

Bauermann, Klaas

Working Paper

German Energiewende and the Heating Market - Impact and Limits of Policy

EWL Working Paper, No. 20/13

Provided in Cooperation with:

University of Duisburg-Essen, Chair for Management Science and Energy Economics

Suggested Citation: Bauermann, Klaas (2013) : German Energiewende and the Heating Market - Impact and Limits of Policy, EWL Working Paper, No. 20/13, University of Duisburg-Essen, Chair for Management Science and Energy Economics, Essen

This Version is available at:

<https://hdl.handle.net/10419/103295>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



Chair for Management Science
and Energy Economics

Prof. Dr. Christoph Weber



**Chair for Management Science and Energy Economics
University of Duisburg-Essen**

EWL Working Paper No. [20/2013]

GERMAN ENERGIEWENDE AND THE HEATING MARKET

—

IMPACT AND LIMITS OF POLICY

by

Klaas Bauermann,

07.05.2013

GERMAN ENERGIEWENDE AND THE HEATING MARKET

-

IMPACT AND LIMITS OF POLICY

by Klaas Bauermann

Abstract

The German Energiewende envisages achieving a climate-neutral building stock in 2050 by means of two major pillars of regulation: First, residential buildings should consume 80% less primary energy and, second, the remaining energy demand should be covered primarily with renewables. This paper simulates the future heating market in Germany under different policy scenarios in order to evaluate the impact and limits of recent and conceivable heating market policy. The investigation is based upon a dual model approach, linking a residential heating model to a discrete choice model for the heating system purchase decision. The major finding is that current regulations will not be suitable for meeting government targets. Carbon emission reductions in scenarios assuming current regulation nearly equal those where there is no regulation. In terms of economic efficiency, all calculated policy alternatives perform better than the regulation currently in place. The model results highlight two policy implications. First, rising renewable requirements deliver better results at lower costs. Second, renewable obligations for heating systems must include the existing building stock in order to achieve the postulated political targets.

Keywords: Residential Heating Market, Policy Evaluation, Decarbonisation, Discrete Choice

JEL-Classification: E27, E61, H21, O18 O38, C35, C53

KLAAS BAUERMANN

CHAIR FOR MANAGEMENT SCIENCE AND ENERGY ECONOMICS,

UNIVERSITY OF DUISBURG-ESSEN (CAMPUS ESSEN)

UNIVERSITÄTSSTR. 11, 45117 ESSEN

++49 - (0)2 01 / 183-XXXX

WWW.EWL.WIWI.UNI-DUE.DE

KLAAS.BAUERMANN@UNI-DUE.DE

The authors are solely responsible for the contents which do not necessarily represent the opinion of the Chair for Management Sciences and Energy Economics.

German Energiewende and the Heating Market

—

Impact and Limits of Policy

Content

1. Introduction	2
2. Targets and Policy Measures	3
2.1 Energiewende, Energy Demand and the Heating Market	3
2.2 Policy Instruments for the heating sector	5
2.3 Heating Market Policy in Germany.....	6
3. Methodology	8
3.1 Methodological Concept.....	8
3.2 Input Data	9
3.3 Scenario Definition	10
4. Results	12
4.1 Heating Market	12
4.2 Final Energy and Renewable Share	14
4.3 CO ₂ Emissions.....	16
4.4 Efficiency and Household Costs	17
4.5 Alternative Policy Approach – CO ₂ Tax.....	18
4.6 Sensitivity Analysis.....	20
5. Discussion and Conclusion.....	21
Appendix	24
References.....	24

1. Introduction

The German residential heating sector offers huge potential for energy and carbon reductions, constituting a central key for the modernisation of the energy supply and for the attainment of climate protection goals. It has been responsible for a rather stable 20% share of annual domestic CO₂ emissions in recent years (Federal Statistical Office, 2012a). It further accounts for approximately 20% of the final energy consumption. There are two fundamental pillars of regulation to exploit these potentials: First, a lower energy demand of the residential buildings and, second, a higher number of renewable heating systems. Both of these pillars are addressed in the energy concept; the long-term energy strategy of the German Government (Federal Government, 2010). Therein, the Federal Government acknowledges that the transformation of the residential heating sector to be a key factor for the success of the Energiewende and postulates the long term target of a “climate-neutral building stock” for 2050. Virtually all heating market policy measures can be traced back to these two major pillars of regulation, a lower energy demand and a higher share of renewable (BMU, 2011). However, the formulated long-term target might be difficult to achieve, given the limited impact such measure have had to date (Diefenbach, Born, 2010).

This paper analyses different scenarios for the transformation of the residential heating market and its decarbonisation. The aim of the study is to analyse the impacts and limits of recent and conceivable German residential heating market policy until 2050. Yet, the main research question is, whether or not policy enacted appears promising to achieve the targets stated in the energy concept. As a corollary, sub-questions arise. What are conceivable alternative measures and how far do these alternatives contribute to the target achievement in terms of heating market structure, renewable heating energy and CO₂ emissions? Additionally to these questions of policy effectiveness, the question of economic policy efficiency is addressed.

To assess these questions, an integrated approach is chosen. A model of the building stock is used to calculate the future number and energetic requirements of dwellings in Germany that have an influence on the economics of heating systems. The heating market development is yet not given, but calculated endogenously with the help of a nested logit approach to consider the individual decision making process for residential heating systems. Five scenarios are calculated to reveal the effects of heating market regulation. Since the focus of this article is to analyse the impacts and limits of existing and conceivable German policy instruments with the help of an analytical model, the scenarios are confined to direct regulation and indirect financial instruments, which represent the major instruments in Germany.

