Using system dynamics modelling to analyse the interplay of policies and societal motivation for promoting energetic renovation

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Abstract

Transforming the existing energy-intense building stock to an energy-efficient one is one vital path to mitigate climate change. However, in most countries the dynamics of energetic renovation of buildings has so far been too slow to meet the climate mitigation targets. Accordingly, a deeper understanding of what factors directly and indirectly influence the decision-making process for or against energetic renovation is required and especially how these are interconnected. For this purpose, we developed a system dynamics model to explain the obtained low energetic renovation rate for the case of Germany focusing on societal motivation processes. The interplay of the five identified feedback loops is found to significantly influence the dynamics of energetic renovation: a rigid behavior at a low rate, an oscillating behavior around a desired rate, or a significantly increasing energetic renovation rate, depending on the policies applied. The central outcome of our investigation was that a relatively short but intense policy intervention pulse seems to be much more effective to induce a sustainable transformation process in a society then a low policy intensity over a long term (which can be commonly obtained nowadays). The simple structure of the developed system dynamics model might be transferable to other systems where societal motivation processes play a vital role for the implementation of climate change mitigation or adaption. To enhance the robustness and validity of the system dynamics model, further investigations are needed especially how the different soft variables of the model are weighted.

1 Problem statement

In Germany, the energy demand to heat buildings induces a high share of greenhouse gas emissions with more than 180 million tons CO_2 emissions per year (DENA 2019). Thus, Germany set a long-term goal to reduce the primary energy consumption caused by the building sector by 80 percent by 2050 and to gain a climate-neutral building stock by the middle of this century (DENA 2019). To achieve such an ambitious plan, the energetic renovation (ER) rate of the entire energy-intense building stock in Germany is desired to be between 1.5 % and 2.5 % (DENA 2019, DIW 2018, Sandberg et. al 2016). However, as illustrated in Figure 1, in the last 15 years the ER rate has been much lower and in addition no significant increase over time can be observed since the reunification of Germany in 1990 and the corresponding backlog of building renovation in the former GDR.

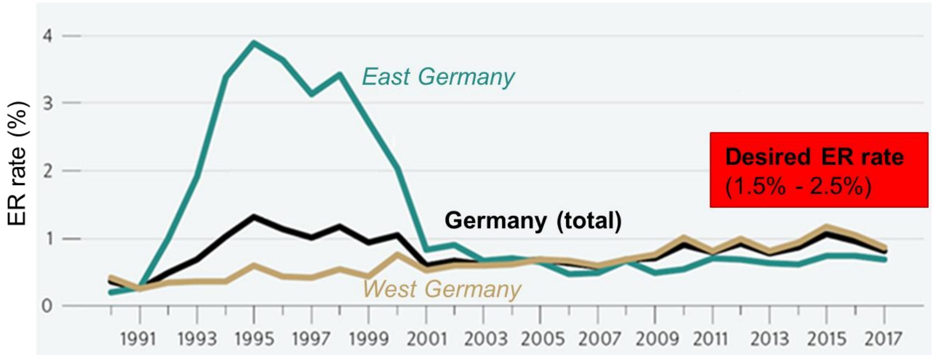

Figure 1: Development of the energetic renovation rate of buildings in percent in Germany (DIW 2018)

That the ER rate needs to increase to meet climate change mitigation goals has been well known for a few decades, as reflected in different policies conducted in the past, including attractive credits and subsidies for energetic renovation of buildings, certification systems, training of energy experts. However, these policy measures only led to a low dynamics in ER rate, still significantly below the desired minimum of at least 1.5 %. Thus, a deeper understanding why the obtained dynamics of the ER rate are relatively rigid independent on the policies applied is essential to identify important leverage points of the system to increase the ER rate. Our approach focuses on understanding what motivates owners of buildings (who are responsible for over 60 % of the building energy demand in Germany) to perform energetic renovation and try to analyse the impact of different changes in motivational factors using system dynamics (SD) modelling. This research question is investigated for the case of Germany, however low ER rates with rigid development are also present for other countries, for which this research can be adapted.

2 Introduction & Literature Review

Several studies address energetic renovation dynamics and how policies affect ER. Onat et al. (2014) focused on the impact of different policies in three fields for residential building GHE reduction in the US using SD, high performance green building construction, building retrofitting, and net-zero building construction. One of the most important outcomes of this study is that focusing on increasing the construction rate of new energy-efficient buildings alone is not sufficient to reduce greenhouse gas (GHG) emissions, making policy change for energetic renovation of the existing residential building stock essential. This was also confirmed by another study investigating long-term changes in dwelling stock composition and expected annual renovation activities up to the year 2050 for 11 European countries using an SD approach (Sandberg et al. 2016). Renovation rates were recommended in the range from 0.6% to 1.6% for these different countries, far too low compared to the desired 2.5% to 3.0% ER rate assumed for many decarbonisation scenarios. Other studies also address energetic renovation in Germany, such as Schmidt et al. (2012), applying five policy scenarios like promotion of renewable energies for heating and obligation for ER to increase the energy efficient building stock in its SD models. McKenna et al. (2013) used a building-stock-model-based analysis for the German residential building stock to analyse scenarios to meet the climate mitigation goals for the year 2020, 2030 and 2050. They demonstrated that a drastic increase of the ER rate is required by policy instruments in order to meet the 2020 climate mitigation targets, especially amongst existing single family buildings. Concerning ER in China, Guo et. al (2019) developed a large SD model including feedback relationship between the service subsystem, the demand market subsystem, and the market regulation subsystem.

However, none of these contributions to the research field focused specifically on motivating or demotivating factors that influence the decision of building owners on whether to perform ER or not. The aim of our investigations is to gain a deeper understanding of this processes by developing an SD model and analyse its dynamic behaviour as well as influence of different policies. It is important to note that this is done from the perspective of the society, not addressing individuals. Research on the factors that directly and indirectly influence the decision-making process for ER agrees on one thing: gaining economic benefit may be a very powerful motivation, but it is not the only one. A set of socio-psychological factors also plays a significant role (Weber et al. 2016, Clayton et al. 2015, Hofe et al. 2016).

The motivation to undertake ER is largely determined by a set of socio-economic characteristics of the decision-maker. These often determine general attitudes toward climate change and other issues related to sustainability. The most frequent influencing factors considered in the scientific literature are *age, gender* and *level of income* (Weber et al. 2016, Abrahamse et al. 2009). *Education* and *political ideology* also determine subjective perceptions of climate change actions. Lower levels of education make it harder to obtain and accurately analyse information (Streimikiene et al. 2020, Banfi et al. 2008, Achtnicht 2014), and conservative political views often lead to denial of climate change (Feinberg et al. 2013, Czarnek et al. 2021). Poortinga et al. (2019) extend these variables by *cross-national differences*, emphasizing the role of place of residence and origin as well.

These factors, along with *emotions* (Böhm et al. 2003, Chapman et al. 2017) and personal *risk aversion* (Zundel et al. 2011), while determining general attitudes toward climate change initiatives, are difficult to manipulate. However, they have an indirect effect on people's mental models, and these, combined with other influences, determine the eventual motivation for energy renovation.

Major literature we have reviewed points to several factors within the implementable manipulative zone. A number of authors highlight the importance of building overall *expertise on the issue* and properly *communicating knowledge to the decision-maker* (Achtnicht 2014, März et al. 2020). The perception of this knowledge depends both on the type of information (Wang et al 2018) and the way it is delivered, as well as on the level of trust in responsible institutions and the subjective perception of being potentially deceived (Perlaviciute 2014).

An important deciding factor for motivating energy renovation is the *influence of society* (Newell et al 2014, Samuelson 1990). Distinguishing between two types of influential social norms - prescriptive norms, which motivate the decision-maker to engage in energy retrofitting out of a desire for approval or fear of being judged, and descriptive norms, which motivate the decision-maker to behave like others, it is important to emphasize the greater influential role of descriptive norms (Valkengoed & Steg 2019). That kind of *behavioural adoption of others* has been described in a variety of psychological literature on incentives for pro-environmental action (Nolan 2008, Smith et al. 2012, Göckeritz 2010).

The next driver of attitudes towards energy retrofit is general *climate change awareness*. This in turn is determined by personal experience (e.g. people who are regularly confronted with weather-related problems are more likely to believe in ongoing climate change and are therefore more motivated to mitigate it), psychological distance from the problem (e.g. a place-attached person forms a place-identity and is more likely to act in defense of that space), as well as a range of values and beliefs (Clayton et al. 2015, Newell et al. 2014, Valkengoed & Steg 2019). Such values and beliefs include convictions about the seriousness of climate change, the personal consequences of climate change, the environmental consequences of climate change, perceived behavioural control (the extent to which people believe they can solve the issue) and personal moral norms and sense of individual responsibility for climate change mitigation actions.

Another important motivational factor being considered in contemporary academic literature is *self-efficacy*. Bandura 1997 describes this motivational factor as a multidimensional construct, representing an individual's confidence in the positive outcome of their actions. This motivational variable, which corresponds in its meaning to internal locus of control (the variable referring to the subjective feeling of control over the outcome of one's actions, on which result-oriented theories are based (Rotter 1966)) can also be transposed from the individual level to the collective level in the form of society as a whole. This refers to *collective efficacy*, reflecting the group's belief in the success of joint action to solve global problems such as climate change (Chen 2015). Empirical research in the field of environmental psychology indicates that collective efficacy considerations have a major role in motivating people towards contributing to pro-environmental action (Goddard et al. 2004).

When discussing the relationships between these various factors and establishing the impact size of each of them, it should be noted that most studies on the subject examine motivational factors separately from one another and the variables are usually not standardized (not placed on the same scale), which leads to difficulties in comparing them with one another (Samuelson 1990, Zundel 2011). Nevertheless, some predominant leverage points can be identified, the superior role of which has been empirically proven.

