# 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.

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

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**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.

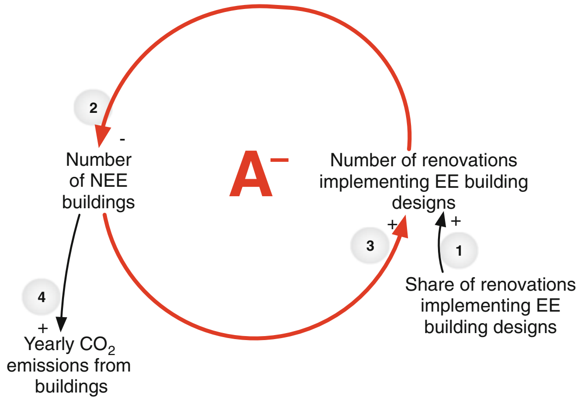


**Fig. 6.1** Loop A: Energy-efficient renovations transform the stock of buildings. Consists of *arrows* 2 and 3

## 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).

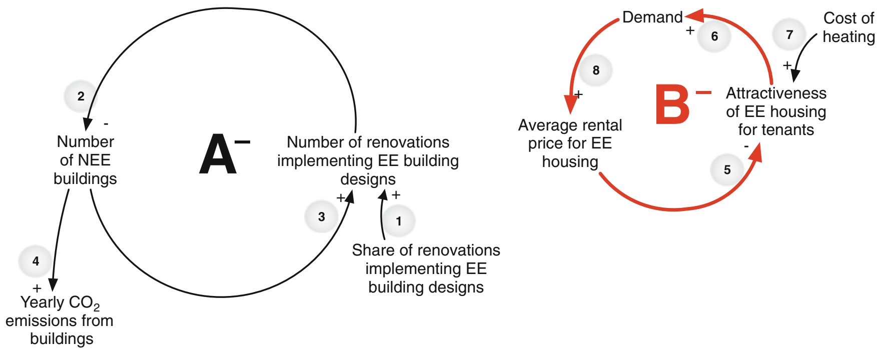


**Fig. 6.2** Loop B: Demand for energy-efficient housing. Consists of *arrows* 5, 6 and 8

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

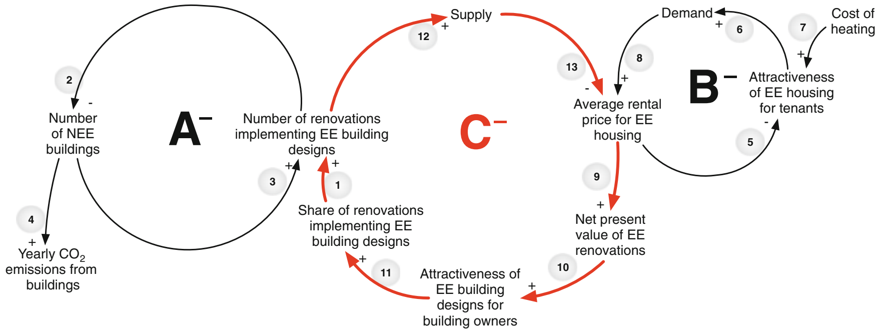


**Fig. 6.3** Loop C: Supply of energy-efficient housing. Consists of *arrows* 9, 10, 11, 1, 12 and 13

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

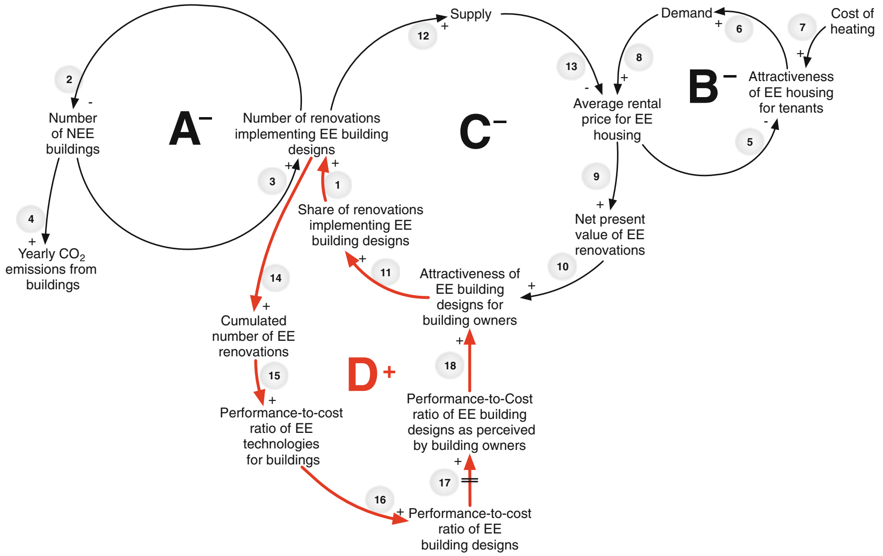


**Fig. 6.4** Loop D: Market-driven technology improvement and its perception by building owners. Consists of *arrows* 14, 15, 16, 17, 18, 11 and 1

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 BUILDING 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

[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.

