The Transition of the Residential Heat Market in Germany - A System Dynamics Approach

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Abstract

This paper presents a System Dynamics model for the study of the residential heat market in Germany with regard to the European and national energy targets for the year 2020. It describes the model properties and specifies the stock-and-flow structures of the demand side based on housing units and of the supply side which is formed by heating systems. An initial model validation indicates the appropriateness of the model assumptions. Five policy scenarios are introduced which take into account different measures for the promotion of renewable and innovative heat generation technologies and obligations for energy-efficient renovation of buildings. The discussion of the scenarios shows that with the given set of policies, the EU targets for heat demand reduction and CO_2 *emission mitigation in the residential sector would not be met, while the envisaged share of renewable and innovative technologies seems to be achievable.*

Keywords

Energy policy analysis, residential heat market, System Dynamics

1 Introduction

In September 2010, the German Federal Government adopted the "Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply" (BMWi, 2010) defining the future German energy system until the year 2050. This concept addresses nine fields of action, among those the fortified use of renewable energy sources, energy upgrading of existing and high energy efficiency standards of new buildings and enhanced research towards innovative and new technologies. Nuclear power had been regarded as a bridging technology within the concept. After the Fukushima incident, the nuclear phase-out was decided upon and the "Energy Concept" was supplemented by a document announcing the "transformation of the energy system" (known in German as the 'Energiewende', BMU, 2011). This program is supposed to speed up the process started by the "Energy Concept" in order to compensate the nuclear phase-out. Besides the announcement of a rapid expansion of the use of renewable energy for both electricity and heat generation, a more effective deployment of the funds for cogeneration and a tightening of efficiency standards and more funding for energy-related modernization of buildings are proclaimed. The milestones for the transition in households are the reduction of greenhouse gas emission of 40 % in the year 2020 compared to the year 1990, the decrease of primary energy consumption of 20 % compared to 2008, a share of 18 % renewable energies on the total final energy consumption in the year 2020 and the doubling of the rate of energy-efficient renovation from 1 % in 2008 to 2 % in the year 2020. With these targets, the German energy policy is in line with or even exceeds the European Union's climate and energy targets of 20 % CO_2 emission reduction, 20 % energy efficiency increase and 20 % share for renewable energies (EC, 2010).

In order to provide an economic and regulatory framework for Germany's "Energiewende", environmental policy instruments for renewable energies (EEG, 2000, EEWärmeG 2009 and MAP 2000) and cogeneration (KWKG, 2002) have been set up or amended. The increase of energy-efficient renovations is supported by low-interest loans (KfW, 2012), and energy efficiency standards both for existing buildings and for new constructions have been introduced (EnEV, 2009).

The aim of this paper is to present a System Dynamics model for the study of the residential heat[1] market in Germany with regard to the European and national climate and energy targets for the year 2020. The model allows for the analysis of economic frame conditions and environmental policies related to heat demand, heat production technology mix, heat prices and CO_2 emissions of private household heating systems. The model simulates the effects of the different policy instruments for the promotion of energy efficiency and renewable and cogeneration (combined heat and power, CHP) heat technologies in the heat market for residential

[1] In this paper, the term "residential heat" is used for space heating; hot water supply is not considered.

buildings in Germany. Recommendations for action and decision support can be derived, when considering the impacts of different economic framework conditions such as fuel prices (oil, gas and biomass) or different environmental policy instruments.
In the first part of the paper, a System Dynamics model for the residential heat market will be described. In particular the properties of the model will be discussed and there will be a short description of the model parts. The model will be tested for structure and behavior validity. In the second part, results of the model will be presented showing various policy scenarios and their impacts for achieving the EU and national energy and climate change mitigation targets, which are further broken down into figures for the residential heat market in Germany.

2 Literature review

There are several options for model-based energy systems analysis of heat markets. With respect to a bottom-up modeling approach energy system models can be classified as simulation models or optimization models. Examples for simulation models using the System Dynamics methodology in the energy context can be found in Dyner et al. (1995) and Gaidosch (2008). Weidlich and Veit (2008) and Genoese (2010) present the application of agent-based modeling to energy systems as further simulation model type. Optimization energy system models are described by Ravn (2001) and Fichtner et al. (2004). More examples for energy system models, especially with the focus on Germany, can be found in TUB (2003) and IER (2005).
There are a significant number of examinations of energy systems applying the System Dynamics method. Sterman (1983), Bassi (2006) and Akbarpour and Vaziri (2007) investigate national energy and resources markets from a macroeconomic perspective. Energy policy analysis on national level can be found in Naill and Belanger (1992), Dyner (1996), Bunn et al. (1997) and Musango et al. (2009). Electricity market liberalization and deregulation processes have been the focus of many System Dynamics models. An overview on the fundamental work in this field can be found in Ford (1997). Later studies, especially for the European context, have been presented by Vogstad (2004), Pruyt (2007), Gaidosch (2008) and Ochoa and van Ackere (2009).
Regarding energy efficiency policies in the residential sector, Dyner et al. (1995) used System Dynamics for the study of the energy saving potential from household appliances. Groesser et al. (2006) examined the "diffusion dynamics of energy-efficient innovations in the residential building environment" with focus on the interactions of physical buildings, owners and architects. Besides developers and consumers acting on the market, Li and Dai (2008) also include the government-issued policies for the analysis of an "energy efficient residence market". Müller and Ulli-Beer (2010) study different energy-efficient renovation

strategies and relate them to CO_2 emissions as an indicator for the policy effectiveness. The model presented by Blumberga et al. (2011) aims at evaluating the EU energy efficiency target achievement of the housing stock in Latvia. Yücel and Pruyt (2011) discuss the importance of policies for the existing building stock in the context of energy efficiency targets. In summary, the listed studies for energy efficiency in buildings all focus on policies for the demand side, while policies and technology diffusion on the supply side are not considered or exogenous to the applied models.

3 A System Dynamics model of the residential heat market in Germany

The following table summarizes specific model properties of the heat market model.

Table 1: Summary of the properties of the heat market model

Model PROPERTIES	**Heat market MODEL**
Model type	Dynamic simulation (System Dynamics), myopic
One economic sector model	Residential heating sector
Model approach	Descriptive, bottom-up, supply side oriented
Multi-periodic/ time horizon	In annual steps, 2005 - 2025
Geographic scale	National, Germany
Supply side	Description of technologies on the level of energy carriers and transforming technologies in three size classes
Demand side	Description of buildings by type, heated floor space and energy consumption coefficients
Environment related policy instruments	Buildings: Energy-efficient renovation quota, required energy coefficient new construction / energy-efficient renovation Technologies: renewable / innovation share obligation, renewable energy feed-in tariff, CHP bonus, investment subsidies, fuel tax
Behavior of market actors	Investment decision: distinction of interest rates for two types of owners - home owners and landlords

The model type presented here can be categorized as a dynamic simulation (System Dynamics) with a myopic perspective. This perspective allows for the study of the behavior of imperfect systems over time like energy markets without the assumption of perfect foresight or the need for optimal results. Delays in technology implementation can be taken into account and policy impacts can be analyzed in particular. Figure 1 provides an overview on the main areas of study and their interactions.