The public interest and academic debate on the residential heating sector have led to a variety of approaches. First, and of particular importance for the Energiewende, scenarios have been calculated. Early contributions (Schlesinger et. al., 2007, Kirchner and Matthes, 2009, Wagner, 2009) have been followed by Schlesinger et. al. in 2010. The energy concept policy measures are based on the results of this study, which show the energy market future under a reference - and four target scenarios. Their heating market calculations, not based on a choice model, show that under the policy framework in 2010 only limited demand and emission reductions of around 30% are attainable until 2050. Direct policy measures for the building sector have been subject to several other studies, answering the question of how to tap into deeper saving potentials and how to overcome barriers, such as low refurbishment rates (Olonscheck et. al., 2011, Schimschar et. al., 2011, Tuominen et. al., 2012, Weiss et. al., 2012). Heating market policy instruments and their impact have in depth been

analysed by Bürger et. al., 2008, Cansino et. al., 2011, and Bjørnstad, 2012. Integrated approaches have been conducted by Schuler et. al. (2000), Dieckhöner and Hecking (2012), Michelsen and Madlener (2012), and Kranzel et. al. (2013) that all calculate considerable reduction potentials for the residential heating market.

This study is the first integrated approach that investigates different heating market policy measures, taking into account both the development of the residential building sector, and the choice process of decision makers. Advantages of this dual approach are the consideration of two markets that are inevitably connected and the ability to show the impact of heating market policy on the households' decision making and the resulting degree of target achievement.

The remainder is organized as follows. In order to set the scene, Section 2 elaborates on the details of the Energiewende targets and the heating market policy in Germany. Section 3 illustrates the methodology behind the results that are presented in section 4. Section 5 discusses and concludes.

2. Policy Targets and Measures

In order to set the scene, this Section provides a contextual and theoretical classification of the heating market and policy concerning this matter. Section 2.1 elaborates on the Energiewende and its role for the residential heating market. A selection of common policy instruments to reduce energy demand and emissions is discussed in section 2.2, while recent heating market policy measures and targets in Germany are presented in section 2.3.

2.1 Energiewende, Energy Demand and the Heating Market

Beside the transformation of the electricity sector, energy efficiency (i.e. the transformation of the residential heating market) is another focal point, crucial for the success of the Energiewende. Recent energy policy in Germany has primarily focused on the electricity sector. While several draft laws like the atomic energy act, the latest renewable energy sources act and the grid expansion acceleration act, just to name a few, were decided on, the particularly important residential heating sector has so far only experienced minor legal modifications (Bürger et. al., 2008). The reasons are as diverse, as is the building sector itself. Different ownership structures, principal-agent conflicts, property rights and upcoming elections inhibit the realisation of the numerous announcements made in the energy concept (Schmid et. al., 2012). However, the two major pillars of heating market regulation, less energy demand and a higher share of renewables, emphasise the importance of the heating market for the success of the Energiewende.

Regarding the household sector in official statistics, the target becomes obvious. While energy consumption in industry and elsewhere can be allotted to numerous different applications, the successful regulation of the residential heating market alone could suffice to substantially reduce energy demand and emissions of the whole household sector. Figure 1 shows the final energy demand per economic sector in 2011 and the distribution to energy applications within the household sector, which solely accounts for 25% of final energy consumption in Germany (BMW, 2013).

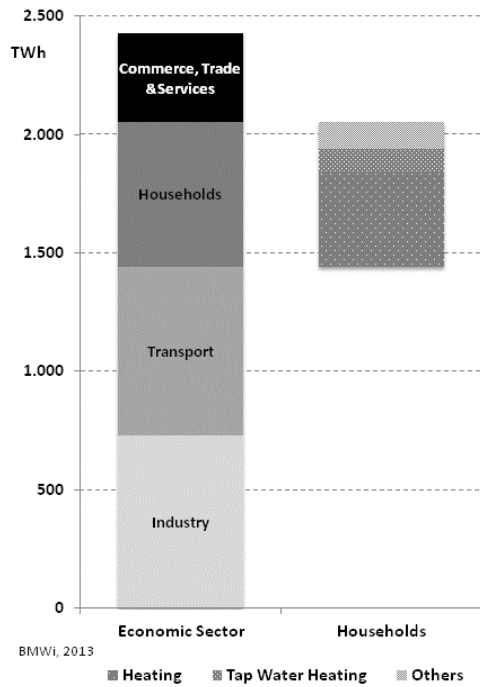


Figure 1 Final energy demand per sector in 2011

The dominating role of heating for household energy consumption shows that targeting one singular appliance allows for major improvements in energy efficiency and CO₂ reductions. Yet again, the two pillars are the option to exploit these potentials, first, a lower energy demand of the building sector and second, a higher number of efficient, renewable heating systems.

The policy maker has discussed several ways to address the two pillars like, proposals for legal amendments, tightening regulation on public buildings, financial assistance for energy-efficient refurbishments and a modernisation roadmap for buildings (BMU, 2011). However, besides repeated announcements and the compensatory increase of financial grants for energy efficient refurbishments instead of a general tax-deduction, only few proposals concerning residential buildings have been realised until today.

As a consequence, rates of energy efficient refurbishments remain low and have not majorly increased since 2000. Today they still average around 1%/a of the stock (Diefenbach et. al., 2010, Neitzel, Lindert, 2012). Besides this, having a dampening effect on the effort to reduce energy demand, the heating market is also still characterized by fossil fuels. Today gas- and oil-fired heating systems still deliver heat to the majority of households in Germany (Figure 2).