An analysis of the factors influencing the implementation of ER in Germany shows that the greatest influence is exerted by economic factors, as well as by knowledge about energy renovation and climate change in general. (Achtnicht 2014, Grösche 2008). März et al. (2020) also highlight the knowledge about energy renovation as a key lever, as well as societal influences and personal belief systems. Valkengoed & Steg (2019) analyze the relationships between different motivational factors and climate change adaptation behaviour on a household level. The analysis shows that the greatest influence on climate change mitigation behaviour comes from perceived behavioural control (the extent to which people believe that their actions actually contribute to a global goal), beliefs about the consequences of climate change for themselves, and the behaviour of others. A study of Abrahamse et al. (2009) also highlights the significant role of perceived behavioural control in household energy conservation. Alongside this factor, there is empirical evidence of a strong influence of personal norms and a sense of personal responsibility, as well as a general awareness of climate change, its relationship with energy conservation and its negative consequences. Streimikiene et al. (2020) expand on these findings and also argue that economic and knowledge-based incentives are essential to facilitate climate change mitigation behaviour related to household energy efficiency.

3 Methods - System Dynamics Model Structure

A central goal of the SD modelling process is to identify explanations for the obtained rigid behaviour of the ER rate in Germany (see Figure 1) and to gain a deeper understanding of the ER dynamic. The motivation for ER leading to the decision to renovate the building is the central element in the SD model developed here. From the literature on factors influencing the motivation for ER, the following key factors/variables are implemented in the model:

- *"Own advantage (individual perception)"* including the impact of *profitability* of ER by comparing energy cost savings to retrofit costs subsidies for ER motivation.
- *"Expertise about ER*" including the quality of energy consulting, the expertise of planers and craftsman and the quality the knowledge is communicated to be able to advise the building owner as good as possible.
- "*Behavioural adoption to others*" the influence of society and its injunctive and descriptive norms on the ER adoption, also including the word-to-mouth effect.
- "*Climate change awareness*" including society's pro-environmental values and beliefs and willingness to change behaviour and lifestyles to address global environmental issues.
- "*ER obligation*" including the effect that obligatory ER can lead to both, a direct rise in ER if it is mandatory to do if a building is changed or renovated, and a decrease in ER motivation through reduced acceptance due to a perceived restriction of freedom of choice.

These factors all influence the motivation in German society to undertake ER and thus the decision of owners to energetically renovate their buildings. For this reason the change of the motivation as a stock is the central element in the SD model. The evolving simplified causal loop diagram is depicted in Figure 2. This motivation for ER directly affects the "ER-rate for buildings in need of renovation" (from here on called "ER-rate"). For low motivation (min. value of 0) the resulting ER-rate is zero, for high motivation (max. value of 1) the maximum ER-rate can lead up to 5 % per year. Here, we assume that higher ER than 5 % per year are unrealistic and define 5 % as a maximum value. Starting from the ER-rate five causal loops are developing to reinforce or balance the effect of changes in motivation for ER, visualised in Figure 2Figure 2 and Table 1. The policy feedback loops B1, B2 and R3 all imply a significant rise of output of the variable "requirement of governmental policy instrument" if the ER-rate is below the desired rate of 2 % aiming to increase the motivation by enhancements of policy instruments (if applied). This drives the ER-rate to the desired 2 % per year if policies are applied. If the ER-rate is larger than 2 % these variable goes to a value of 1 meaning no policy is required to apply. In the SD model, we focussed on three different policy instruments to influence the motivation for ER:

- "*policy instrument A: increasing profitability*" (by subsidies and credits)
- "*policy instrument B: increasing climate change awareness*" (by informative instruments)
- "*policy instrument C: obligatory ER*" (prescribe that buildings in need of non-energetic renovation have ER through statutory regulations)

All policy instruments can be regulated in intensity separately to investigate the individual policy impact.

Besides the "forced" increase in ER-rate to the desired value of 2 % if policy instruments are applied in sufficient strength, two reinforcing feedback loops are affecting the motivation for ER in an intrinsic manner. The impact of the loops "Behavioural adoption" and "Expertise about ER" on the motivation for ER rises, the higher the ER-rate becomes. These two loops reflect that the effect of adoption and available expertise increases when the ER-rate is high (especially for values above 1 %) and thus represent reinforcing feedback loops.

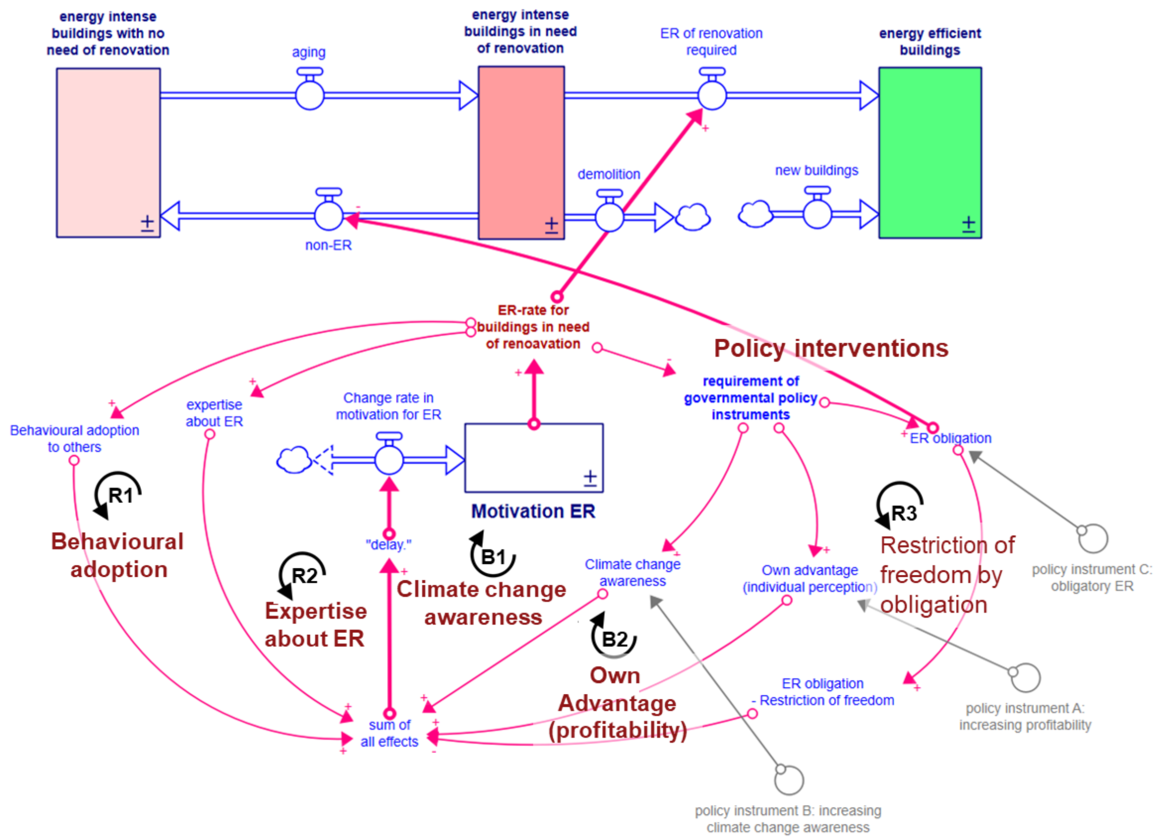

Figure 2: Causal loop diagram including the three different building stocks, the central stock for motivation ER and six feedback loops for energetic renovation (ER).

In sum five feedback loops influences the change in motivation (variable "change rate in motivation for ER") with a delay which reflecting the "mean" time needed for a change of mental model for ER or against it. This delay implements different processes like duration from first consultation about ER to implementation or from implementing a new policy to get them known in the society. Thus, summarising it as one delay is a hard assumption making it difficult to find representative values. The "ER-rate" resulting from the "motivation for ER" stock is multiplied with the stock of "energy intense buildings in need of renovation" to increase the "energy efficient building" stock. The latter stock can also be increased by new buildings which must be built in an energy efficient manner by the German energy act. The last feedback loop R3 describes the transitions of energy intense buildings from the stock of "energy intense buildings with no need of renovation" to "energy intense buildings in need of renovation" via aging or vice versa by non-energetic renovation. For the latter one the policy instrument C can prescribe that e.g. general (non-energetic) renovation also must be ER which indirectly leads to an increase in energy efficient buildings. The process of demolition of buildings which are in need of renovation is implemented in the SD model as well. In Table 1 the six feedback loops of the SD model are described and their impact on the motivation for ER is correlated. This impact is implemented in the model by different table functions with varying output values in the variables of the loop from -1 to 7 representing the different weight of the variables on the change in ER motivation. All effects of variables are summarised by simple addition, assuming that the processes in the feedback loops are independent on each other.

Table 1: List of feedback loops in the SD model with name and numbering (R1…B3) from the causal loop diagram of Figure 2 Figure 2with a description what the loop represents and the strength of the motivation rate for ER.