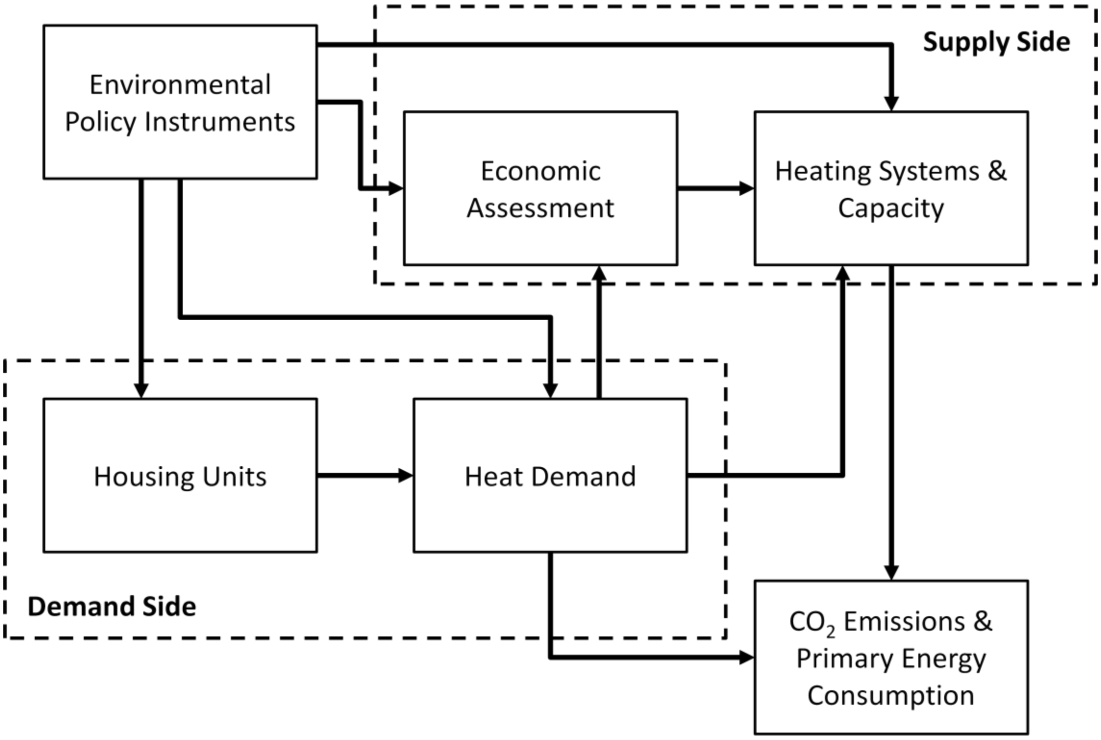

Figure 1: Scheme of the main model interactions

Environmental policy instruments influence the effects and the effectiveness of the evolution of the heat demand side as well as the heat supply side. The long-term development of the residential heat market can be evaluated using scenario analysis with comparison to the EU three time 20 % targets. Table 2 summarizes the most important input and output parameters.

Table 2: Main input und output parameters

INPUT	OUTPUT
Supply side • Number of installed heating systems • Initial average size of heating systems • Lifetime of heating systems • Techno-economic parameters of heating systems • Interest rate by type of ownership • Fuel price development • Environmental policy instruments: renewable / innovation production share obligation, feed-in tariff, CHP bonus, investment subsidy, fuel tax Demand side • Heated floor space • Initial number of housing units • Lifetime of buildings • Initial energy coefficients • Environmental policy instruments: Energy-efficient renovation quota, required energy coefficient new construction / energy-efficient renovation per building type	• Installed capacities for heat and CHP technologies • Heat demand in residential buildings • Energy coefficients • Competitive heat prices per technology size • Primary energy consumption per fuel • CO_2 emissions

3.1 Scope of the model

The model concentrates on the economic sector of residential heat generation and does not consider the heat markets of other economic sectors (like industry or tertiary) or other energy sectors like electricity or resource markets. The model can currently be used for the exclusive analysis of the residential heat sector without analyzing macroeconomic impacts on other sectors. However, there already exist links to the electricity market with the integration of combined heat and power generating technologies. At this stage, a competitive heat price is being derived from the residential heat market model. This output can be potentially fed into an existing electricity market model (Jäger et al., 2009) to study possible impacts of increasing shares of CHP technologies in the residential sector on the electricity market in Germany.

The model shows a time horizon until the year 2025. The target values of energy policies refer to the year 2020. Nevertheless, possible impacts of those policies can be observed beyond this date. The residential heat market model presented here is able to display annual changes of the output parameters over the entire period from 2005 to 2025. Anticipating a future combination of the described heat market model and the electricity market model (Jäger et al., 2009) the time resolution for both models is set to daily values. Thus, it will be possible to integrate intrayear heat demand profiles into the combined model.

The model described here considers the residential heat market in Germany. Building types and their heated floor space as well as the heating systems are aggregated to the national level as well as the decision parameters for new investments. The model also integrates an exogenously defined percentage of district heating in the heat supply mix.

3.2 Heating technologies

The model can be characterized as a bottom-up techno-economic model. The parameters of heating and CHP systems are described for the supply side of the heat market on an aggregated level of technology classes distinguishing energy carriers and/or transformation technologies (Represented technologies are: Solid fuels, oil conventional, oil innovative, gas conventional, gas innovative, gas CHP, pellets, wood logs, electric conventional, electric heat pump, biomass CHP, hybrid 1: combination gas innovative and solar thermal, hybrid 2: combination gas CHP and solar thermal, hybrid 3: combination pellets and solar thermal and hybrid 4: combination heat pump and photovoltaic). Further, the technologies can be divided into three size classes: small, medium and big. Each technology differs in terms of investment, operating costs, CO_2 emissions and its status of technological progress.

3.3 Heat demand from residential buildings

Although the presented model is focusing on the evolution of heating and CHP technologies on the German heat market, the demand side is also modeled with a certain level of detail. It takes into account different types of residential buildings: Single family houses (EFH), semi-detached/terraced houses (RDH), multi-family houses (MFH), big multi-family houses (GMH) and high-rise buildings (HH) (IWU/BEI, 2010). For each type, the heated space is defined according to Destatis (2010). Depending on its energy efficiency level, each class of buildings is assigned to a specific energy coefficient (Blesl et al., 2009), resulting in the demand for space heating from the residential heat market. In order to derive the total heat demand of the residential sector, a fixed amount of heat for hot water supply is added taking the assumption that energy efficiency measures do not affect the individual's behavior concerning hot water consumption.

3.4 Instruments for environmental policies

Environmental policy instruments in Germany have been analyzed and are integrated for both the demand and the supply side. For the demand side, it is possible to study the impacts of different energy-efficient renovation quotas and varying mandatory minimum requirements concerning the specific energy coefficients of new or renovated buildings. Here, energy-efficient renovation quota does not describe an existing policy instrument, but is derived from the targets defined in the "Energy Concept" which includes the increase of the annual energy-efficient renovation quota from 1 % in 2008 to 2 % in 2020. The policy instrument on specific energy coefficients of new or renovated building is based on the Energy Saving Ordinance (EnEV 2009) which defines the technical minimum requirement of new and existing buildings and their components with regard to energy consumption.