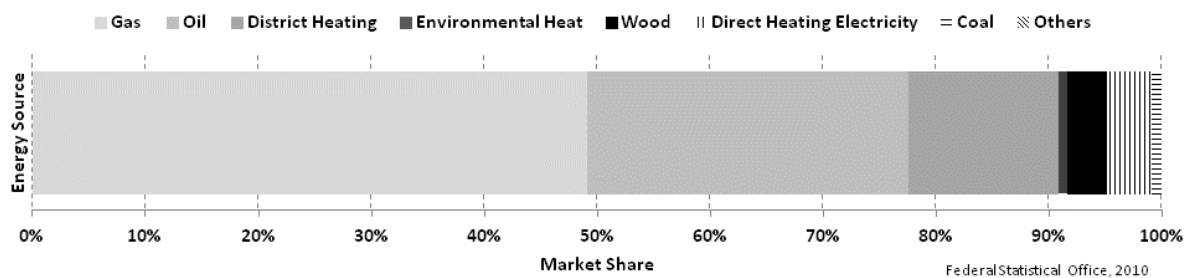


Figure 2 Share of occupied dwellings per energy source used for heating (2010)

Together with district heating (which is considered a very efficient, but still majorly fossil fired, technology (Paar et. al., 2013)) and coal furnaces, 92% of the German dwellings are supplied by fossil

heat. Concerning the building stock, a total of only 6% is quasi exclusively heated with renewables (BMU, 2012a). Furthermore, the market for heating systems in new constructions – already under regulation - and for system replacements is shrinking since 2000 and has stabilised in 2008 with about 600.000 systems sold/a. Despite impetus by the Federal Government and rising energy prices, the overall share of renewable systems sold is declining since 2008 (BDH, 2012). However the share of exclusively renewable heating systems in new constructions has increased over the last years (Federal Statistical Office, 2012c).

Referring again to the two pillars of heating market regulation, it can be said that the *Energiewende* which implies a revolution to the energy sector, only provides little stimulus to a slowly developing residential heating market. Until today, no sustainable transformation of the heating market can be stated. The residential heating sector is still characterised by fossil fuels and has made only small steps towards lowering energy demand.

2.2 Policy Instruments for the heating sector

As discussed above, resolutions such as the *Energiewende* in Germany, serve as a guideline for future policy. Policy has a wide range of instruments to intentionally influence citizen behaviour and social processes (Braun, Giraud, 2009). Historic policy instruments vanish or change while new instruments can be developed. Their variety and intensity also differs with political and societal moral concepts as well as with the prevalent form of governance (Braun, Giraud, 2009).

A number of instruments currently legal in European member states are a result of European legislation and regulation. The EU climate and energy package (Council of the European Union, 2008), known as the “20-20-20” targets, is a set of legislation and the superstructure of European energy and climate policy. Similar to the *Energiewende* in Germany, the 20-20-20 targets formulate multiple targets and measures. Their key objectives are

- a 20% reduction in EU greenhouse gas emissions from 1990 levels
- raising the share of EU energy consumption produced from renewable resources to 20%
- a 20% improvement in the EU's energy efficiency¹

All of the three key objectives affect the building sector and heating energy demand to a certain extent. The most important European influence on the building and heating sector is the energy efficiency objective. It is exerted by the Directive on the energy performance of buildings (EPBD) (European Parliament, 2002), its recast in 2010 (2010/31/EU) and later supplements. It obliges all EU Member States to legislate, that by the end of 2020 all newly constructed buildings meet the “zero-energy” standard and that their energy demand must be met predominantly by renewable resources. Other directives and communications, such as the directive on energy efficiency (European Parliament, 2012) and the energy efficiency plan (European Commission, 2011) were adapted to foster energy efficiency and lower import dependency, energy consumption and emissions.

Many concepts have been designed to classify policy instruments, with no two concepts being alike (Howlett, Ramesh, 1995). Suitable for the approach followed in this article, Braun and Giraud (2009) have distinguished two essential types of policy instruments. Besides instruments to secure the access to public goods and resources, policy notably aims to influence behaviour. This influence can

¹ http://ec.europa.eu/clima/policies/package/index_en.htm

either be direct or indirect. Direct influence can be exercised by regulation. The regulator can directly control, set up constraints and imperatives for individual or institutional action, backed by the coercive powers of government (Bemelmans-Vidéc et. al., 2010). Indirect regulation is a more tender form of the exertion of influence. Citizens and institutions are guided into the desired direction without dictating or prohibiting certain behaviour. This can be carried out by the help of financial instruments, structuring, i.e. procedural steering and persuasion (Braun, Giraud, 2009). The following is confined to direct regulation and indirect financial instruments, which represent the major instruments in Europe and Germany.