Feedback loop	No.	Type	Description	Impact*
Behavioural adoption	R1	reinforcing	describes the effect that adoption of ER will increase with ER rate (because of more "visibility" of the topic ER in society for high ER-rates)	High (4)
Expertise about ER	R2	reinforcing	represents that with increasing ER-rate the expertise of renovation experts, planners and handcrafts for ER will rise	Low (2)
Climate change awareness	B1	balancing	Embeds the effect of policies to enhance the climate change awareness on the societal motivation for ER	Medium (3)
Own advantage (profitability)	B2	balancing	stands for implementation of financial policies (e.g. subsidies and credits) to make ER more profitable and thus more attractive	Highest (7)
Restriction of freedom by obligation	R3	reinforcing	represents the negative effect of pressure by obligatory ER on the society to decide for ER	Low (-1)

* value in brackets stands for the ratio that how the variable influence the motivation (not normalised)

4 Results

4.1 Direct structure test

The chosen SD model approach focus the research question regarding which factors and processes lead to a change of owners' motivation for ER of their building on a societal level. Three reinforcing and two balancing loops were identified which qualitatively can describe the obtained low ER rate of the last decades in Germany as a consequence of relatively low motivation for ER in the German society. Focussing on different soft factors influencing the motivation leads to the problematic that the weighting of the factors is hard to quantify in numbers, even in mean values for society. However, these weighting has a strong impact on the interplay of the different feedback loops and thus on the outcome of the SD model. The assumed weighting of the factors for ER motivation change is implemented by different maximum output values in the table function of the feedback loops (see Table 1), depicted in Figure 3Figure 3. These factors are based on the qualitative comparison of the factors found in the literature review and are related with high uncertainties in quantitative numbers. In future these assumed maximum values (red circles in Figure 3) needs to be validated by surveys or Group Model Building workshops to enhance the robustness of the developed SD model. The sensitivity analysis in the appendix in section 9.2 shows the impact of changing the values for different table functions on motivation for ER. Other limitations of the present SD model are discussed in section 5.2. For the SD modelling the software STELLA 2.1 was used.

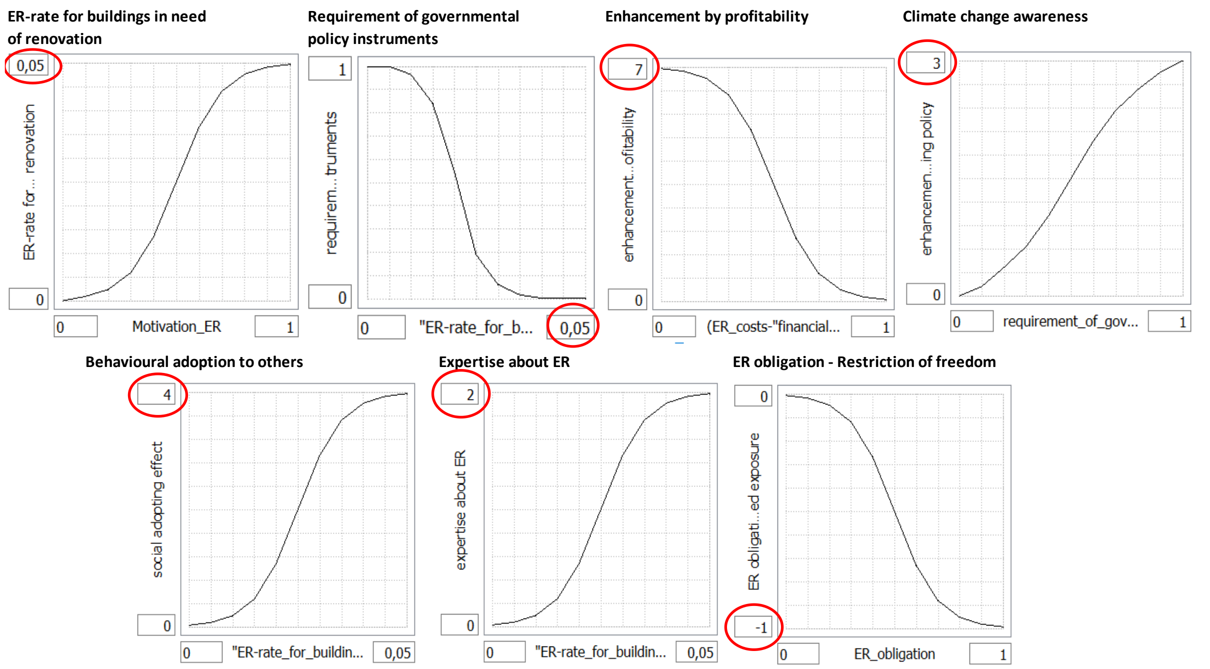

Figure 3: Table functions defined for the SD model with assumed maximum values which need a deeper proof in red circles

4.2 Indirect structure conformation tests

The model was validated by carrying out integration error tests, sensitivity analysis, behaviour reproduction tests and dimensional consistency. A variation of simulation time steps or integration methods leads to no significant difference in outcomes and dynamics. The sensitivity analysis and extreme conditions testing can be found in section 9.2 of the appendix. Summarising, the analysis showed that the dynamics of model significantly depend on:

1. Shape of the table function graphs, especially for the “ER-rate for buildings in need of renovation” and “requirement of governmental policy instruments” because numerous feedback loops depend on this variables. Oscillatory dynamics are obtained when table functions show a steep course caused by the interaction of balancing and reinforcing feedback loops. These oscillations are reasonable, if they are also realistic must be evaluated in future.
2. Analysis of the different weighting the factors (feedback loops) influencing the motivation for ER was done by varying the maximum for the table functions (seeFigure 3 Figure 3). Different combinations of maximum values are found to strongly affect the dynamic behaviour and thus show the necessity to find reliable values based on data to be created in future to gain a more robust SD model.
3. The variables “averaging time” and “motivation adjustment time” represent different delays and affect the dynamics of the model. For more precise data is desired to enhance the robustness of the SD model.

4.3 Simulation Analysis

4.3.1 Reference mode – explaining the past decades:

Continuous moderate policies:

Apart from the effect of the higher ER rate after German reunification from 1990 to 2000, the ER rate remain nearly constant around 1 % in the last two decades (see Figure 1). In the reference mode this behaviour can be reflected very well by the SD model as represented in Figure 4a by concerning a low to moderate level of applied policies (value of 0.4 for “policy instrument A: increasing profitability”, value of 0.4 for "policy instrument B: increasing climate change awareness" (values can go from 0, no policy applied, to 1, maximum potential of policy)). These values of 0.4 can be shifted between the different policy instruments leading to the same sum of enhancement on motivation. However, the sum of the applied policies is moderate and the induced ER-rate in the range of 1 % leads to a very low level of behavioural adoption effect. The selected parameters of moderate applied policies to meet the renovation rate of 1 % in reality and its rigid behaviour is explainable with past and current policy instruments implemented in the past by the German state to enhance the attractiveness of ER, like subsidies or programs to strengthen climate change awareness.

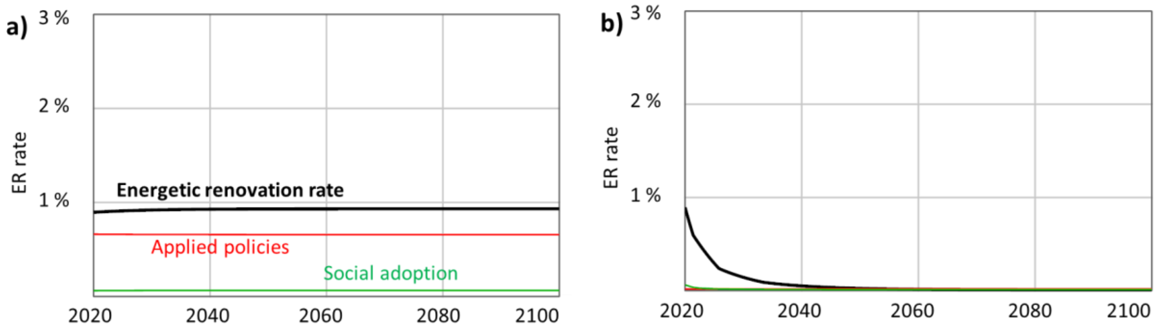

Figure 4: a) Low energetic renovation rate with constantly low intensity of applied policies representing the constant rate in reality in the last decades and b) energetic renovation going down to nearly zero for not policy instruments applied in the SD model. The red line stands for applied policies, green line for the behavioural/social adoption effect.

Cutting policies – expiring ER-rate:

For the case that policies were cut off in the year 2020 (see Figure 4b), the initial ER-rate (set to around 1%) went down to 0% in two decades. This second case can also explain real behaviour because the motivation for ER will decrease with time if the ER is not profitable, no ER expertise is present, ER is not obligatory and societal awareness is not promoted.

4.3.2 Policy and Implementation

High initial policies – high and partly oscillating ER-rate:

According to the SD model, the desired increase in ER-rate from 1 % in the past to 2 % in future can be achieved by implementing more intense policies by increasing "policy instrument A: increasing profitability" to enhance the profitability of ER and/or "policy instrument B: increasing climate change awareness". Figure 5Figure 5a and c demonstrates that several policy combination can be applied to gain the desired 2 % ER rate. Because of the larger maximum in the table function for the variable "own advantage (indiv. perception)" (own advantage (indiv. perception)) compared to the variable "climate change awareness" (see Figure 3), the desired policy intensity to achieve the same ER-rate is higher for the latter one. In the scenarios in Figure 5a to c policies are required for the whole time to result in ER rate of 1 %. The oscillations in Figure 5Figure 5a and b are caused by the dynamics that impulses of intense policy implementation induce fast increase in ER-rate and thus lead to a strong rise of the behavioural adoption process. Because the aimed ER-rate is defined to be in the range of 2 %, the applied policy decreases when the behavioural adoption process. However, the behavioural adoption process is not strong enough to sustain the ER rate at this high level and the implementation of policies is again required. This strong oscillations between behavioural adoption and policies induce the oscillation of the ER rate around the value of 2 %.

In contrast, when assuming initial maximum policies (value of 1) for both, the rise in ER-rate in the first years in Figure 5d is such high that the reinforcing loops of social adoption effect and ER expertise can sustain a high ER-rate in future without further policies. Such a scenario is theoretically possible, however the fast increase in ER-rate by the high policy investment in the beginning must be seen critically and probably requires adjustments of the delay functions in the SD model.