On the supply side, two policy instruments are linked to the electricity market regulations: feed-in tariffs are paid for electricity produced in CHP plants which are fed by renewable energy sources (EEG, 2000) and a CHP bonus is paid for electricity generated in small fossil fired CHP systems (KWKG, 2002). Further, the model takes into account investment subsidies for pellets heating technologies and heat pumps (BMU, 2005). In 2009, the renewable energy heat law came into force (EEWärmeG, 2009). House owners installing a new heating system in their building are obliged to either generate a certain percentage of consumed heat with regenerative energies or to install innovative energy-efficient technologies like cogeneration units or heat pumps. This fact is modeled by means of a renewable / innovation share obligation. Renewable or innovative technologies include gas-fired CHP units, pellet boilers, electric heat pumps, biomass-fired CHP units and all hybrid technologies (defined as combinations of before-mentioned technologies). Finally, it is possible to consider increased fuel taxes on certain fossil fuels such as fuel oil. The German tax system currently does not make such a differentiation, but this is still under discussion for future energy policies in the residential sector (BMWi, 2010, 23).

3.5 Investment decisions

In the presented model, investment decisions for new space heating capacities are taken from an individual investor's point of view. This means that a house owner decides on the basis of his limited information on future economic and political conditions. He is only choosing a new heating system when replacement is necessary at the end of the lifetime of existing equipment. In order to distinguish two different types of ownership (and decision making) of a building or housing unit, the heat market model applies a higher interest rate for landlords and a lower interest rate for house owners. The two interest rates illustrate the fact that landlords are more risk-averse in their investment decision compared to house owners. Thus, the behavior of the market actors only depends on economic factors. This means a simplification of the complex decision-making process that underlies investment decisions in the heat market.

4 Model components

The main model interactions as well as the major model properties have been explained in the preceding chapters. In this chapter insight into the structure of the heat market model will be provided by the description of the model components. Table 3 gives an overview on the ten fundamental elements of the residential heat market that are taken into account in the presented model.

Table 3: Main parts of the heat market model

- Housing Units
- Floor Space
- Heat Demand
- Heating Systems
- Heating Capacities
- Resource Efficiency
- Economic Assessment
- Competitive Heat Price
- CO_2 Emissions
- Primary Energy Consumption

The model parts subsume four major aspects of the heat market model: The demand side consists of Housing Units, Floor Space and Heat Demand. Heating Systems, Heating Capacities, Resource Efficiency Thermal and Resource Efficiency Electrical form the supply side. The

Economic Assessment is a module on its own and Competitive Heat Price, CO_2 Emissions and Primary Energy Consumption provide additional results beyond those that can be derived by the calculations on the supply and demand side. In the following, the four main model components will be described.

4.1 Main model interactions

On the demand side, two important feedbacks have been identified. The first loop is describing the transition of the stock of energy-intensive buildings into a stock of energy-efficient buildings (see Figure 2). This process is driven by the aging of the energy-intensive housing stock and the policy instrument "energy-efficient renovation quota". The second loop stands for the reluctance of house owners to carry out energy-efficient renovation measures. Buildings can be renovated without energy-efficiency gains. In this case they enter the stock of energy-intensive buildings after a certain period of time which is represented by a delay. For the supply side, a similar structure can be applied. One causal loop contains the transition of the stock of old fossil-fuelled heating systems into a stock of renewable (RES) or innovative (inno) heating systems. This loop in turn is decelerated by another loop which describes the fact that old heating systems can - depending on the profitability of RES/inno compared to conventional technologies - also be replaced by fossil-fuelled heating systems.

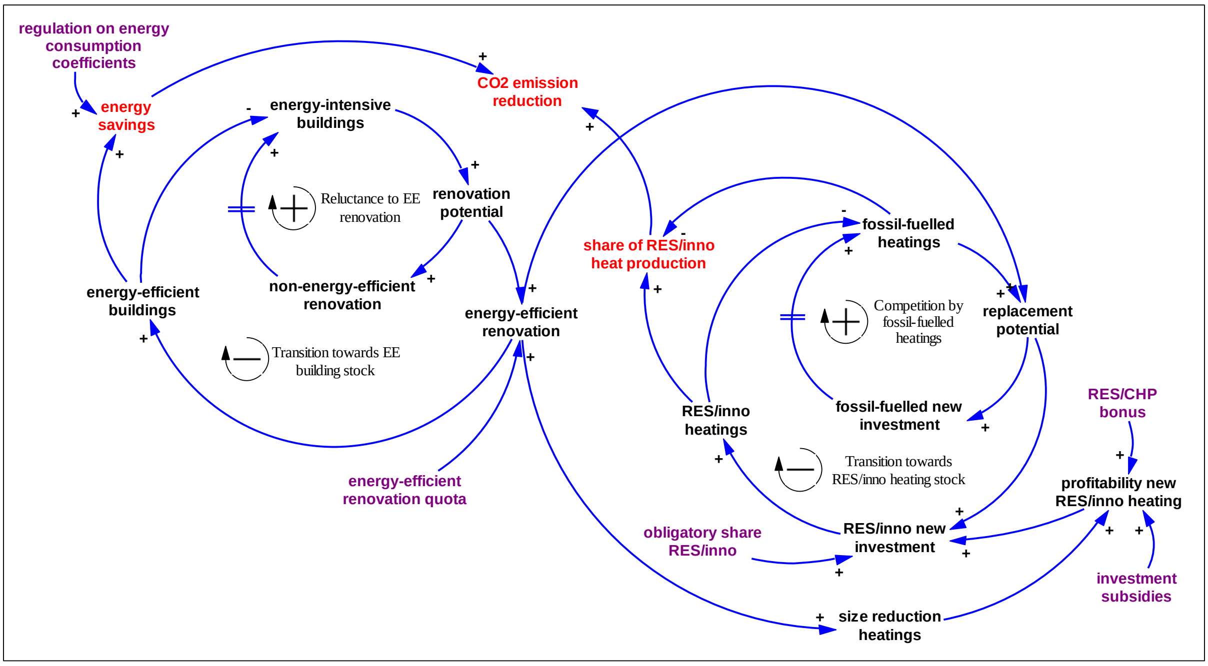

Figure 2: Causal loop diagram of the System Dynamics model

Figure 2 futher illustrates the influence of the demand side on the supply side. Here, energy-efficient renovations increase the potential for replacement of heating systems based on the assumption that during the energy-efficient renovation, the heating system will also be replaced. Due to energy-efficient renovations, the specific size of a new heating system to be installed in a building decreases. In turn, investment costs are lower and profitability increases. This effect is stronger for RES/inno technologies which are characterised by higher investment costs and lower operation costs compared to conventional fossil-fuelled technologies. Finally, the causal loop diagram highlights the influence of the environmental policy instruments on the model structure and the model variables representing the results.

4.2 Demand side structure

For the modeling of the demand side of the German heat market, the first three model components presented in Table 3 have to be combined. One reason for this procedure is the fact that the two policies included for the demand side affect different parts of the demand side: energy-efficient renovation quotas determine flows in the system of housing units, while obligatory energy coefficients for new constructions and renovation can be directly linked to the part of heat demand. Further, energy coefficients are defined specifically relating heat demand to the heated floor space. Hence, the demand side can be implemented by means of a typical ageing chain structure (Forrester, 1969) of the housing units and two co-flow structures (Sterman, 2000, 497pp.) for the heated floor space and for the heat demand in the respective housing units (see Figure 3).