In order to implement European regulation and to meet national climate and energy reduction targets, European Member States have decided on different policy measures. Implemented in at least 22 member states (Cansino et. al., 2011), subsidies are the most widespread indirect policy instrument to raise the share of renewable energy in the residential heating sector. Other indirect instruments used to make renewable heating systems more attractive are taxes on fossil fuels, and tax breaks on renewable energies or other tax. Beside taxation, government grants, low interest loans on renewable systems and feed-in tariffs, like in the case of electricity production, are known indirect instruments to promote heating from renewable sources. On the other side, an obligation for the use of renewables is the most widespread direct policy instrument to raise their share in the residential heating market. Such a use obligation applies in cases of new installations or replacements of heating systems and has first been introduced for solar thermal heat in Spain. Another variety of direct policy instruments are purchase, sale and remuneration obligations or technology bans, which target retailers instead of households (Bürger et. al., 2008). An overview about policy measures in Europe and their success has been subject to existing studies and e.g. can be found in (Bürger et. al., 2008; Cansino et. al., 2011; Schimschar et. al., 2011; Tuominen et. al., 2012)

An alternative policy instrument for the residential heating market currently implemented in any member state but frequently discussed within economic and environmental studies is a carbon tax (Newell and Pizer, 2008; Tol, 2013). The economic textbook theory argues (Pigou, 1932; Weitzmann, 1974) that a carbon tax as an economic first-best instrument is the best policy instrument to reduce carbon emissions (Labandeira, 2010). Since carbon emissions are an issue of fossil fuels and climate policy is strongly linked to energy policy, the question about the implementation of a carbon tax on heating energy is a corollary of the aim to reduce heating energy demand and associated emissions. Following the rules of market economy, building owners are free to decide whether to reduce tax burdens by energy efficient refurbishments or by the installation of a renewable heating system. Although not by a carbon tax, taxes used to make heat generated from renewables relatively more profitable than heat generated from fossil fuels have already been implemented successfully in Sweden (Ericsson, 2009).

2.3 Heating Market Policy in Germany

Heating market policy today is a remnant of the Energy Saving Act from 1976. As one of its two cornerstones, the first Thermal Insulation Ordinance (Bundesgesetzblatt, 1977) was decided and incepted in 1977. Its aim was to reduce the energy demand of buildings. It was followed by two amendments in 1982 and 1995 (Bundesgesetzblatt, 1978). The second cornerstone was the Heating Appliances Ordinance from 1978 with its four amendments, which posed efficiency requirements on heating systems. Today, both ordinances are replaced by the Energy Saving Ordinance (EnEV) from

2002 (Bundesgesetzblatt, 2001). Two minor amendments in 2004 and 2007 led to the current ordinance, which is in force since October 2009 (Bundesgesetzblatt, 2009). The EnEV 2009 considers the EPBD requirements and is announced to be amended again to fully incorporate the EPBD recast from 2010.

Today the EnEV is an important part of the German energy and climate policy and the main policy instrument to tackle the heating energy demand and carbon emissions of the residential building sector. It primarily addresses new constructions and limits their primary energy demand, including energy demand for hot water. A builder is thus free to choose whether the limited primary energy demand should be met by an improved thermal insulation or by the use of renewable energy for heating. As a realistic average for new constructions, Schimschar et. al. (2011) have found a value of 65 kWh/m²/a for the overall primary energy demand. For existing buildings the EnEV requires standards for the thermal insulation coefficient or U-value of exterior structural elements in case of major refurbishments, but includes no monitoring for existing buildings. The EnEV can be understood as a direct policy instrument, primarily targeting the construction instead of the heating system. Since 2009, the EnEV is complemented by the Renewable Energies Heat Act (EEWärmeG) (Bundesgesetzblatt, 2008a). Its objective is to increase the share of renewables in the final energy demand for heating (domestic hot water, cooling and process heat) from around 11% in 2011 to 14% until 2020 (BMU, 2012a). The EEWärmeG prescribes a specific share of renewable energy used for heating in every newly constructed building. Depending on the renewable energy source applied, the minimum shares to fulfil the requirements differ between 15% for solar energy and 50% for geothermal energy. Existing buildings are not part of the national regulation but may be included on regional level, like for example in Baden-Württemberg. The minimum requirements for renewable heat are another example of a direct policy instrument used by the German policy maker. In the case of the EEWärmeG, regulation directly targets the heating market. Since the Heat Act has been enacted, the two pillars of heating market regulation are followed again directly. Less demand, stipulated via EnEV and a higher renewable share stipulated via EEWärmeG.

Direct regulation via EnEV and EEWärmeG predominantly target new constructions, thus with a low rate of new constructions this only affects a minor part of the population. Since the expansion of the regulation on existing buildings would face massive problems of acceptance due to proprietary rights and the tenet of economic efficiency, indirect policy instruments are used to overcome the limited range of existing regulations. The Market Incentive Programme (MAP) offers subsidies for the investments in thermal solar collectors, biomass boilers and heat pumps (BMU, 2012b). The MAP is a typical example of an indirect financial instrument to influence citizen behaviour. Additionally to the MAP, the semi-state owned KfW Development Bank offers low-interest loans and subsidies for energy efficient refurbishment measures and isolated measures, such as a boiler exchange if a condensing boiler is installed (KfW, 2013). The level of funding is based on the efficiency standard a building achieves after refurbishment compared to the EnEV standard. Besides the back coupling of KfW and EnEV, the combination of instruments results in reciprocal effects that are intended in order to amplify the policy impact compared to stand-alone instruments.

However, direct, thus effective regulation primarily affects new constructions. As the building stock of 2010 will still dominate the existing building stock in 2050 due to low construction and demolition rates, policy could be far more accurate, targeting the existing stock. Much more can and must be done to stimulate the building stock that is crucial for the attainment of recent policy targets. It is therefore questionable if the heating market targets fit the recent regulation

3. Methodology

Section 3 elaborates on the methodology applied to answer the research question posed above. A model of the heating market is used, which is presented in 3.1. Section 3.2 provides a short overview about the data input for the analytical model, while section 3.3 provides insight into the scenario development for analysing the impacts and limits of conceivable future heating market policy in Germany.