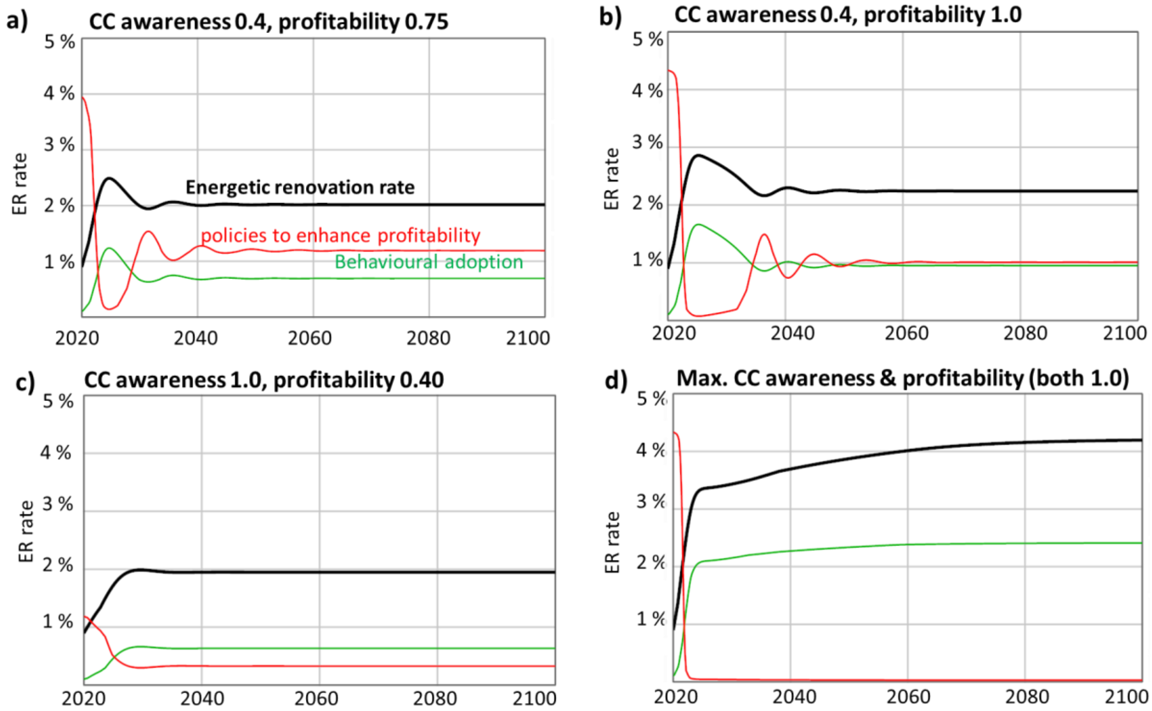

Figure 5: Energetic renovation (ER) rate for different intensity of applied policy to enhance societal motivation and to enhance profitability by financing instruments.

Policy pulse – the duration makes the difference:

Another scenario is to apply an intense investment pulse, meaning the variable "policy instrument A: increasing profitability" is set to a maximum value of 1 for a certain duration. The results in Figure 6 Figure 6demonstrate that the duration of such a pulse has a strong impact on the dynamics of the model and the resulting ER-rate. While for a 4 year long pulse the increase in ER-rate is not high enough to induce a sustainable social adoption effect with sustaining high ER-rates, a five year long pulse can do so. Like in the paragraph before, the question arises if such sharp tipping point is realistic and even more if one year longer investment would create such difference.

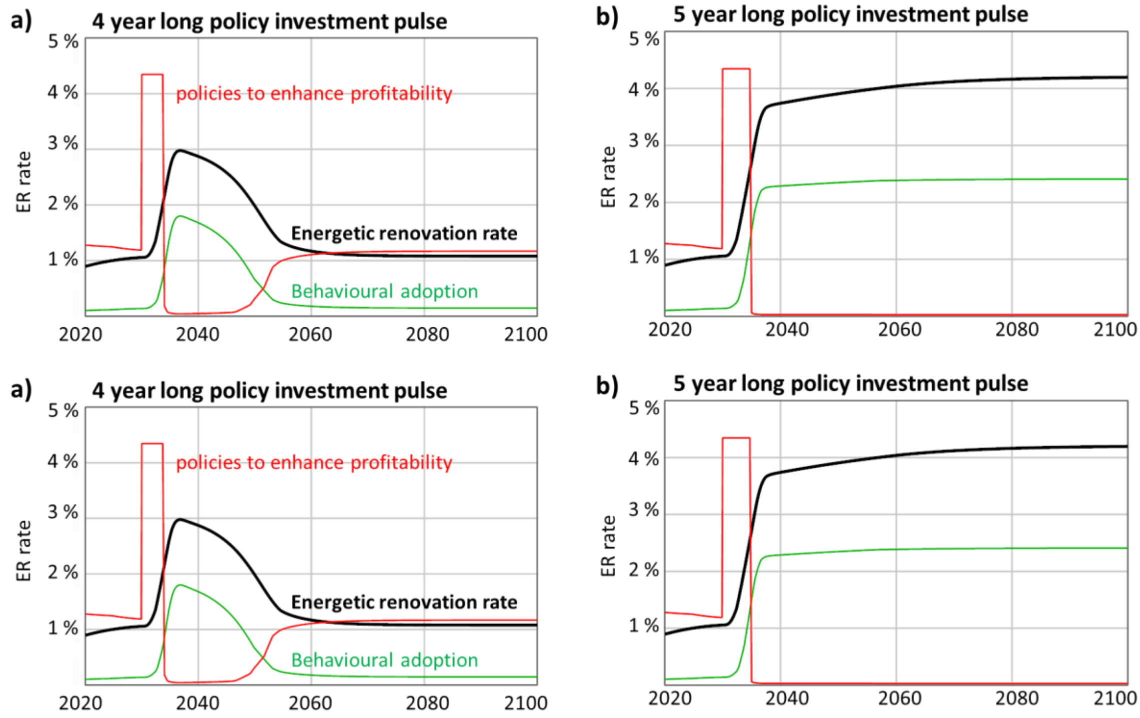

Figure 6: Energetic renovation (ER) rate for a) 4 year and b) five years ongoing maximum policy investment to enhance the profitability of energetic renovation. The red line stands for applied policies to enhance profitability, green line for the behavioural/social adoption effect.

5 Discussion

5.1 Outcomes and connection to the literature

The implementation of policies in different intensities strongly affect the dynamics of the SD model and thus the motivation for ER and the corresponding ER rate. Most important aspect of this model is the interaction of the behavioural adoption and ER expertise feedback loop in relation with the policy driven feedback loops of climate change awareness and profitability increase. We indicate three scenarios for different policies:

a) If moderate policy instruments are applied for longer terms (cf. Figure 3Figure 3a), the behaviour of rigid ER rate lower than the desired 2 % can be obtained, explaining the evolving ER-rate of the past decades in Germany (cf. Figure 1). For this scenario the low ER rate induced by moderate policies cannot induce a strong behavioural adoption effect and ER expertise increase. To put it more simply, low subsidies do not lead to ER being “in vogue” and adopted by the society.

b) For the scenario that policies are implemented more intense (meaning more subsidies and/or persuasion for climate change), oscillating ER rates can be obtained (cf. Figure 5Figure 5a and b). These oscillations are induced by interacting feedback loops, more precisely mainly by behavioural adoption processes induced by intense policies applied and the fact that the ER rate is not high enough to sustain a high behavioural adoption in the society. In other words, the implementation of more intense policies oriented at a fixed ER rate (e.g. of 2 %) can strongly increase the social adoption process to bring ER more popular but when lowering the policies the behavioural adoption alone cannot sustain the ER rate and policies are required again to increase once more the behavioural adoption and so on.

c) For the scenario that ambitious policies are implemented for a certain duration, the ER rate increases tremendously which leads to a strong behavioural adoption process that sustain over long time and does not require any policies (cf.Figure 6 Figure 6). For this dynamics, the duration of the policies are found to be crucial because the rise in ER rate by policies must increase in time to a tipping point that ER becomes such popular that no further policies are required to sustain at high ER rates solely caused by behavioural adoption processes and high expertise in ER.

Comparing the findings to dynamics of other processes, the three scenarios are able to describe realistic behaviour. However, a main question arises if the tipping points identified in the system show such strong influence on motivation for ER in reality. Especially the simple structure of the model and the rough assumptions about the weighting of motivation factors for ER demonstrate that further work is needed to enhance the robustness of the model. One example that the behaviour of the developed model is realistic can be found in the dynamics of installed photovoltaic (PV) power in Germany in the last decades (Statistica 2020). To support the expansion of PV in Germany the Renewable Energy Sources Act guaranteed a high feed-in tariff making installation of PV highly profitable. This led to an exponential growth of installed PV until the year 2012 when the subsidies were strongly cut and the PV installation significantly dropped. However, since 2018 the yearly PV installation increases again because low PV production costs making installation of PV profitable again. This dynamics demonstrates first, the significant impact of high profitability policies to implement new climate change mitigation technologies, second and oscillating behaviour of the yearly PV installation in Germany and third that for times between 2013 and 2017 where PV installation was less profitable business the PV installation remained on 20% of the values of 2012. The latter point seems to demonstrate the behavioural adoption effect because PV becomes popular in the years before and was performed by media and state. Additionally the system of PV installation in Germany demonstrates the significance of profitability for new climate change mitigation technologies to be accepted by the society. Both dynamics can be also found for the developed ER model which can be seen as prove that the basic dynamics are correct. Additionally, the basic structure of the presented SD model might be transferable to other systems, especially concerning climate change mitigation and adaptation issues, where motivation of society might be a key challenge for implementation.