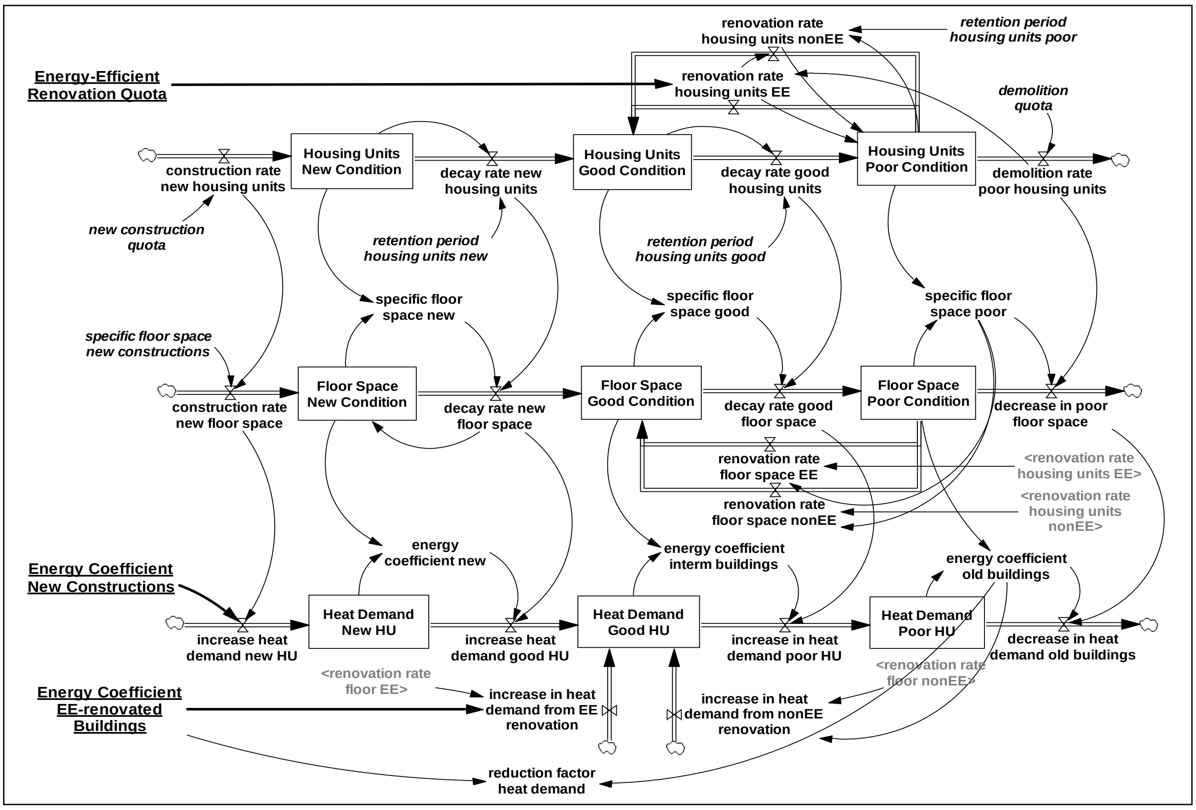

Figure 3: Structure of the demand side in the heat market model

The ageing chain of housing units in the residential sector is driven by three exogenous parameters. A new construction quota determines the number of housing units that are added to the system each year, increasing the stock of housing units in new condition. Depending on the period housing units are typically expected to stay in new and in good condition, respectively, the ageing process is simulated. Housing units that are in poor condition can either be demolished according to the exogenous demolition quota, or they can be renovated with or without energy efficiency measures. The share of non-energy-efficient renovation is derived from the policy driven share of energy-efficient renovation. In parallel, the ageing of the heated floor space can be modeled, using the specific values resulting from the co-flow structure. In order to keep the model as flexible as possible for further policy studies, the exogenous factor of specific floor space of newly constructed housing units is modeled explicitly. This can have a significant impact on the total heat demand. Finally, the co-flow of the residential heat demand is influenced by the given policies of energy coefficients required for new constructed buildings and energy-efficient renovated buildings. From the heat demand and the floor space co-flows, specific energy coefficients are calculated and a reduction factor for the specific heat demand can be derived. This percentage reduction serves as input for the supply side as explained in the following section.

4.3 Supply side structure

The use of ageing structures and co-flows proved to be expedient for the implementation of the demand side of the German residential heat market. For the supply side, a similar approach has been chosen. Based on the ageing chain of the heating systems, co-flows for installed heating capacity, thermal resource efficiency and electrical efficiency for cogeneration are defined. Figure 4 shows the structure of the described model parts.

Drivers of the dynamics of the heating systems are on the one hand the installation of new heating systems and the decommissioning of heating systems, which are directly linked to the construction of new housing units and the demolition of housing units in poor condition. On the other hand, new heating systems replace old heating systems reaching the end of their lifetime. Depending on the economic assessment of the technological possibilities for new installation (cf. Chapter 4.3), on the accessibility of a gas grid and on the obligatory share of renewable or innovative technologies, the technology mix for new heating systems is derived. It is assumed that this mix also reflects the heating systems installed in new constructions. The heating capacity co-flow is calculated from the reduction of the specific heat demand (cf. Figure 3). Based on this reduction the installed capacity of new heating units replacing old ones can be derived. The newly installed heating units are allocated to the group with reduced capacity according to the rate of housing units with energy-efficient renovation.

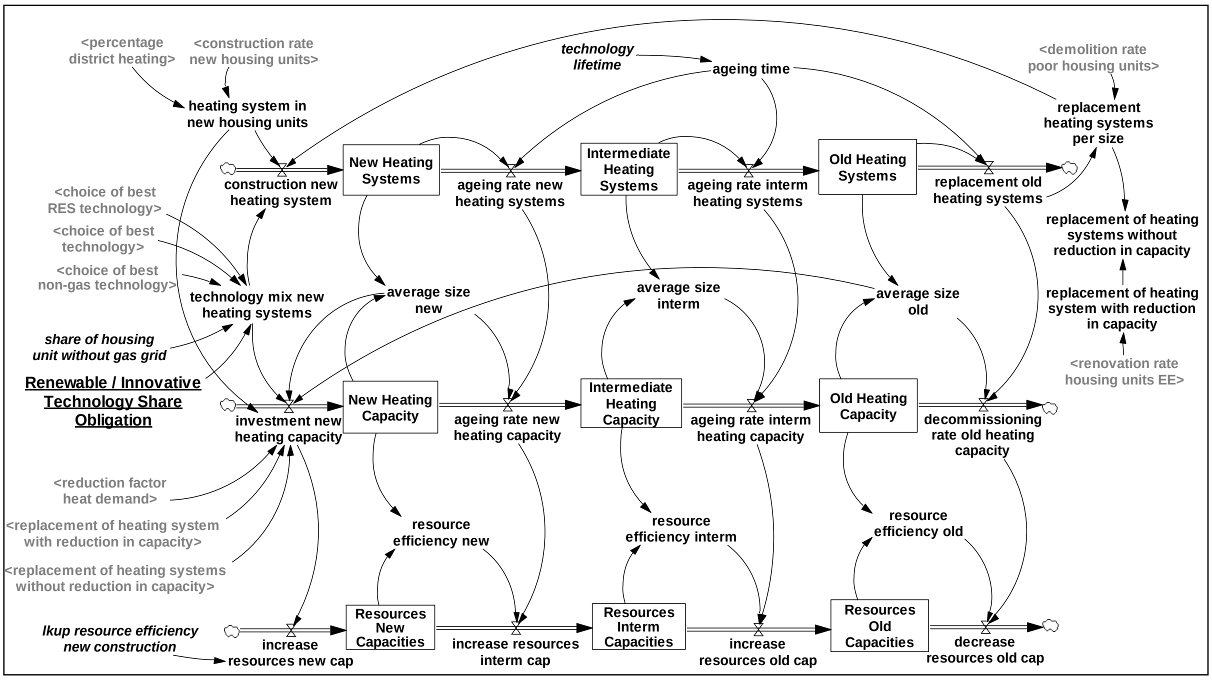

Figure 4: Structure of the supply side in the heat market model

The remaining heating units stay constant in their installed capacity. Finally, technological progress is influencing the development of the resource efficiencies of the heating and CHP technologies in the model. By means of an exogenous function, the heating system's resource efficiencies are increasing over time. This causes the dynamics of the resource requirements co-flow resulting in a lower specific consumption of primary energy sources.