3.1 Methodological Concept

The simulation of the future heating market requires information about the building stock development and the choice of heating systems. Decision makers will usually decide on a heating system based upon the energetic requirements of the building that is to be heated. If the impact of heating market policy is addressed, a dual model approach that explicitly considers the decision making process is advisable, because it is the decision maker who translates regulation into the market reality.

The applied residential building and heating model is a dynamic model to simulate the future development of the German residential heating market until 2050. Based upon comprehensive information about the residential building stock, 5 different building types from single-family houses to tower blocks, and 18 age classes from before 1918 until 2050 are distinguished summing up to 75 building categories². Every building category provides information about the category specific living space, number of dwellings per building, living space per dwelling, specific heating energy demand per m², final energy demand in kWh/m²/a and heating technology installed. The heating system distribution per building category is added. This data allows for the calculation of the heating system capacity for every building category. The 75 building categories are expanded by the introduction of two additional insulation standards, partly refurbished and fully refurbished. Since the construction and development rates are derived by historic data, the rates of partly and fully refurbishments can be added exogenously to the model to consider alternative scenarios. The vintage structure of the heating systems installed in 2010 allows for the estimation of replacement cycles until 2050. Furthermore, each category of the German building stock is distributed to the four areas of supply infrastructure (gas, district heating, gas & district heating, none).

A nested logit model is grafted on the residential building model in order to consider the choice process of the households. Full annual heating costs are used as the main choice parameter. They are calculated for every considered heating system (Table 1) and every building category to allow the decision maker to opt for its optimal heating solution.

² Since tower block were only erected between 1958 and 1983 (comprising 3 vintage classes), the five building types and 18 vintage classes result in 75 categories instead of 90 categories.

Table 1 Residential heating systems considered by fossil, combined and quasi exclusively regenerative systems

Fossil Systems	Combined Systems	Regenerative Systems
Gas Boiler	Gas Boiler + Solar TWH 60%	Gas Boiler + Biomethane 100%
Oil Boiler	Gas Boiler + Solar TWH&Heating 10%	Pellet Boiler
District Heating	Gas Boiler + Solar TWH&Heating 44%	Wood Chip Boiler
Cogeneration with Peak Load Boiler	Gas Boiler + Biomethane 15%	Air Source Heat Pump
Coal Furnaces (among others)	Oil Boiler+ Solar TWH 60%	Ground Source Heat Pump
Direct Electric Heating (among others)	Oil Boiler+ Solar TWH&Heating 10%	Cogen Unit + PLB 100% Biomethane
-	Oil Boiler+ Solar Solar TWH&Heating 44%	-
-	Oil Boiler 10% Biooil	-
-	Gas Fired Heat Pump	-
-	Cogen Unit + PLB 30% Biomethane	-

Besides full annual heating costs further choice parameters are considered by the logit model. The technology image is represented by a preference parameter and a diffusion process is added to consider a time-lag of market developments. The parameters are estimated on the basis of real market and price developments between 1999 and 2009. More, detailed information about the model can be found in Bauermann, Weber (2013).

The combination of the two model approaches allows calculating the future residential heating market development under given refurbishment rates. The economics of the heating systems are heavily influenced by assumed policy interventions. Policy instruments affecting the heating market can be adjusted by expanding use obligations or by implementing a different subsidy scheme. Hence different direct and indirect policy instruments can be tested upon their impacts and limits on the heating market, energy demand and associated emissions that ultimately follow the households' choice.

3.2 Input Data

The German building stock serves as the foundation for the applied residential heating market model. The building stock comprises about 39 million dwellings with a vacancy of about 3 million (Federal Statistical Office, 2012c). For the analysis, additional micro census data was sent on request. Information about the energetic requirements of the buildings is provided by the Institute for Housing and Development (IWU) (Diefenbach, Born, 2007, Diefenbach et. al., 2010). The micro census data is joined with the IWU data and the slightly different vintage classes are matched to obtain a consistent data set³.

The future development of the building stock is calculated, using new construction and demolition rates, derived from the population development forecast and average dwelling sizes (Federal Statistical Office, 2006; 2011). The applied refurbishment rates differ from official expectations. The Federal Government has postulated the target of a rate of about 2%/a and offers financial support for refurbishments (BMU, 2011). Yet, the rates still lag far behind the official target (Diefenbach et. al., 2010, Neitzel, Lindert, 2012). Therefore and because refurbishments rates can only hardly be mandated, they are expected to increase slower and remain below official targets (Table 2).

³ For more information about the model construction see: Bauermann, Weber, 2013

Table 2 Annual full and partial refurbishment rates as used for the main scenarios

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Partial Refurbishment	0.6%	0.7%	0.8%	0.9%	1.0%	1.0%	1.0%	1.0%	1.0%
Full Refurbishment	0.2%	0.3%	0.4%	0.5%	0.6%	0.6%	0.6%	0.6%	0.6%

The number of households, temperature changes and energy or fuel prices, which significantly influence the heating market development, are held constant over all scenarios for comparison purposes. Energy prices correspond to future prices as observable on the European Energy Exchange homepage and are perpetuated by means of the World Energy Outlook 2013. Yet, they could be subject to further investigation, focusing on the effects of altering energy prices on the heating market⁴. Prices for wooden energy carriers are calculated endogenously, depending on their installed capacity. The Renewable Energy Sources charge (EEG charge) is added to the electricity retail price in Germany to finance the feed-in tariff for renewable energy production (Bundesgesetzblatt, 2008b⁵). Users of electric heat pumps are not exempted from that charge. Possible future changes of this and other influencing factors are neglected. Data on heating systems, their costs and future reductions⁶ are obtained by a series of heat cost comparisons (Voß, Zech, 2012; Ebert, Bohnenschäfer, 2008), and manufacturer data. The full annual heating costs calculation is based on Bauermann et. al. (2010). More detailed information can be found in Bauermann, Weber (2013).