5.2 Limitations of the model

Although the dynamics of the developed SD model result in an identification of several leverage points, attention is needed when interpreting these outcomes.

As mentioned, several assumptions were done in this model. The impact of uncertain variable is discussed in more detail in the sensitivity analysis in the appendix (see section 9.2). The main uncertainty of the SD model is the weighting of the factors that motivate ER in society, represented by different maximum values as well as the shape of the table functions in the feedback loops (cf.Figure 3 Figure 3). Although the trend and the maximum values are based on a literature review, the assumptions needs to be verified in future. Interviews and surveys can help to quantify the weighting which is discussed and compared in literature only in a qualitative way.

Besides that limitations, the following uncertainties needs to be addressed to result in a more robust SD model:

- The approach of one central ER-rate might be too rough, probably it should be divided at least into thermal renovation by insulation and applying green heating technologies.
- The weighting of the motivating factors for ER in the SD model is expected to vary for different stakeholders like single-family home owners, housing cooperatives, homeowners' associations or owners of office and industrial buildings.
- The aim of this aggregated model is to keep it as simple as possible to describe the main societal processes that happens in ER. However, some general variables like “own advantage (indiv. perception)” might be resolved in larger detail like profitability, resale value of the building loop etc.

- To keep the SD model simple in structure some variable were not included which need further estimation of relevance for ER motivation like balancing loops concerning stubbornness and misinformation communication, aesthetic concerns in connection with ER, burden during renovation time, etc. The same applies to the collective efficacy variable: implicitly included in the SD model through other variables, by itself it is difficult to estimate.
- The availability of *qualified* as well as *unqualified* planers and craftsman need to be implemented in the model because they are important how the effectiveness of ER is perceived in the society
- A deeper understanding and definition of the delays present in the SD model, like what is the "mean motivation adjustment time of a society"
- A limitation of the ER rate for buildings which, for some regulatory reasons, are not eligible for ER (for example architectural monuments) is not implemented.
- The impact that ER might become more cost effective in future, especially for high ER dynamics
- Because the SD model was developed as case study focusing ER dynamics in Germany, factors affecting the motivation like age, gender and level of income, education and political ideology or cross-national differences were neglected
- Emotions as further factor influencing the motivation were also neglected because they remain beyond the regulatory manipulation area

6 Conclusion

In this work, we analysed the impact of different motivational factors that influence building owners in Germany to transform their energy intense building to an energy efficient one. Based on a literature research a SD model was developed with the stock of motivation for ER as central variable. We identified three reinforcing and two balancing feedback loops resulting in a non-linear behaviour of the system. The key variables in these feedback loops were:

- Perceived own advantage (individual perception) including profitability of ER
- Available expertise about ER
- Behavioural adoption to others including injunctive and descriptive norms
- Climate change awareness
- Obligatory ER

Although the literature research do only result in qualitative information these factors are weighted, the rigid dynamics of the past ER development in Germany could be reproduced by the SD model and some leverage points could be identified. Our policy analysis demonstrates that policies already applied in Germany in the last decades to increase ER were far too low to achieve the desired high ER rate of 2 % by a societal transformation process. The impact of the policies "A: increasing profitability" (by subsidies and credits), "B: increasing climate change awareness" (by informative instruments) and "obligatory ER" (prescribe that buildings in need of non-energetic renovation have ER through statutory regulations) on the dynamics of ER were elaborated. The SD simulation results demonstrates that at a certain tipping point in policy implementation intensity together with policy duration exist which lead to a tremendous increase in ER rate that the behavioural adoption process in the society becomes dominant. Thus, high ER rates can be achieved without any further policies required because ER becomes such popular in society that the "behavioural adoption to others" loop becomes dominant. Our findings suggest that high investment of policies for a short time period are much more effective to induce a societal driven transformation process than lower investments for a long time. Concerning the basic, simple structure of the presented SD model, it might be transferable to other systems, especially concerning climate change mitigation and adaptation issues, where motivation of society might be a key challenge for implementation. However, further work is needed to enhance the robustness and validity of the modelling results, especially concerning weighting of the different feedback loops and understanding of delays within the system.

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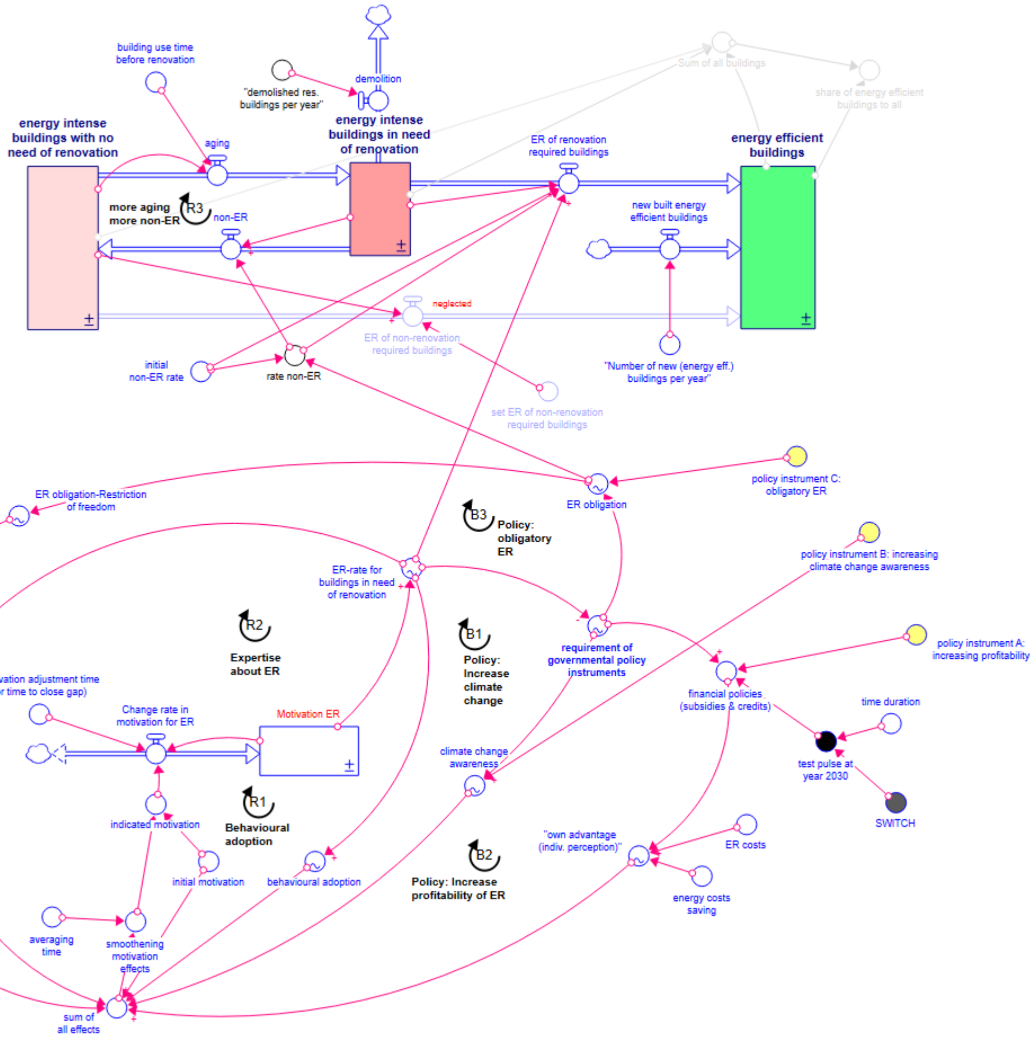
9 Appendix

9.1 Model structure: Stock and flow diagram



9.2 Sensitivity analysis

While the initial values for the buildings stocks as well as for the motivation stocks or the defined flows do not affect the model behaviour, several parameters, especially the numerous table functions show strong impact on the motivation stock and correspondingly ER-rate. This impact does not solely result in different heights of ER-rate but on different SD model behaviour reaching from constant ER-rate to steadily increasing until oscillatory courses. Especially the impact of the central table functions “ER-rate for buildings in need of renovation” and “requirement of governmental policy instruments” is dominant for the whole system because several loops are starting from this variables.

9.2.1 Impact of table functions shape of "ER-rate for buildings in need of renovation" and "requirement of governmental policy instruments"

The shape of the table functions, especially of "ER-rate for buildings in need of renovation" and "requirement of governmental policy instruments", are found to strongly influence the model dynamics as illustrated in Figure 9 and Figure 10. The steeper the table function graph is defined the more oscillations appear in the model. This finding is not unexpected and is a result that small changes in input (x-axis in table function) induce a strong change in output (y-axis of the table function) for steep functions. Together with delaying and smoothing functions in the model this leads to oscillations. However, the question arises what shapes these functions have in real world and thus if oscillations appear in reality or not. This needs to be clarified in detail in future. For the table function "requirement of governmental policy instruments" in Figure 10 a steep function, representing implementing a lot of policies below the desired 2% ER-rate and neglecting policies at ER-rates above 2% is in our opinion not unrealistic. However, the shape must be discussed in future with experts and policy stakeholders regarding ER.