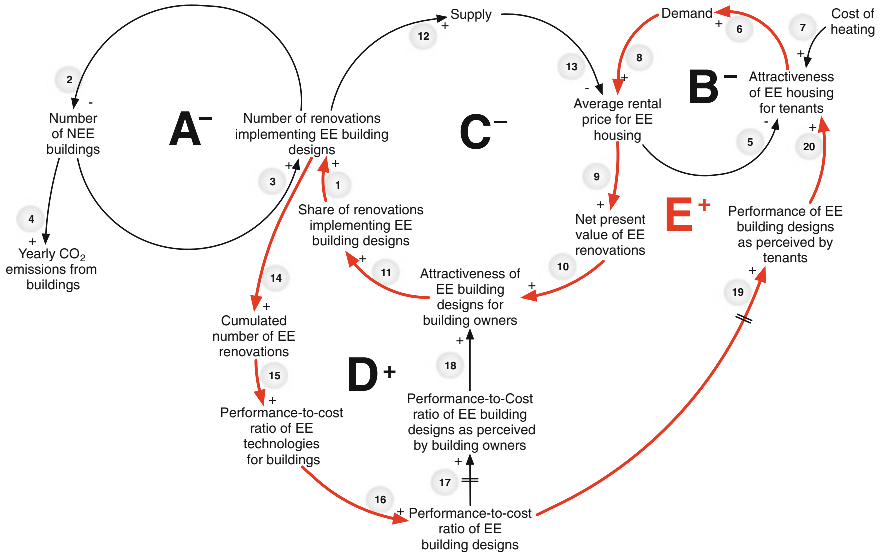


**Fig. 6.5** Loop E: Market-driven technology improvement and its perception by tenants. Consists of *arrows* 14, 15, 16, 19, 20, 6, 8, 9, 10, 11 and 1

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.

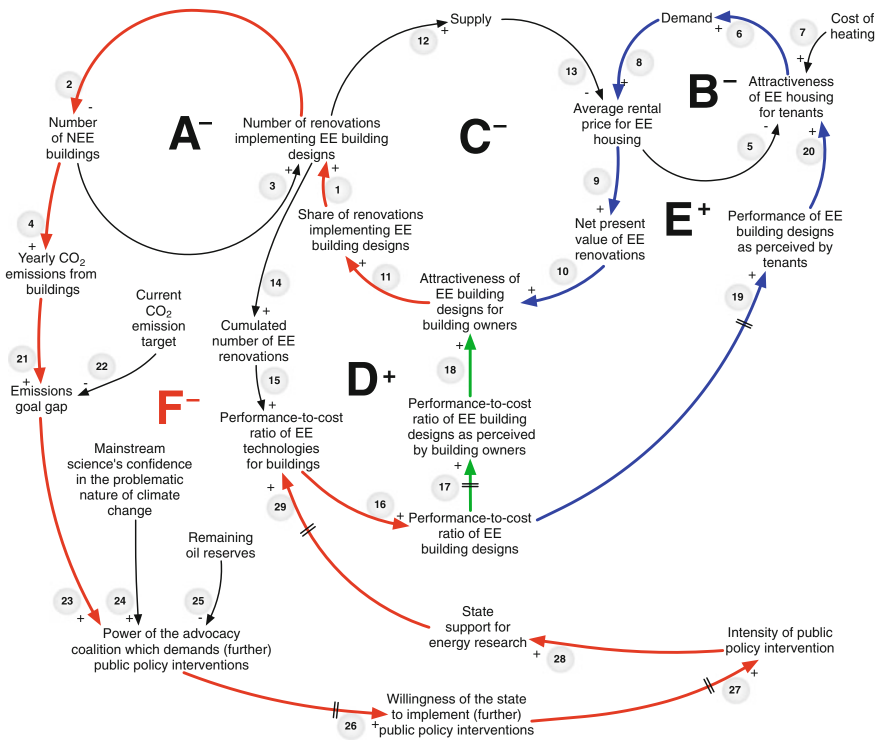


**Fig. 6.6** Loop F: Public policy accelerates technology improvement. Consists of *arrows* 2, 4, 21, 23, 26, 27, 28, 29, 16 and then branches off to loop D by way of *arrows* 17, 18 and to loop E by way of *arrows* 19, 20, 6, 8, 9 and 10. It finally runs further by way of *arrows* 11 and 1