3.3 Scenario Definition

Future developments are always associated with uncertainty. Unlimited policy alternatives exist, therefore policy alternatives in the present study are confined to scenarios. These scenarios cover the conceivable policy alterations in reality, as they expand or modify existing regulation. In addition to that, alternative policy considered is oriented towards the two pillars of residential heating market policy.

Five scenarios are calculated to evaluate the current heating market policy as well as alternative, more rigorous policy measures. These are a:

- Zero-Scenario with no policy intervention
- Policy-as-Usual-Scenario to continue recent policy
- Renewables-Plus-Scenario with higher renewable requirements
- Renewable-Obligation-Scenario to consider a general obligation for the use of renewable
- Renewable-Obligation-Plus-Scenario that combines the two aforementioned scenarios

In addition to the main scenarios, a CO₂ tax as an alternative policy approach is provided. The sensitivity analysis covers the impact of higher energy efficient refurbishment rates, hence less energy demand on the heating market development.

The first of the five main scenarios serves as a reference scenario to assess the impact of all other calculated scenarios. It is named the *Zero- or 0-Scenario*, and simulates a heating market free of political intervention from 2010 onwards. In this scenario, decision makers are free to choose, no subsidies are granted, and the market does not face any regulatory barriers like the EEWärmeG. The

⁴ See Appendix for energy price assumptions

⁵ Latest amendments can be found in the non-binding version as of January 2012. Available at: http://www.bmu.de/fileadmin/bmu-import/files/english/pdf/application/pdf/eeg_2012_en_bf.pdf

⁶ See Appendix for reduction path

EnEV focusing on buildings is assumed still to be in place. Since this is obviously not a conceivable policy option for the future residential heating market, it can well be used to compare for the results of other scenarios, i.e. the success, effectiveness and efficiency of alternative policy measures.

The second scenario is a *Policy-as-Usual-Scenario*. The *PAU-Scenario* simulates the recent German heating market policy and assumes no further tightening until 2050. The announced amendments of the EnEV standards to meet the EPBD requirements are respected, but there are no further requirements resulting from an amended EEWärmeG. Subsidies by the MAP and the KfW are granted until 2050 and not expected to rise or fall.

The *0-Scenario* and the *PAU-Scenario* can be used as a reference to evaluate the success of recent regulation, yet they do not account for the expansion of the existing policy instruments.

The third scenario therefore considers the tightening of the EEWärmeG requirements. The *Renewables-Plus-Scenario (RE PLUS)* represents a possible amendment of the recent EEWärmeG, to stipulate a higher share of renewable energy used for heating in every newly erected building from 2020 on (Table 3).

Table 3 Rising requirements for the share of renewable energy used for heating until 2050

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Boiler + Solar Tapwater 60%	✓	✓	x	x	x	x	x	x	x
Boiler + Solar Tapwater&Heating	10%	10%	20%	20%	25%	25%	30%	30%	44%
Biomethane	15%	15%	30%	30%	40%	40%	50%	50%	60%
Biooil	10%	10%	20%	20%	25%	25%	30%	30%	40%

Wood fired systems as quasi exclusively renewable systems are not affected by the EEWärmeG amendment. Electric heat pumps that need electricity as operating power are also not affected by the EEWärmeG amendment. In line with the Energiewende, energy generation in Germany is becoming renewable based and has the target of being 80% renewable by 2050. In turn, the share of renewable electric energy used in heat pumps also increases until 2050.

Another alternative is the fourth scenario, where the obligation for the use of renewables is expanded to every case of heating system installation. The *Renewable-Obligation-Scenario (RE OB)* reflects a modification of the EEWärmeG and its expansion on existing buildings. In contrast to the recent policy principle of the non-existing coexistence of support and regulation at one time, it is assumed that heating system subsidies for the building stock are continued despite the use obligation for renewables.

In order to conclude the direct policy instruments depicted in scenario *RE PLUS* and *RE OB*, the fifth main scenario combines the aforementioned policy amendments. The *Renewable-Obligation-Plus-Scenario (RE OB PLUS)* is the last direct policy instrument considered. It is designed so as to raise the share of renewable energy used for heating by combining the two aforementioned regulation amendments. Thus, reflecting conceivable options for the heating market. Table 4 provides an overview of all scenarios and the main scenario assumptions and abbreviations.

Table 4 Overview of main scenario assumptions

Scenarios	Subsidies for replaced heating systems	EEWärmeG Renewable Quota	EEWärmeG Range
0-Scenario	x	x	x
PAU	✓	standard	new constructions
RE PLUS	✓	high	new constructions
RE OB	✓	standard	building stock
RE OB PLUS	✓	high	building stock

Alternative indirect instruments based on existing policy, like for example the elevation of valid subsidies, could well be considered. Subsidies however are closely linked to budgetary resources and constraints. In the light of the European debt crisis and with respect to a budgetary-induced funding stop for the MAP in 2010, the elevation of subsidies is neither expected nor calculated.