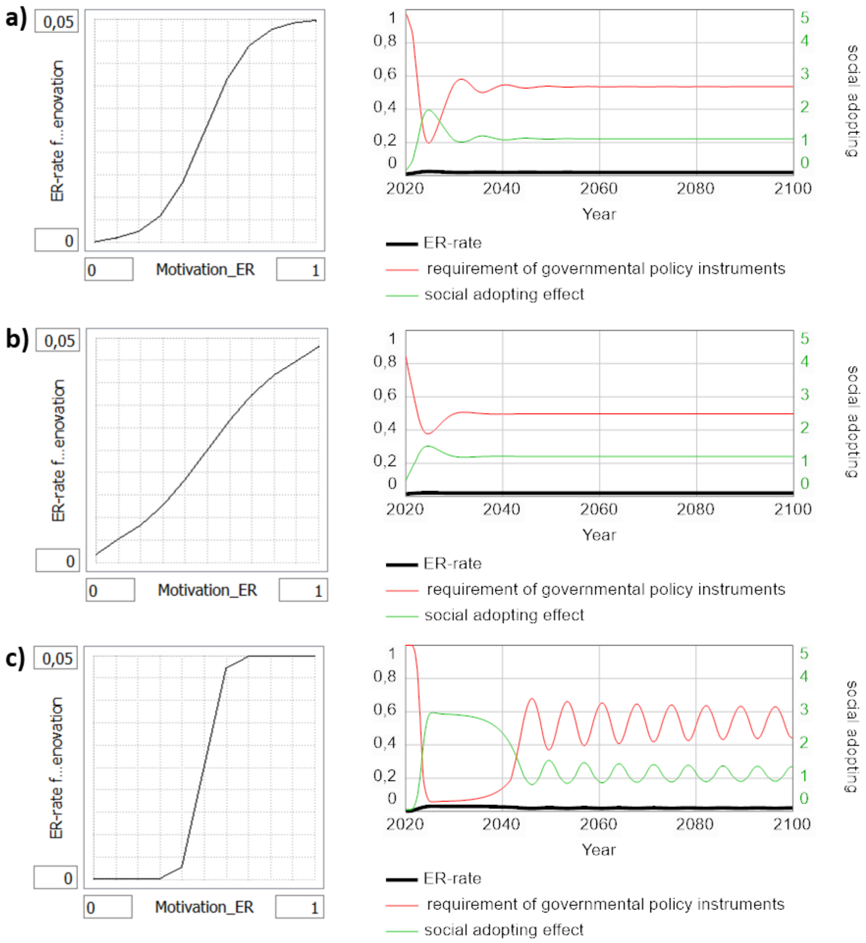


Figure 7: Impact of the shape of the table function graph in "ER-rate for buildings in need of renovation" on ER-rate, requirement of governmental policy instruments and behavioural/social adoption effect for a) the selected standard shape of the SD model, b) a smoother course and c) a steeper course of the graph. The "policy instrument A: increasing profitability" was set to 0.75 and the "policy instrument B: increasing climate change awareness" to 0.40 for these graphs.

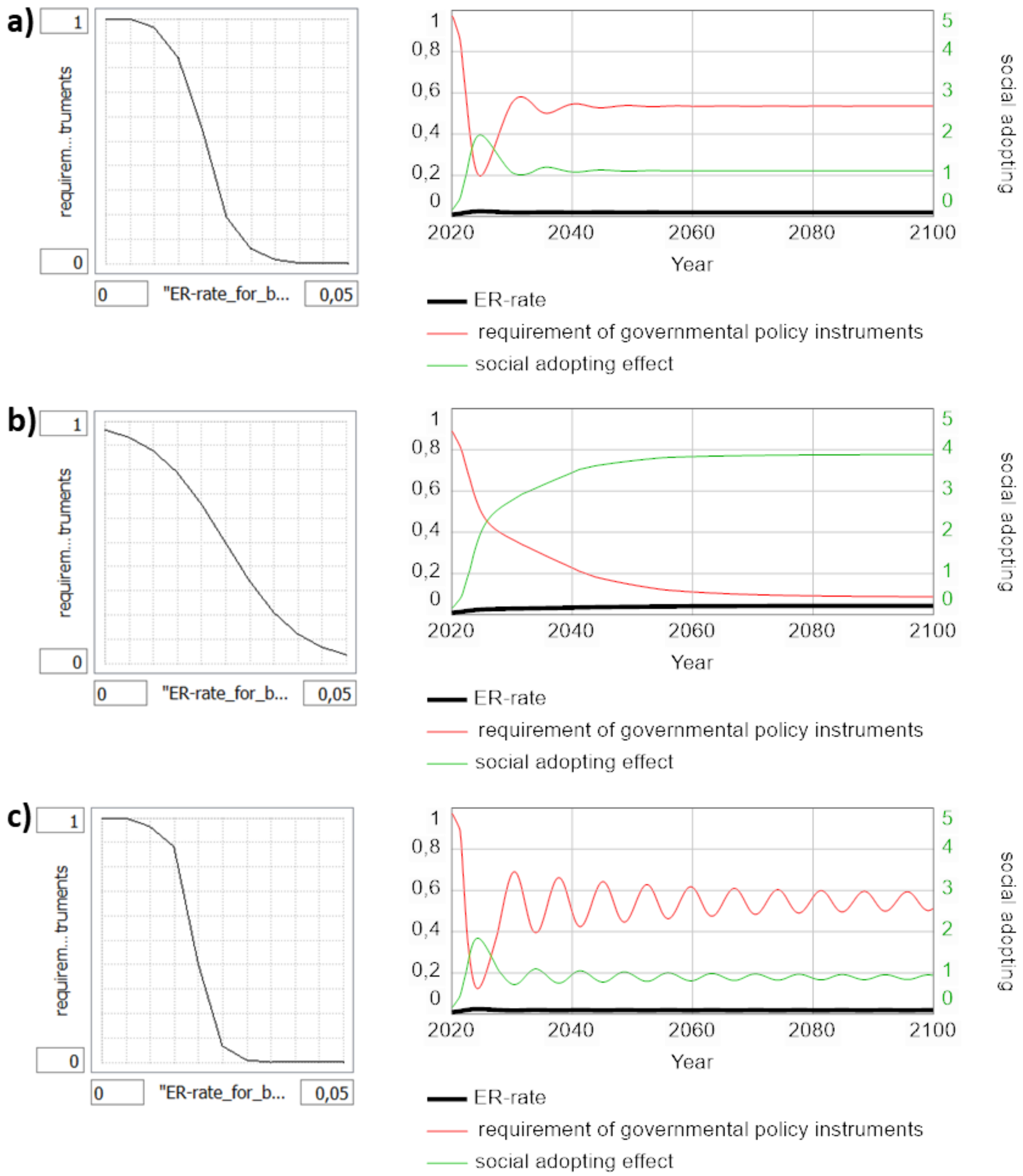


Figure 8: Impact of the shape of the table function graph in "requirement of governmental policy instruments" on ER-rate, output of requirement of governmental policy instruments and behavioural/social adoption effect for a) the selected standard shape of the SD model, b) a smoother course and c) a steeper course of the graph. The "policy instrument A: increasing profitability" was set to 0.75 and the "policy instrument B: increasing climate change awareness" to 0.40 for these graphs.

9.2.2 Impact of "policy instrument A: increasing profitability" / "policy instrument B: increasing climate change awareness"

In 4.3.2 the impact of the two policy types

a) "policy instrument A: increasing profitability" and
b) "policy instrument B: increasing climate change awareness"

on the evolving "ER-rate", "own advantage (indiv. perception)" and "social adoption effect" is illustrated. While values of policy A / policy B of 0.4 / 0.4 lead to a constant ER-rate of 1% (like reference mode) with constant low social adoption and medium profitability, values of 0.75 / 0.4 result in desired

ER-rate of 2% starting with oscillations due to interacting activation of activation of policy A (leading to enhancement in profitability) and the induced behavioural adoption effect. Maximising policy A in the combination of 1 / 0.4 does not lead to a significant increase in ER-rate. However when now enhancing policy B with maximum policy A (1 / 0.6) the ER-rate rises to 3 % because of high policies at the beginning (in year 2020) leading to such a high motivation that the full potential of social adoption effect can be used. However, with time the ER-rate drops to the politically desired 2% because the motivation and thus social adoption decreases with time. For maximising policy A and B (1 / 1) the initial policy enhances the motivation in such a tremendous way (to 60%) that the induced ER-rate and thus the social adoption effect increases to nearly its maximum value of 4. This high behavioural adoption (together with the "expertise about ER" sowing similar behaviour) leads to the result that the ER-rate stabilises itself without any need of policies in future at aver high level above 4%. This general finding is plausible but it should be critical reflected if this behaviour can be expected in real world. Here, our results would suggest that a very (very) high policy to enhance profitability of ER and motivates the society for ER leads to a reinforcing effect that o more policies are needed because the social adoption is such high that the society does ER independent if they are not profitable. In our opinion such a transformation of a society can happen but is not very likely. Therefore further research is needed to tune the model by perhaps more realistic table functions.

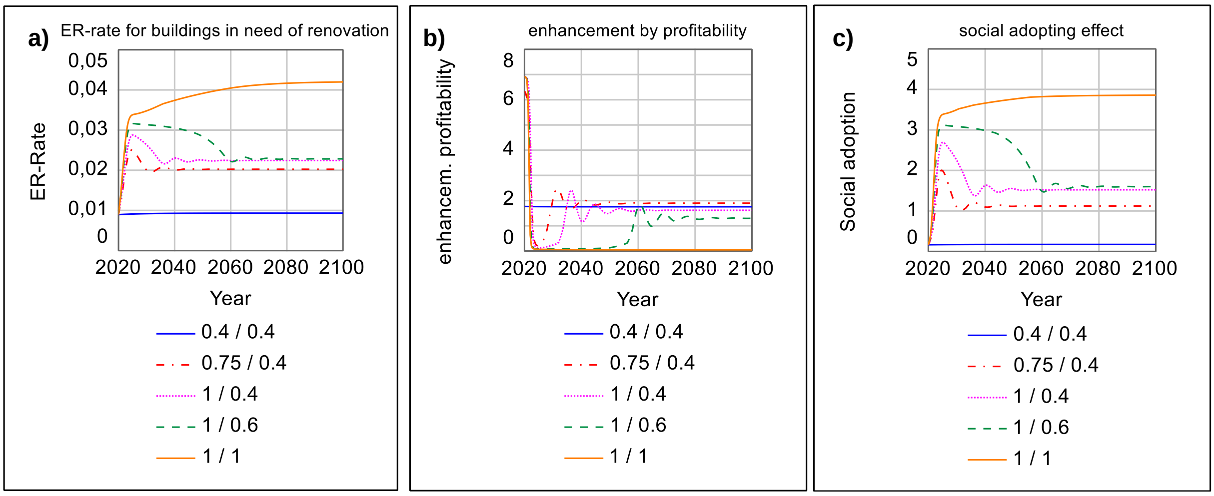


Figure 9: Influence of the applied ratio "policy instrument A: increasing profitability" / "policy instrument B: increasing climate change awareness" on a) ER-rate, b) own advantage (indiv. perception) and c) behavioural/social adoption effect.