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

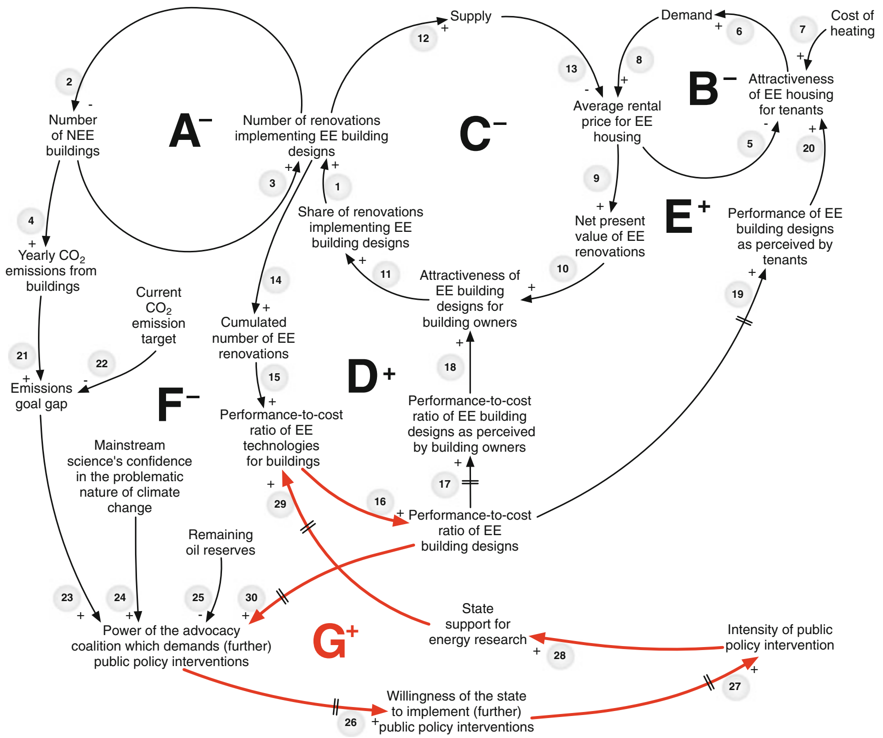


**Fig. 6.7** Loop G: The availability of adequate technology creates further pressure for public policy interventions. Consists of *arrows* 30, 26, 27, 28, 29 and 16

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 Intervention, a second type of policy instruments aimed at accelerating the diffusion of energy-efficient building designs gains prominence.[3] Specifically, loop H describes

[3] See Sect. 6.7, specifically p. 191, for a discussion of the different policy types.

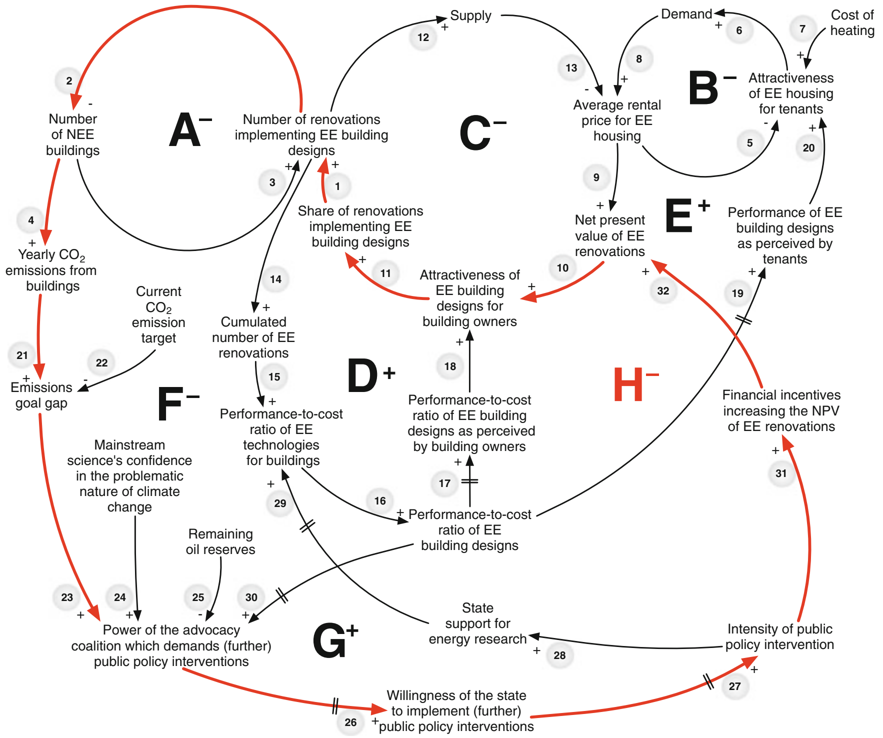


**Fig. 6.8** Loop H: Public policy accelerates the diffusion of energy-efficient building designs. Consists of *arrows* 31, 32, 10, 11, 1, 2, 4, 21, 23, 26 and 27

how Financial Incentives 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 Incentives 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 Incentives 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.