4.4 Economic Assessment

In the previous chapters, the dynamics of the demand and the supply side of the heat market model for Germany have been described. It has already been mentioned that the technological possibilities for new heating systems depend on an economic assessment. Moreover, four of the environmental policy instruments that will be studied in this paper - investment subsidy, feed-in tariffs for renewable energies, CHP bonus and fuel tax - have an impact through decreasing costs of the technologies they are designed for.

Each time a heating system has to be replaced because of age or as a measure of energy-efficient renovation, the investor has to decide which new technology should be installed. In the presented model it is assumed that investment decision is based on an economic approach. The annuity A of each technology m can be calculated according to the following equation:

Equation 1: Annuity

$$A_m = -I_m * \frac{(1+i)^n * i}{(1+i)^n - 1} + CF_n,$$

where I_m is the specific investment costs for a new heating capacity including investment subsidies, CF_n is the annual net cash flow, i is the interest rate and n is the lifetime of the heating system. CF_n can further be described by:

Equation 2: Annual net cash flow

$$CF_n = C_{fix,m} + (C_{var,m} + C_{fuel,m} - R_{EEG,m} - R_{CHP,m}) * FLH_m,$$

where C_{fix} are fixed costs of operation and maintenance, C_{var} are variable costs of operation and maintenance, R_{EEG} are revenues resulting from feed-in of electricity from biomass CHP technologies, R_{CHP} are revenues from sales of electricity according to the CHP law and FLH are the typical annual full load hours of operation of each size class. In the model, it is assumed that technologies of the small size class are run in one family and semi-detached/terraced houses, technologies of the medium size are run in multi-family houses and technologies of the big size are run in big multi-family houses and high-rise buildings. After the calculation of the technology-specific annuities, it is possible to create a merit order of heating technologies by increasing annuities. That means that an investor will choose the technology with the lowest (negative) annuity in order to minimize the total heating costs. Since the model also takes into account a share of housing units that is not connected to a gas grid and the obligatory share of renewable or innovative technologies, three different merit orders are constructed: one including all technologies, one including all technologies except gas-fired ones and one including only renewable or innovative technologies (cf. Chapter 3.2). The first technology of each merit order finally serves as input for the investment into new heating capacity on the supply side.

4.5 Additional results

Beyond the model outputs concerning heat demand, energy coefficients and installed heating capacity that can be derived from the model parts of demand and supply, three values are of special interest for the residential heat market in Germany: competitive heat price, CO_2 emissions and primary energy consumption. The competitive heat price is defined by the heat production costs of the most competitive heat technology (cp. Woldt et al., 2007) and can be used for the economic assessment of CHP technologies on the electricity market. With the perspective of the combination of the herein described heat market model and an electricity market model, the competitive heat prices for each technology size are explicitly calculated. With regard to the energy targets to be studied by means of the presented model, the development of the CO_2 emissions are calculated as a further model output. The simulation of the heat demand development for space heating has already been explained in section 4.1. The total heat demand is derived by adding a fixed percentage of heat demand for hot water. In order to calculate the technology specific heat production, a percentage technology mix is derived from the ratio of the installed capacity of each technology related to the total installed capacity. The resulting values are multiplied by the total heat demand - heat from district heating is supposed to remain constant and is excluded from this calculation - and the technology-specific CO_2 emission coefficients, resulting in the total CO_2 emissions from the residential heat market. Finally, the primary energy consumption is calculated using the total heat demand and the percentage technology mix as described above, multiplied with the thermal efficiency of each system.

5 Initial model validation

According to Forrester and Senge (1980) and Sterman (2000), the validation process should establish confidence in the appropriateness of a model for a certain purpose. For this process, they propose several tests which can be divided in two main parts: structure testing and behavior testing. In this paper, a structure assessment test and a parameter assessment test as structural tests and a basic behavior reproduction test as behavior test are presented.

5.1 Structure tests

A structure verification test of a System Dynamics model should examine whether the "model structure is consistent with relevant descriptive knowledge of the system" (Sterman, 2000, 859). The main model structures both of the demand side and the supply side are derived from classical ageing chains and co-flow structures which represent the fact that replacement of technologies and renovation of housing units is mainly driven by ageing processes (cp. Vogstad, 2004, 102 and Müller and Ulli-Beer, 2010, 16). Thus, it can be assumed that the model represents the existing knowledge of the system. By initializing the stocks with statistical data, the parameter verification has been realized. The tested parameters and their sources are summarized in Table 4.

Table 4: Parameter verification of the heat market model

Parameter	Source
Initial housing units by building type and vintage	IWU 2007 (2005 data)
Initial floor space per building type and vintage	IWU 2007 (2005 data)
Initial energy coefficients per building type and vintage	Blesl et al., 2009, p. 33 (2004 data)
Initial heating systems per technology, size and vintage	ZIV, 2010 (2010 data)
Initial average installed capacity per technology and size	ZIV, 2010 (2010 data)

The source for heating systems refers to the situation in the year 2010. Since the model simulation starts in the year 2005, the data had to be adapted taking into account the average lifetime of one system and the average age of all systems of each technology.

5.2 Behavior tests

In order to test a model for its appropriate behavior, statistical measures of correspondence between model simulation results and observed data can be applied (Sterman, 2000, 860). This procedure requires adequate availability of historical data. In the case of the residential heat market for Germany, it turned out to be difficult to find exhaustive historical data for most of the model variables. The Federal Ministry of Economics and Technology regularly publishes data on space heating demand in Germany per economic sector (BMWi, 2011). In a first step, the simulation results are plotted against the historical data for the years 2005 to 2010 as a visual comparison (Figure 5).

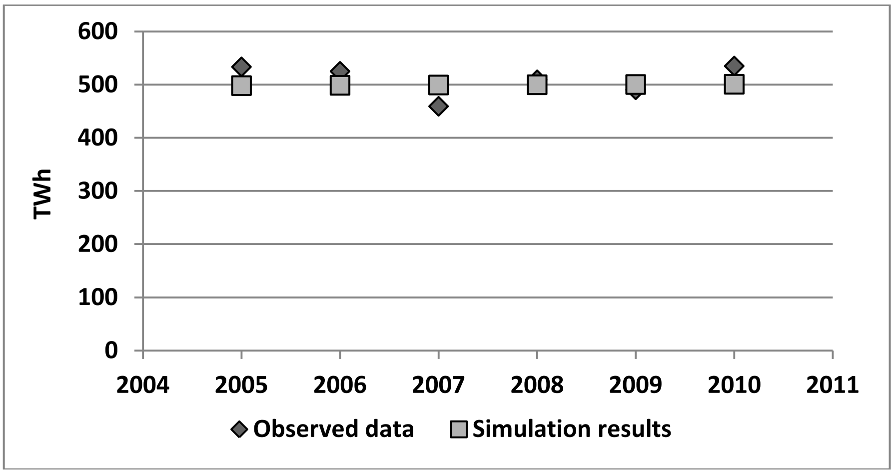

Figure 5: Comparison of observed and simulated values for space heating demand from private households in Germany in the years 2005 to 2010

The simulation results and the historical data have further been used to calculate statistical measures (Andres and Spiwoks, 2000) presented in Table 5.