9.2.3 Maximum output values and thus weighted influence on motivation of table functions

Another uncertainty in the model is the weighting (meaning maximum values) of the different table functions summarised to affect the motivation (see Table 1 and Figure 3Figure 3). We want to discuss the impact again on the table function "social adoption effect" and "own advantage (indiv. perception)" by varying only the maximum values of the table function an thus the impact on motivation for ER for different policy applied, visualised in Figure 10. Concluding the impact of a different ratio of social adaptation and profitability (e.g. if 7 / 4 or 4 / 7) has a tremendous impact on the evolving ER-rate and in addition this strongly depends on the applied policy intensity at the beginning. With the assumption that profitability can only go to maximum values of 4 while the social adoption effect is stronger in influence (with maximum values of 7) lower policy instruments lead to an enormous increase in ER-rate up to 5% because of the dominant reinforcing loop of social adoption. Comparing with Figure 9 shows that the reinforcing loop of social adoption effect is not such dominant when the maximum values of social adoption is lower than profitability enhancement which is expected to be more realistic. However, the variations show how sensitive the SD model is on the maximum values of the embedded table functions and thus weighting of the impact on motivation for ER. Thus, we strongly need to clarify the impact of the different influences in the real world because in the present state these weighting is assumed by the authors solely.

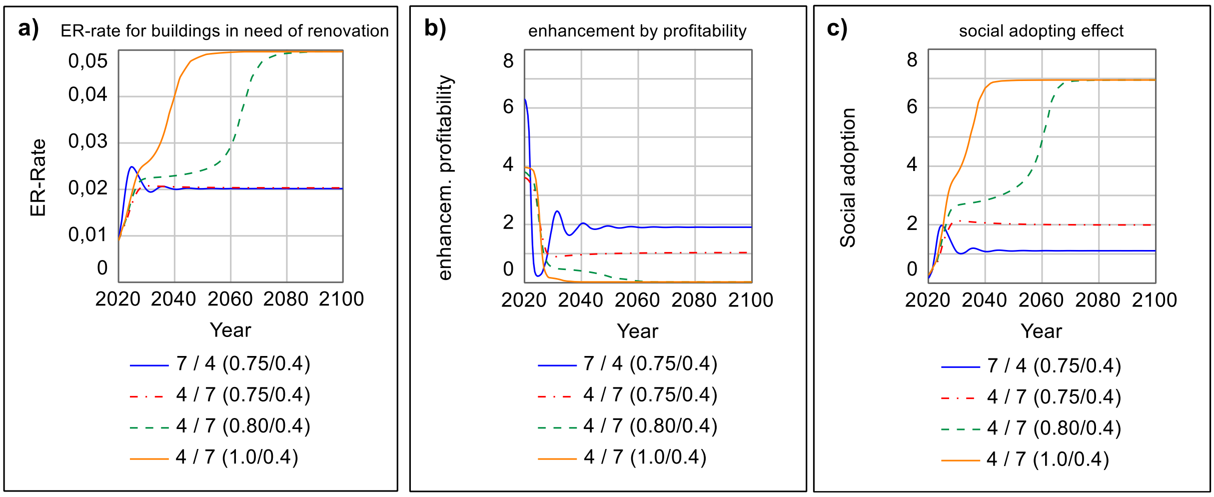


Figure 10: Influence of maximum values of the table functions "own advantage (indiv. perception)" / "behavioural adoption effect" (e.g. 7 / 4) in dependence of the applied ratio "policy instrument A: increasing profitability" / "policy instrument B: increasing climate change awareness" on a) ER-rate, b) own advantage (indiv. perception) and c) behavioural/social adoption effect.

9.2.4 Other variables with low sensitivity on model results

Besides the discussed sensitivity other variables are influencing the dynamic behaviour of the model as well:

a) "Averaging time" and "motivation adjustment time" as influences to change the motivation stock strongly affect the oscillation strength and periodicity which is valid because different delays and smoothening induces different outcomes of interplaying feedback loops. The values used in the SD models are rough assumptions which need to be clarified in future.
b) "Initial motivation" of the motivation for ER stock is set to 34%, meaning the initial motivation is quite low but not negligible explaining the 1% ER rate observed in the past in reality. This parameter is also used for normalisation of the "sum of all effects" variable.
c) The two loops R3 and B3 evolving from obligatory ER lead to cancelling effects when parameter "policy instrument C used: obligatory ER" is activated. The reinforcing loop of non-ER is reduced leading to more ER but on the other side the "ER obligation forced exposure" table function lead to a negative feedback on the motivation stock for ER. Thus the sensitivity of the SD model of this policy is comparable low.
d) For the table function "expertise about ER" of the reinforcing loop R2 the similar sensitivity on the SD model is present as for the "social adoption effect" table function discussed in section 7.4.2 and 7.4.3 but with lower impact because the maximum value of 2 is lower as for social adoption effect with 4 leading to a lower influence on motivation change.

9.3 Model documentation

	Equation	Properties	Units	Documentation	Annotation
Stocks:					
energy_efficient_buildings(t)	energy_efficient_buildings(t - dt) + (new_built_energy_efficient_buildings + ER_of_renovation_required_buildings + "ER_of_non-renovation_required_buildings") * dt	INIT energy_efficient_buildings = 3000000	Buildings	This stock contains mainly on energy efficient resid. buildings erected after year 2000. (Source: DENA Gebäudereport 2016).	
energy_intense_buildings_in_need_of_renovation(t)	energy_intense_buildings_in_need_of_renovation(t - dt) + (aging - "non-ER" - demolition - ER_of_renovation_required_buildings) * dt	INIT energy_intense_buildings_in_need_of_renovation = 5000000	Buildings	This stock contains mainly on energy intense resid. building erected before 1979 and are mainly in need of a complete renovation. (Source: DENA Gebäudereport 2016).	
energy_intense_buildings_with_no_need_of_renovation(t)	energy_intense_buildings_with_no_need_of_renovation(t - dt) + ("non-ER" - "ER_of_non-renovation_required_buildings" - aging) * dt	INIT energy_intense_buildings_with_no_need_of_renovation = 12000000	Buildings	In this stock mainly consists of resid. buildings erected between 1979-2000 which are relatively energy intense but do not need a complete renovation at 2020. (Source: DENA Gebäudereport 2016).	
Motivation_ER(t)	Motivation_ER(t - dt) + (Change_rate_in_motivation_for_ER) * dt	INIT Motivation_ER = initial_motivation	Dimensionless	Mean motivation in German society for energetic renovation maximum 1, minimum 0	
Flows:					
aging	energy_intense_buildings_with_no_need_of_renovation/building_use_time_before_renovation		Buildings/year	aging of resid. buildings to get renovated per year	UNIFLOW
Change_rate_in_motivation_for_ER	(indicated_motivation-Motivation_ER)/"motivation_adjustment_time_(or_time_to_close_gap)"		Per Year	Change rate in societal motivation affected by influencing factors (indicated motivation) and motivation adjustment time.	

demolition	"demolished_res._buildings_per_year"		Buil-dings/year	demolition rate of energy intense buildings in need of renovation (Source: Dena Gebäudereport 2019)	UNIFLOW
"ER_of_non-reno-vation_re-quired_buildings"	"set_ER_of_non-renovation_required_buildings"*en-ergy_intense_buildings_with_no_need_of_renovation		Buil-dings/year	energetic renovation of non-renovation required resid. buildings (in this step not implemented)	UNIFLOW
ER_of_renova-tion_re-quired_buildings	("ER-rate_for_buildings_in_need_of_renovation"+("ini-tial_non-ER_rate"-"rate_non-ER"))*energy_intense_build-ings_in_need_of_renovation		Buil-dings/year	energetic renovation rate of all renovation required buildings	UNIFLOW
new_built_en-ergy_effi-cient_buildings	"Number_of_new_(energy_eff.)_buildings_per_year"		Buil-dings/year	rate of new built energy efficient resid. buildings	UNIFLOW
"non-ER"	energy_intense_buildings_in_need_of_renova-tion*"rate_non-ER"		Buil-dings/year	non energetic renovation of resid. buildings in need of renovation	UNIFLOW
Parameters/Con-verter:					
"demol-ished_res._build-ings_per_year"	10000		Buil-dings/year	demolition rate of energy intense buildings in need of renovation (Source: Dena Gebäudereport 2019)	
"Num-ber_of_new_(en-ergy_eff.)_build-ings_per_year"	100000		Buil-dings/year	Average number of new (all new buildings are energy eff.) resid. buildings per year (Dena Gebäudereport 2019)	
averaging_time	2		Years	Averaging time that a influence on motivation is be-coming perceptible	
				ASSUMED to be 2 years	