4. Results

This section presents the simulation results. Section 4.1 displays the future development of the heating market concerning the market share of different heating technologies. Section 4.2 provides the development of the final energy demand for heating and the corresponding share of renewables on the final energy demand for heating, while CO₂ emissions are shown in section 4.3. An outlook on costs beard to the households and the scenarios efficiency is given in section 4.4. The carbon-tax as alternative policy measure and further sensitivity analysis are presented in sections 4.5 and 4.6.

4.1 Heating Market

The heating market development i.e. the market share development of heating technologies is a useful indicator to subsume the evolution of the heating market in the course of time. Considering the target of a heating market whose remaining demand is predominantly covered by renewables, the ratio of dwellings supplied by quasi exclusively renewable systems and those still fired by fossil fuels provides information about the success of policy applied. Figure 3 reveals the effectiveness of the five main scenarios concerning the transformation of the heating market.

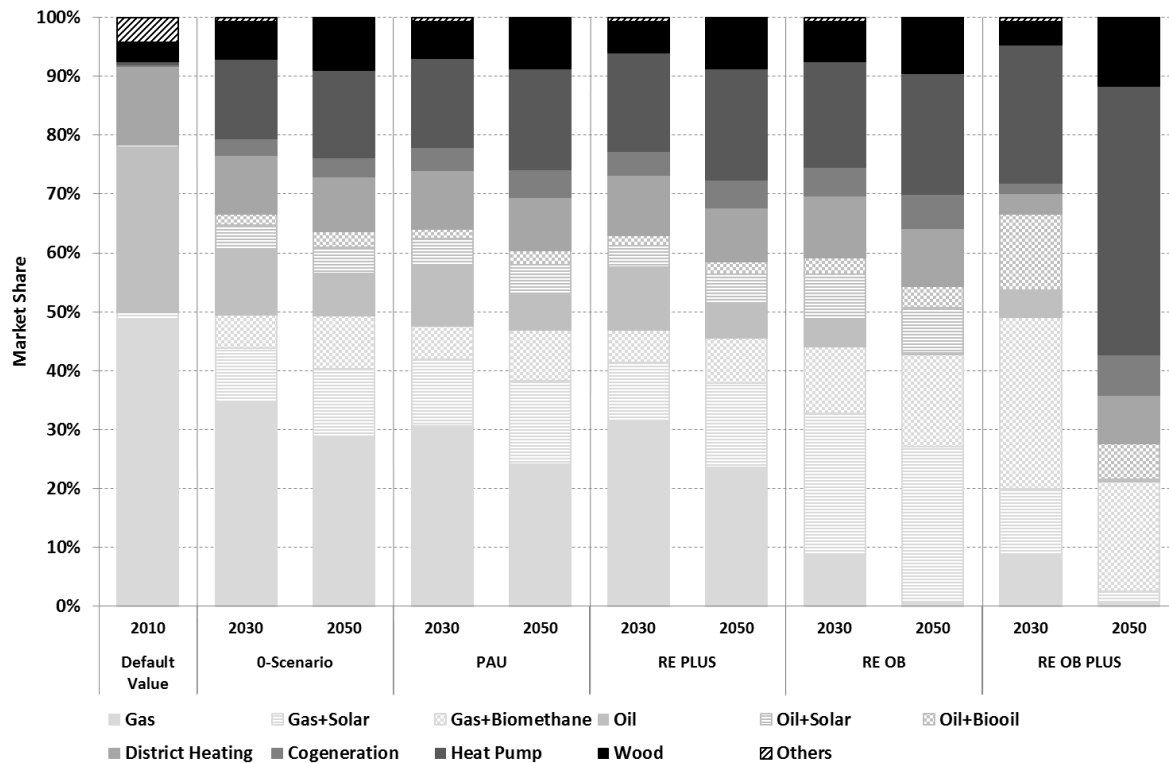


Figure 3 Market share of heating technologies 2010, 2030 and 2050 in Germany for the five main scenarios

The results are striking as they emphasize the limited impact of the recent regulation and subsidy scheme (*PAU-Scenario*) on the heating market transformation. In comparison to the *0-Scenario*, with no regulation and subsidies at all, only four additional percentage points can be collected by combined and regenerative heating systems until 2050. Moreover, the number of dwellings supplied by exclusively fossil fired heating systems (gas and oil) in 2050 is only 2.2m below the number of dwellings in the *0-Scenario*. Nonetheless, the *PAU-Scenario* regulation stipulates an earlier heating market transformation and therefore facilitates a longer period of reduced consumption and emissions.

The tightening of the EEWärmeG requirements relating to the share of renewables in newly erected buildings is covered by the *RE PLUS-Scenario*. Again results show only limited effects on the heating market, due to low construction quotas in Germany. Still, the directions of the market share shifts reveal the effects of the EEWärmeG amendment. As higher requirements for combined systems raise their costs, renewable systems become comparably cheaper. Yet, the higher requirements do not substantially push the shares of renewable systems. Combined gas and oil systems lose around 1.5% market share that is collected by heat pumps⁷. Wood pellet systems do not benefit. They are not selected by house owners, due to their comparably low economic efficiency in well insulated new constructions. In terms of the transformation of the heating market, higher requirements relating to the share of renewables in newly erected building prove to be ineffective.

The two scenarios that include the existing building stock into the heating market regulation reveal a politically desirable heating market until 2050. The *RE OB-Scenario* that expands recent regulation to every case of heating system installation leads to the highest share of combined heating systems. The number of dwellings supplied by combined solar thermal systems more than doubles (26%) in

⁷ Compared to the *PAU-Scenario*

comparison to the *PAU-Scenario*, however 60% of them being systems for solar tap water heating only. Combined biomethane and biooil systems also benefit as they are an easy to implement system for former gas and oil clients. Regenerative systems also collect more market share, but fall behind combined solutions that appear to be more favorable heating systems in existing buildings. District heating also benefits and still accounts for 10% of the market share in 2050 – its highest final value over all main scenarios.