Table 5: Statistical measures of space heating demand in Germany as behavior reproduction test

Statistical measure	Value
Mean Absolute Error	34.27 TWh
Mean Percentage Error	2.86 %
Mean Absolute Percentage Error	6.87 %
Mean Square Error	1801.86 $(TWh)^2$
Root Mean Square Error	42.44 TWh
Percentage Root Mean Square Error	1.65 %

These tests give a first estimation of the model's appropriateness to reproduce developments on the demand side of the heat market in Germany. In a next step, they will be extended to the supply side.

6 Scenario definition and analyses

The main output parameters of the simulation model for the heat market are “Heat Demand”, “Share of Renewable and Innovative Heat Production” as well as “CO_2 Emissions”. The residential energy demand for space heating and hot water in Germany accounted for 533 TWh in 2005 and for 535 TWh in 2010 (BMWi, 2011). According to BEE (2010), the share of renewable heat production amounted to 6.8 % in the German residential heat market in the year 2005 and 11.4 % in the year 2010. The households emitted 111 Mt of CO_2 for heating purposes in 2005 and 112 Mt of CO_2 in 2010 (BMWi, 2011).

As shown in Table 6, estimations for the developments of the input parameters cover the time period from the year 2008 to 2020. The economic frame conditions are reflected in the fuel prices. Fuel prices are driven by global demand. This demand of commodities depends on global economic growth. Thereby it is assumed that the German economy goes along with the development of the world economy and causes respective effects for the fuel price developments in Germany. The same coherence with the growth of the German economy is assumed with the development of the construction of new buildings in the residential sector. Again it is assumed that for e.g. many new buildings will be erected in Germany if the country has large economic growth rates. The selected main policy instruments in Germany promoting the heat supply technologies are “feed-in tariffs for electricity from renewable energies”, “cogeneration bonus” and “investment subsidies for some distributed generation technologies”: For the heat demand of the residential sector the policies "energy-efficient renovation quota”, “energy coefficient for new buildings” and “energy coefficient for energy-efficient renovated buildings” are chosen. All input parameters are given as total development over the considered time frame, except the energy-efficient renovation quota. This is given in the usual formulation per year.

For the evaluation of the policies, the three 20 % goals set by the EU are the benchmark. These European goals need to be allocated to national respective sector-specific goals. Referring to the leading scenario from DLR for the German government (DLR, 2009), a target for the share of renewable energies with regard to final energy demand of 18 % for the year 2020 is determined. The government decided based on the same study for energy efficiency in the year 2020 a 20 % reduction of primary energy compared to 2008 and also a 20 % cut referring to 2008 until the year 2020 for the heat demand of buildings. Germany faces EU requirements with a 20 % goal and has set a more ambitious own target of 40 % reduction of

CO_2 emissions compared to 1990. Buildings should contribute with a share of the reduction of CO_2 emissions of 46 %. Regarding the time period from 2008 to 2020, CO_2 emission savings from the residential sector should account for 34.5 % (BMWi, 2011).

Five scenarios are distinguished. A "Reference" scenario is characterized by an extrapolation of the current trend of the parameters, an "Ecology" scenario emphasizes an environment driven policy on the supply and demand side of the economy. The Scenario 3 ("Demand") and the Scenario 4 ("Technology") should represent effects on the heat market of exclusive policies for the demand side or the heat supply technologies. Scenario 5 describes a "Growth" scenario and analyses the effects of high economic growth and high fuel prices in addition to strong environment orientated policies for the heat sector.

The "Reference" scenario (Scenario 1) expresses a development based on the continuation of the current trend of the values. It assumes a moderate economic growth, which means an average growth of the fuel prices as well. The decline of the values for feed-in tariffs and cogeneration bonus follow the trend until the year 2015 as indicated by the law and beyond. Investment subsidies remain on the current level. Regarding energy-efficient renovation quotas, in this scenario it is assumed that the government is not able to attract owners of all types of buildings in the residential sector to invest in energy-efficient renovation beyond the current level. Energy coefficients for new and renovated buildings decline as it is foreseen in the respective laws and continue with the same trend until the year 2020. The second scenario (Scenario 2) can be characterized as an "Ecology" scenario, where the environmental policy will be more successfully implemented. Although the economy can only achieve a moderate growth, the government decides to follow a "green" development path. Due to high demand of subsidized distributed generation technologies and renewable energies, pellet and wood log prices as well as electricity prices rise stronger than in the "Reference" scenario. With respect to the moderate growth situation the quota for energy-efficient renovation are raised only for single family buildings to avoid further burdens for investors and safe the growth path.

The third (Scenario 3: "Demand") and fourth scenarios (Scenario 4: "Technology") highlight the supply or demand side of the heat market. The "Demand" scenario focuses exclusively on the bundle of energy efficiency measures lowering heat demand to demonstrate the effect of this bunch with regard to the EU goals. Scenario 3 assumes a low economic growth and only measures on the demand side are implemented. The "Technology" scenario (Scenario 4) deals exclusively with heat supply technology emphasizing policy instruments and is faced with the same weak economic situation. Therefore no measures on the demand side beyond the currently existing will be implemented, but the few financial means are put into the promotion of decentralized technologies and technologies based on renewable energies. Finally

Scenario 5 ("Growth") contains a development path, where strong economic growth has the main focus and due to this success financial policies for heat demand and supply are affordable and can be seen as a further stimulus for investments. Although high price increases for fossil fuels can be regarded as an economic burden, price increases of pellets, wood logs and electricity should reflect strong investment activities in renewable energies for heat and electricity. In addition due to the well endowed financial situation policies for the promotion of energy efficiency on the demand side of the heat market are implemented.

Table 6: Economic and environmental policy based scenarios in the period 2008 to 2020

Item/ Scenario	Unit	Scenario 1 Reference	Scenario 2 Ecology	Scenario 3 Demand	Scenario 4 Techno logy	Scena-rio5 Growth
Economic growth		moderate	moderate	low	low	high
New Building quota per year 2008 – 2020	%	1	1	0.5	0.5	1.5
Price development (change for the whole period) Natural gas Light fuel oil Wood chips Pellets Electricity **2008 – 2020**	%	+30 +70 +100 +50 +30	+30 +70 +150 +70 +50	+30 +50 +70 +30 +/-5	+40 +60 +100 +50 +/-5	+60 +150 +150 +70 +50
Feed-in tariffs for renewable energies (change for the whole period) 2008 – 2020	%	+/-5	+30	-30	+30	+30
Cogeneration bonus (change for the whole period) 2008 - 2020	%	+/-5	+30	-30	+30	+/-5
Investment subsidies for heat pumps and pellets heating (change for the whole period) 2008 - 2020	%	+/-5	+30	+/-5	+30	+30
Obligatory share of renewable / innovative new heating systems (in 2020)	%	10	30	10	30	50
Energy-efficient renovation quota per year EFH / RDH MFH / GMH / HH **2008 - 2020**	%	1 1	2 1	2 2	1 1	2 2
Required Energy Coefficient for new buildings 2008 - 2020	%	-20	-80	-60	-40	-80
Required energy coefficient for energy-efficient renovated buildings 2008 - 2020	%	-20	-80	-80	-40	-60

7 Results

The scenario results from the model calculations for the residential heat market of Germany are presented for the parameters “Heat Demand”, "Share of Renewable and Innovative Heat Production” and “CO_2 Emissions”. According to the research questions the simulations have been run for a time frame between the years 2005 and 2025. The scenario analyses refer to the time period between the years 2008 and 2020 which corresponds to the horizon of the environmental policies.