build-ing_use_time_be-fore_renovation	50		Years	mean use time of a resid. building before renovation required	
energy_costs_saving	1		Dimension-less	savings of energy costs caused by energetic renovation (set to 1)	
climate_change_a-wareness	GRAPH(requirement_of_governmental_policy_instru-ments* MAX(policy_instrument_B:_ increasing_cli-mate_change_awareness; test_pulse_at_year_2020)) Points(11): (0,000, 0,000), (0,100, 0,118), (0,200, 0,363956513675), (0,300, 0,632454880433), (0,400, 1,02221883465), (0,500, 1,500), (0,600, 1,97778116535), (0,700, 2,36754511957), (0,800, 2,63604348632), (0,900, 2,855), ...		Dimension-less	Policy to enhance the societal motivation for energetic renovation an contains: - enhancing climate change awareness in society - energy expert quality & quantity support - consulting & informing about energetic renovation maximum motivating policy of 1 means maximum out-put value of 3 no motivating policy of 0 leads to minimum output value of 0	
own advantage (in-div. perception)	GRAPH((ER_costs-"financial_policies_(subsidies_&_cred-its)"-energy_costs_saving)) Points(11): (0,000, 6,95315004353), (0,100, 6,87409653027), (0,200, 6,66801888776), (0,300, 6,16557954585), (0,400, 5,11741005041), (0,500, 3,500), (0,600, 1,88258994959), (0,700, 0,834420454155), (0,800, 0,331981112243), (0,900, 0,125903469735), ...		Dimension-less	Profitability of energetic renovation = Costs for ER - Energy savings - financial policies profitable means value of 0 and maximum output value of 7	

				non-profitability means value of 1 and minimum output value of 0	
ER_costs	2		Dimensionless	Costs for energetic renovation (set to 2)	
ER_obligation	GRAPH(1*requirement_of_governmental_policy_instruments*policy_instrument_C_used:_obligatory_ER) Points(11): (0,000, 0,00669285092428), (0,100, 0,0179862099621), (0,200, 0,0474258731776), (0,300, 0,119202922022), (0,400, 0,26894142137), (0,500, 0,500), (0,600, 0,73105857863), (0,700, 0,880797077978), (0,800, 0,952574126822), (0,900, 0,982013790038), ...		Dimensionless	Degree of obligatory energetic renovation when a building must be renovated (to minimize the non-energetic renovation) as policy instrument (e.g. by laws)	
ER_obligation_forced_exposure	GRAPH(ER_obligation) Points(11): (0,000, -0,00669285092428), (0,100, -0,0179862099621), (0,200, -0,0474258731776), (0,300, -0,119202922022), (0,400, -0,26894142137), (0,500, -0,500), (0,600, -0,73105857863), (0,700, -0,880797077978), (0,800, -0,952574126822), (0,900, -0,982013790038), ...		Dimensionless	Negative effect of pressure by obligatory energetic renovation on the society maximum of 1 (maximum obligation applied) means minimum output value of -1 minimum of 0 (no obligation applied) leads to maximum output value of 0	
"ER-rate_for_buildings_in_need_of_renovation"	GRAPH(Motivation_ER) Points(11): (0,000, 0), (0,100, 0,000899310498105), (0,200, 0,00237129365888), (0,300, 0,00596014610111), (0,400, 0,0134470710685), (0,500, 0,025), (0,600, 0,0365529289315), (0,700, 0,0440398538989), (0,800, 0,0476287063411), (0,900, 0,0491006895019), ...		per year	rate of energetic renovation for buildings in need of renovation as a consequence of the motivation level for ER. maximum motivation for ER of 1 leads to a maximum ER-rate of 0.05. Here, we assume that higher ER than 5% per year are unrealistic and thus took this as a maximum value.	

				 no motivation for ER represented with a value of 0 leads to a motivation rate of 0.00.	
expertise_about_ER	GRAPH("ER-rate_for_buildings_in_need_of_renovation") Points(11): (0, 0,0133857018486), (0,005, 0,0359724199242), (0,01, 0,0948517463551), (0,015, 0,238405844044), (0,02, 0,53788284274), (0,025, 1,000), (0,03, 1,46211715726), (0,035, 1,76159415596), (0,04, 1,90514825364), (0,045, 1,96402758008), ...		Dimension-less	Expertise effect represents that with increasing expertise of experts and handcrafts for energetic renovation the ER rate will rise maximum expertise effect of 1 (when ER-rate is at least 0.05) means maximum output value of 2 no expertise effect of 0 (when ER-rate is 0) leads to minimum output value of 0	
"financial_policies_(subsidies_&_credits)"	requirement_of_governmental_policy_instruments* MAX(policy_instrument_A:_increasing_profitability; test_pulse_at_year_2030)		Dimension-less	implementation of financial policies (e.g. subsidies and credits) make energetic renovation profitable y-value 1: maximum financial policies y-value 0: no financial policies	
indicated_motivation	initial_motivation*smoothing_motivation_effects		Dimension-less	Indicated societal motivation affected by influencing factors	
initial_motivation	0,34		dimension-less	Initial societal mean motivation for energetic renovation in year 2020 (also used for normalisation)	
	0,005		Per Year	assumed initial rate of non-energetic renovation.	

"initial_non-ER_rate"				 -->More research needed!!!	
"motivation_adjust-ment_time_(or_time_to_close_gap)"	10		Years	Adjustment time for societal mean motivation ASSUMED to be 10 years.	
policy_instru-ment_A:_increas-ing_profitability	0,40		dimension-less	Intensity of policy of subsidies and credits applyind as policy to enhance the profitability of energetic renova-tion (1 maximum, 0 nothing)	
policy_instru-ment_B:_ increas-ing_cli-mate_change_awareness	0,40		Dimension-less	Intensity of policy to enhance the societal motivation of energetic renovation (e.g. advertisment, quaility of energy experts, ...) (1 maximum, 0 nothing)	
policy_instru-ment_C:_obliga-tory_ER	0		Dimension-less	Intensity of policy of obligatory energetic renovation when a building must be renovated (e.g. by laws) (1 maximum, 0 nothing)	
"rate_non-ER"	"initial_non-ER_rate"*(1-ER_obligation)		Per Year	rate of non-energetic renovation of resid. buildings	
require-ment_of_govern-mental_policy_in-struments	GRAPH("ER-rate_for_buildings_in_need_of_renovation") Points(11): (0, 1,000), (0,005, 1,000), (0,01, 0,965), (0,015, 0,820), (0,02, 0,289), (0,025, 0,061), (0,03, 0,000), (0,035, 0,000), (0,04, 0,000), (0,045, 0,000), ...		Dimension-less	necessity of implementing governmental policies to achieve 2% of energetic renovation (ER) rate y-value 1: maximum governmental policies y-value 0: no governmental policies	
"set_ER_of_non-renovation_re-quired_buildings"	0		Per Year	energetic renovation rat of energy intense buildings with no need of renovation (neglected so far)	

smoothing_motivation_effects	SMTH3(sum_of_all_effects; averaging_time)		Dimensionless	Averaging for all influences on motivation becoming perceptible	
social_adopting_effect	GRAPH("ER-rate_for_buildings_in_need_of_renovation") Points(11): (0, 0,0267714036971), (0,005, 0,0719448398484), (0,01, 0,18970349271), (0,015, 0,476811688088), (0,02, 1,07576568548), (0,025, 2,000), (0,03, 2,92423431452), (0,035, 3,52318831191), (0,04, 3,81029650729), (0,045, 3,92805516015), ...		Dimensionless	Social adoption effect means the effect of other people energetically renovating their building and the copying effect in neighborhoods and society	
social_adopting_effect sum_of_all_effects	GRAPH("ER-rate_for_buildings_in_need_of_renovation") Points(11): (0, 0,0267714036971), (0,005, 0,0719448398484), (0,01, 0,18970349271), (0,015, 0,476811688088), (0,02, 1,07576568548), (0,025, 2,000), (0,03, 2,92423431452), (0,035, 3,52318831191), (0,04, 3,81029650729), (0,045, 3,92805516015), ... (social_adopting_effect+climate_change_awareness+own advantage (indiv. perception)+ER_obligation_forced_exposure+expertise_about_ER)*initial_motivation		Dimensionless Dimensionless	maximum social adoption of 1 (when ER-rate is at least 0.05) means maximum output value of 4 no social adoption of 0 (when ER-rate is 0) leads to minimum output value of 0 sum of all the effects influencing the motivation for energetic renovation (sum because the influences are (more or less) independent on each other)	
SWITCH	0		Dimensionless	Switch for test pulse of motivating and financial policies in the year 2030	
sum_of_all_effects	(social_adopting_effect+climate_change_awareness+own advantage (indiv. perception)+ER_obligation_forced_exposure+expertise_about_ER)*initial_motivation		Dimensionless	(1...on, 0...off)	
test_pulse_at_year_2020 time_duration	SWITCH*(STEP(1; 2030) -STEP(1; 2030+time_duration)) 2		Dimensionless Years	Test pulse of motivating and financial policies in the year 2030 at a certain time duration	

test_pulse_at_year _2020 time_duration	SWITCH*(STEP(1; 2030) -STEP(1; 2030+time_duration)) 2		Dimension-less Years	Time duration in years fo the test pulse of motivating and financial policies in the year 2030	

Total	Count
Variables	42
Stocks	4
Flows	7
Converters	36
Constants	19
Equations	24
Graphicals	8
Macro Variables	10

9.4 Simulation runs

Run Specs	
Start Time	2020
Stop Time	2100
DT	1/10
Fractional DT	True
Save Interval	0,25
Sim Duration	1,5
Time Units	Year
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000

<u>Equilibrium and baseline scenario (Reference Mode):</u>

- value of 0.4 for “policy instrument A: increasing profitability” to enhance the profitability of ER and a
- value of 0.4 for “policy instrument B: increasing climate change awareness”
- value of 0 for “policy instrument C used: obligatory ER”