M, Mosler H-J, Müller A, North N, Ulli-Beer S, Wichtermann J (2001) A typology of tools for building sustainability strategies.

In: Changing things – moving people. Strategies for promoting sustainable development at the local level. Birkhäuser, Basel, pp 33–108

Kriesi H, Jegen M (2000) Decision-making in the Swiss Energy Policy Elite. J Public Policy 20 (1):21–53

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

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

Levine MD, Ürge-Vorsatz D, Block K, Geng L, Harvey D, Lang S, Levermore G, Mongamell M, Mirasgedis S, Novikova A, Rilling DJ, Yoshino H (2007) Residential and commercial buildings. In: Metz B, Davidson O, Bosch P, Dave R, Meyer L (eds) Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK

Linder W (1999) Schweizerische Demokratie. Institutionen, Prozesse, Perspektiven. Haupt Verlag, Bern

Lovell H (2005) Supply and demand for low energy housing in the UK: insights from a science and technology studies approach. Hous Stud 20(5):815–829

Mills E (2011) Building commissioning: a golden opportunity for reducing energy costs and greenhouse gas emissions in the United States. Energy Effic 4:145–173

Müller MO (2012) How can the diffusion of energy-efficient renovations of buildings be accelerated?, Ph.D. thesis, University of St. Gallen. http://www1.unisg.ch/www/edis.nsf/SysLkpByIdentifier/4030. 03 Oct 2012

Müller MO (2013) Diffusion dynamics of energy-efficient renovations. Causalities and policy recommendations, vol 14, Lecture notes in energy. Springer, Heidelberg

Müller MO, Ulli-Beer S (2008a) Diffusionsdynamik energieeffizienter Renovationen: Akteursanalyse. Bericht zum ersten Workshop am 20. Juni 2008, Arbeitspapiere aus der IKAÖ, Nr. 2, Universität Bern. www.ikaoe.unibe.ch/publikationen/arbeitspapier_02.pdf. 12 Dec 2008

Müller MO, Ulli-Beer S (2008b) Modeling the diffusiondynamics of a new renovation concept. In: Proceedings of the 26 system dynamics conference, July 20–24, Athens

Müller MO, Ulli-Beer S (2010) Policy analysis for the transformation of Switzerland's stock of buildings. A small model approach. In: Proceedings of the 28th international conference of the system dynamics society, pp 25–29, Seoul. http://www.systemdynamics.org/conferences/2010/proceed/papers/P1172.pdf. 18 Feb 2012

Müller MO, Groesser SN, Ulli-Beer S (2012) How do we know who to include in collaborative research? Toward a method for the identification of experts. Eur J Oper Res 216(2):495–502

Novatlantis (2007) The 2000-watt-society, website of novatlantis – sustainability in the ETH domain. http://www.novatlantis.ch/2000watt.html. 29 Aug 2011

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

Reddy BS, Assenza GB (2009) The great climate debate. Energy Policy 25(6):587–600

Richardson GP (2011) Reflections on the foundations of system dynamics. Syst Dyn Rev 27 (3):219–243

Sabatier PA (ed) (2007) Theories of the policy process. Westwiev Press, Cambridge, US

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

Schulz Th. F (2007) Intermediate steps towards the 2000-watt society in Switzerland: an energy-economic scenario analysis. Ph.D. thesis, Eidgenössische Technische Hochschule Zürich, DISS no 17314

Schwaninger M, Groesser SN (2008) System dynamics as model-based theory building. Syst Res Behav Sci 25(4):439–445

Schwaninger M, Groesser SN (2009) System dynamics modeling: validation for quality assurance. In: Meyers RA (ed) Encyclopedia of complexity and systems science, vol 9. SpringerScience +Business Media, LLC, New York, pp 9000–9014

Schwaninger M, Pfister Th. F (2007) System dynamics as model-based theory-building: a low-key, small-scale approach [version of 13 Mar 2007]. Paper presented at the European system dynamics workshop, University of St. Gallen, pp 23–24

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

Sterman JD (2000) Business dynamics. Systems thinking and modeling for a complex world. Irwin McGraw-Hill, Boston

TEP & ETH (2009) Gebäudeparkmodell SIA Effizienzpfad Energie. Dienstleistungs- und Wohngebäude. Vorstudie zum Gebäudeparkmodell Schweiz. Grundlagen zur Überarbeitung des SIA Effizienzpfades Energie, Studie im Auftrag des Bundesamts für Energie (BFE). Available online http://www.ibi.ethz.ch/nb/publications/reports/200910_ETH.TEP_Endbericht.Gebaeudeparkmodell.pdf. 20 Dec 2011

Ulli-Beer S, Müller MO (2006) DeeR. Modelling the diffusion of energy-efficient building refurbishment. Analysing socio-technological change processes within the innovation system. Unpublished Project Proposal, Interdisciplinary Centre for General Ecology, University of Bern

Ürge-Vorsatz D, Metz B (2009) Energy efficiency: how far does it get us in controlling climate change? Energy Effic 2:87–94

Weart SR (2008) The discovery of global warming, Revised and Extended edn. Harvard University Press, Cambridge, US

Weible CM, Sabatier PA, McQueen K (2009) Themes and variations: taking stock of the advocacy coalition framework. Policy Stud J 34:121–140