[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.

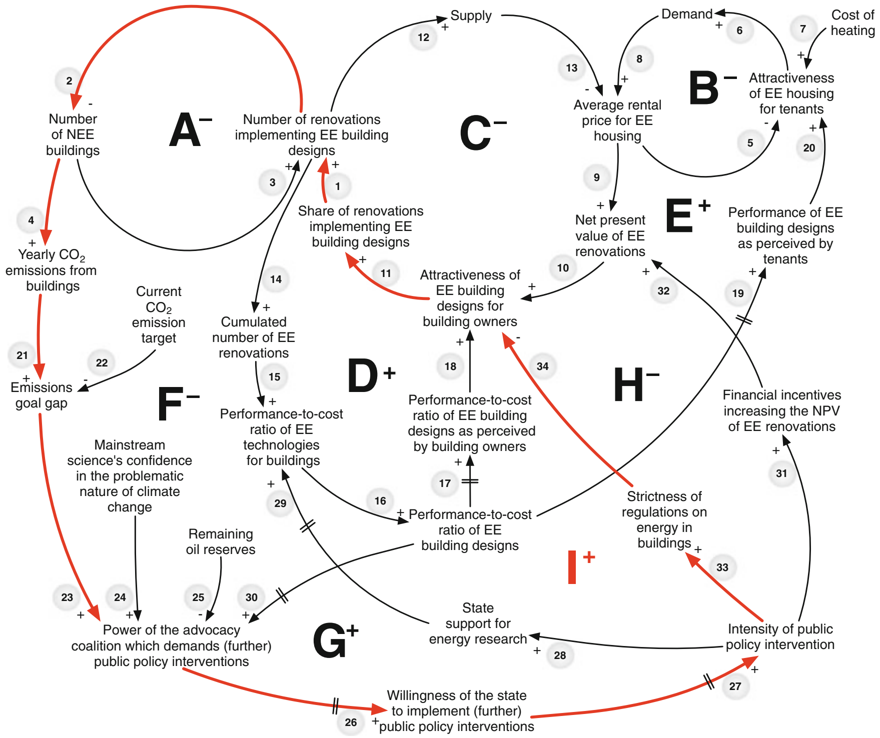


**Fig. 6.9** Loop I: Public policy tightens mandatory standards. Consists of *arrows* 33, 34, 11, 1, 2, 4, 21, 23, 26 and 27

## 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

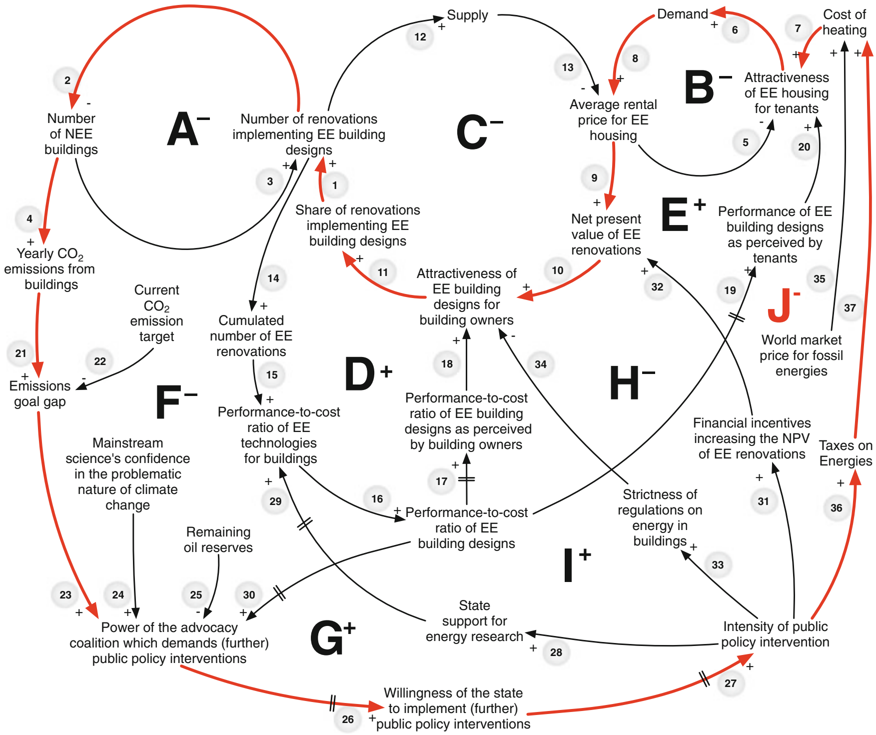


**Fig. 6.10** Loop J: Public policy increases the price of energy. Consists of *arrows* 36, 37, 7, 6, 8, 9, 10, 11, 1, 2, 4, 21, 23, 26 and 27

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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