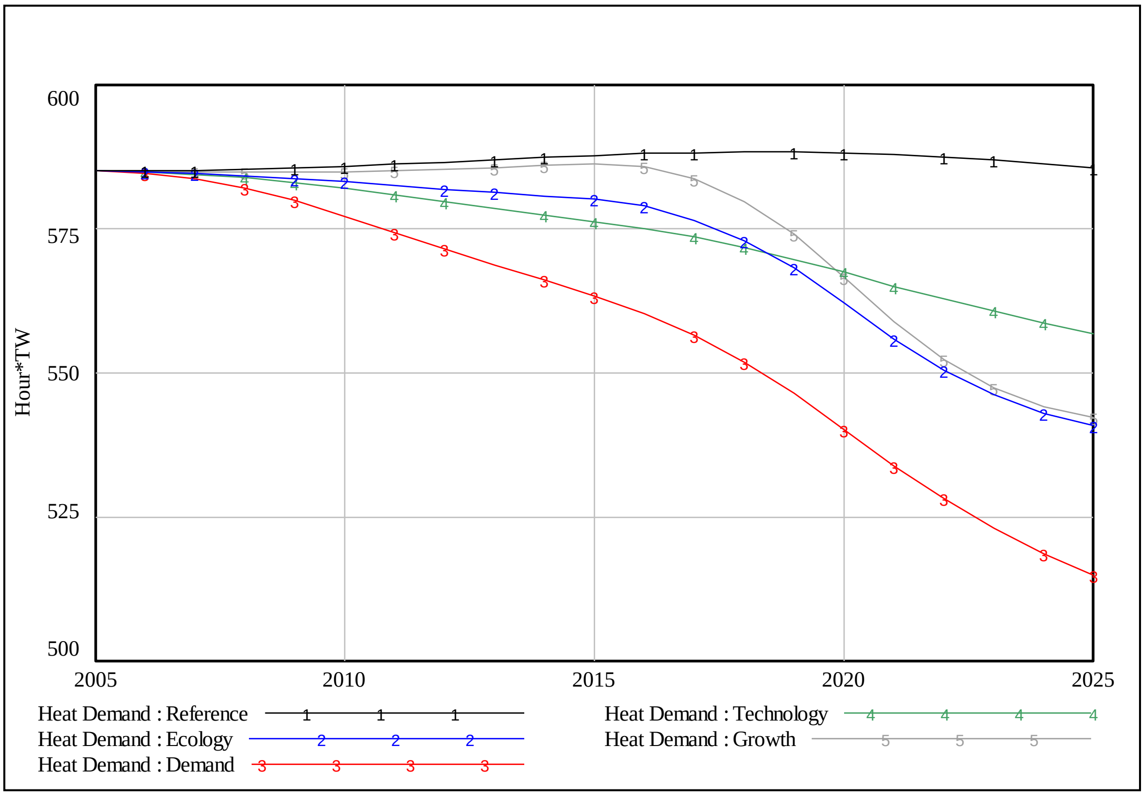

Figure 6: Development of heat demand of the residential sector in Germany

Considering the heat demand of the residential sector of Germany in the period 2008 until 2020, the development of the "Reference" scenario (Scenario 1) remains nearly stable, with an increase of 0.5 %. A decline of heat demand of 2.8 % between the years 2008 and 2020 can be found in the "Technology" scenario (Scenario 4), where stronger promotion of innovative heat supply technologies and those based on renewable energies are implemented alongside moderate policies on the demand side. Stronger decrease in the development of the heat demand in the period of 2008 to 2020 can be seen in the "Growth" (3.1 %, Scenario 5) and the "Ecology" (3.8 %, Scenario 2) scenarios. In both of them, effects of ambitious energy efficiency measures on the demand side are damped by moderate (Scenario 2) or even high (Scenario 5) economic growth. The strongest decrease of 7.2 % in heat demand between 2008 and 2020 can be observed in the "Demand" scenario (Scenario 3), where fortified policies on the demand side are accompanied by low economic growth.

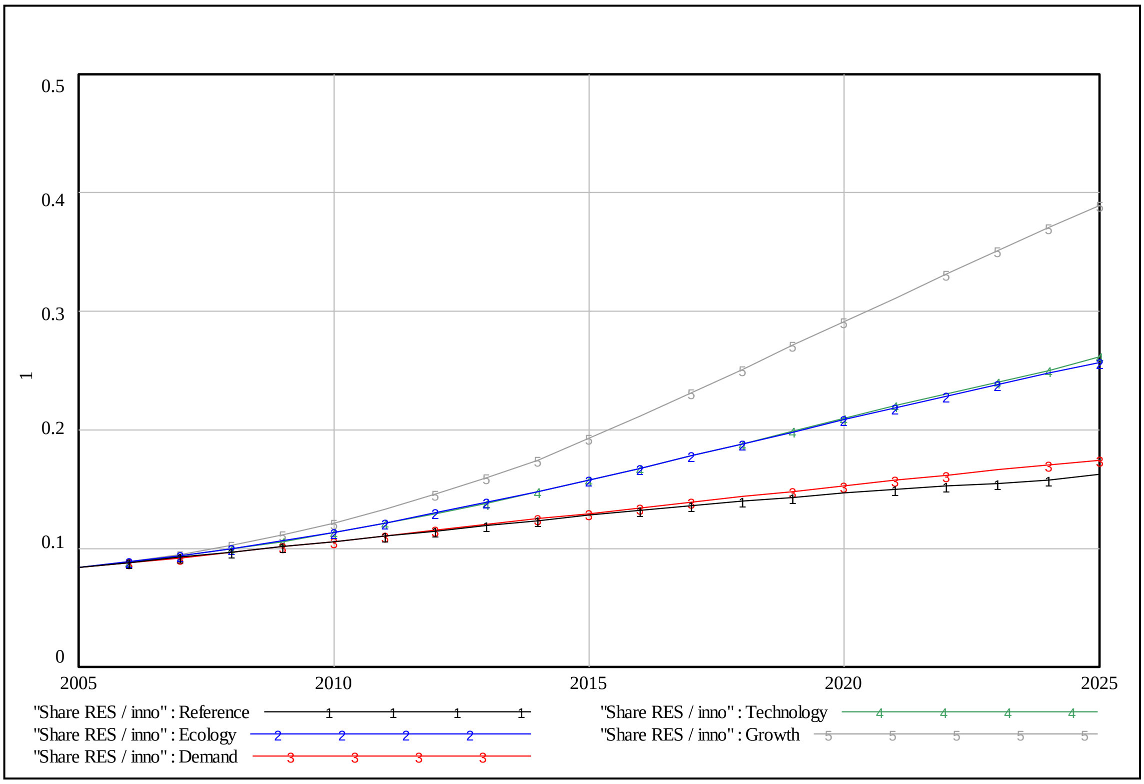

Figure 7: Development of heat production share from renewable or innovative technologies in the residential sector in Germany

The lowest share of heat production from renewable or innovative technologies on the German residential heat market for the year 2020 (14.6 %) can be found in the "Reference" scenario (Scenario 1) with limited incentives for the promotion of renewable and innovative heat production and with moderate growth rates and fuel price rises. A slightly higher value (15.3 %) is achieved in a situation where demand side policies are preferred to technology policies (Scenario 3: "Demand"). In the "Ecology" scenario (Scenario 2) which is characterized by moderate economic growth, moderate fuel prices and enhanced policies on both the demand and the supply side, 20.8 % of the heat production in year 2020 is provided by renewable or innovative technologies. A similar ratio (21.0 %) can be observed in the "Technology" scenario (Scenario 4) where priority is given to policies for the supply side of the heat market. The highest share in comparison to all scenarios is achieved in the "Growth" scenario (Scenario 5) with a share of 29.1 % of renewable or innovative heat production in the year 2020. In this scenario high economic growth, the highest fossil fuel price increases and strong technology policies promote a high share of renewable and innovative heat production.

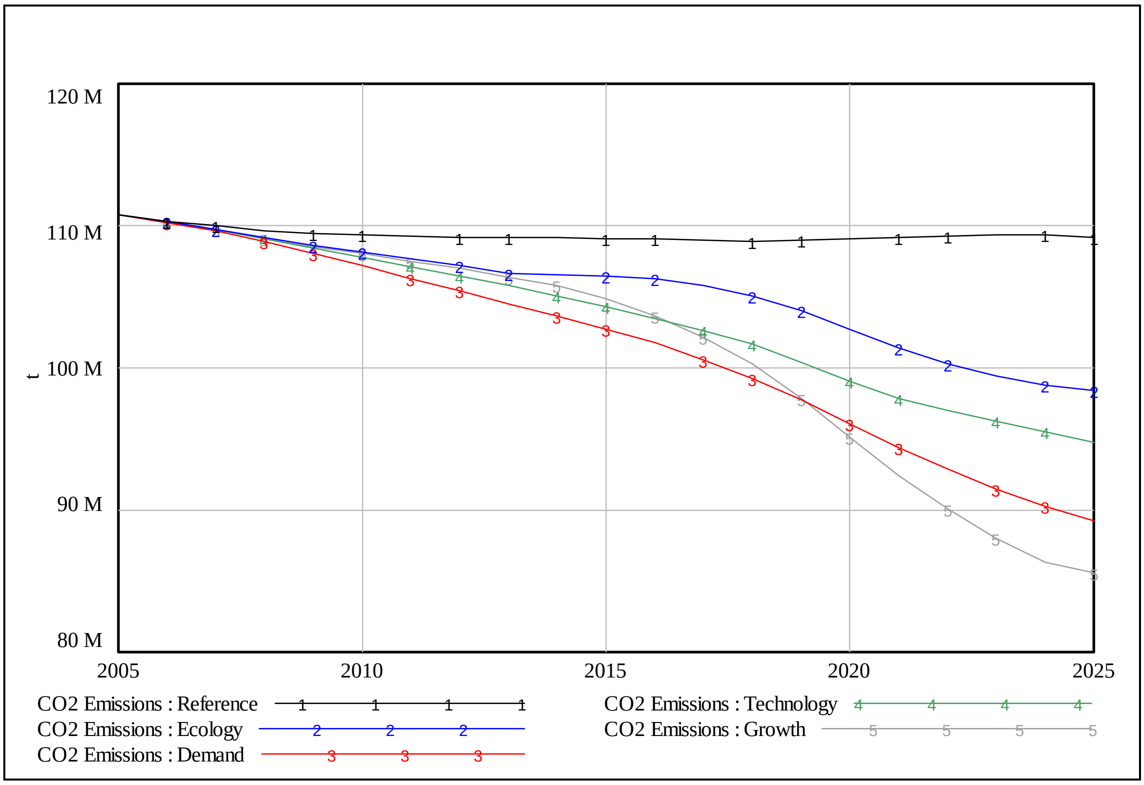

Figure 8: Development of CO_2 emissions of the residential sector in Germany

The lowest reductions of CO_2 emissions from the residential heat market in Germany are achieved in the "Reference" scenario (Scenario 1) with 0.5 % between the years 2008 and 2020. The economic growth rate and the fuel prices are assumed as moderate and policy instruments for the supply and demand side of the heat market have moderate lowering effect on CO_2 emissions as well. 5.9 % of CO_2 emission reduction in the time period between 2008 and 2020 are reached in the "Ecology" scenario (Scenario 2) in a situation with moderate economic growth and fuel price development and the provision of incentives and environmental constraints on both sides of the heat market. A CO_2 emission decrease of 9.1 % in the year 2020 can be obtained in the "Technology" scenario (Scenario 4), where strong financial incentives for renewable and innovative heat production are provided, but energy efficiency gains on the demand side are comparatively low. The scenario emphasizing energy saving activities on the demand side in a situation with low economic growth and fuel price rises (Scenario 3: "Demand") allows for a CO_2 emission reduction of 11.8 % in the year 2020 compared to the year 2008. The highest CO_2 emission reduction can be found in the "Growth" scenario (Scenario 5) with a decline of 12.8 % from the year 2008 to 2020. Although a high economic growth leads to a higher growth rate of new buildings, high fossil fuel prices and strong policies both on the supply and the demand side enable significant CO_2 emission reductions from residential heating.

8 Conclusions and outlook

In this paper, a System Dynamics model of the German residential heat market has been introduced and described by its main parts. Different scenarios for future developments have been defined taking into account economic growth and environmental policy instruments for the supply and the demand side of the market and the obtained results have been presented. Regarding the EU three times 20 % targets for the period from 2008 to 2020, the simulation results can be summarized:

Economic growth has a strong impact on the development of the heat demand. Low economic growth together with strong measures on the demand side of the heat market will result in high gains in energy efficiency. However, none of the considered scenarios will result in the envisaged reduction of residential heat demand by 20 %.

Intensified policies for the promotion of renewable and innovative heat production lead to an overachievement of the foreseen share of 18 % independently from the assumed economic growth and the considered fuel price developments.

High economic growth could allow for strong environmental policy measures both on the supply and the demand side. A high share of renewable and innovative heat production together with medium gains in energy efficiency will result in the highest reductions in CO_2 emissions among the simulated scenarios. Nevertheless, the ambitious goals of 34.5 % of CO_2 emission reduction target from residential buildings would be missed.

Further work will be dedicated to the integration of the investment decision on the demand side and the resulting competition of supply and demand side measures on the available budget. Non-economic criteria on the investment decision making could be introduced because it can be assumed that word-of-mouth effects, green image, ideology and lifestyle have an impact on the investment decision as well. An additional step will be the combination of the presented model with a System Dynamics model of the German electricity market which allows for exhaustive studies of the (combined) effects of environmental policy instruments on the level of the national energy system.

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