While the sum of combined systems in 2050 still accounts for the majority of heating systems in the *RE OB –Scenario*, the opposite effect can be observed for the *RE OB PLUS-Scenario* as their market share falls to only 28% until 2050. The rising requirements for the share of renewable heat in combined systems cause a higher appreciation for heat pumps and to some extent also for wood. It appears that higher costs as a consequence of higher requirements lead to a “fuel-switch” between combined and regenerative systems in the building stock. The 46% market share for heat pumps in 2050 appears unrealistic at first sight. However, in the light of a building stock that is quasi equally split between dwellings in one or two family houses and apartment buildings, this is a conceivable consequence of the amended regulation. In addition to the highest share of regenerative systems among all scenarios, cogeneration – another politically desired technology – reaches its highest market share serving 7% of dwellings in 2050.

4.2 Final Energy and Renewable Share

The reduction of the final energy demand for heating is predominantly triggered by energy efficient refurbishments, and only to a smaller extend by the heating system distribution. Besides the first pillar of regulation, the reduced energy demand, the share of renewable heat as the second pillar is easier to regulate and quasi solely triggered by the heating system distribution. Refurbishment rates as per definition are assumed to be constant over the five main scenarios (cf. Table 2). However, the refurbishment rates assumed lead to a constant decline in final energy demand. Figure 4 reveals the development of the final energy consumption until 2050 with the 2020 reduction target, as well as the share of renewables in the final energy demand for heating in increments of 10 years.

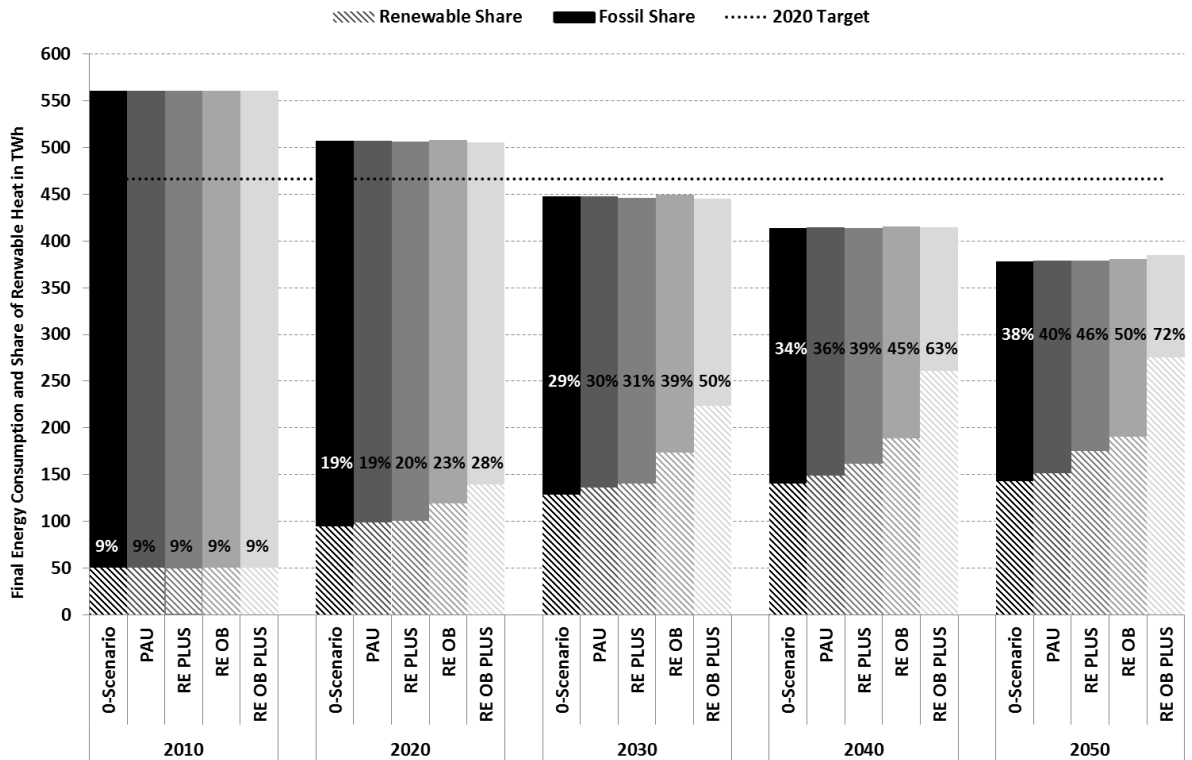


Figure 4 Final energy demand for heating and share of renewables until 2050 for the five main scenarios

All calculated scenarios fail to reach the 2020 reduction target for the final heating energy demand⁸. The final energy demand reduction achievement is primarily due to building insulation measures. The small differences that occur between the scenarios are a result of the varying heating system distribution that only slightly influences the final energy demand. The final energy demand development until 2050 shows the need for higher energy efficient refurbishment rates, as refurbishment rates at recent levels are only hardly sufficient.

Concerning the share of renewable energy for heating, the results again emphasise the comparably low effects of the recent regulation. While energetic building refurbishments and the dwellers decisions without political intervention (*0-Scenario*) lead to a 38% renewable share in the final energy demand for heating by 2050, it is only two percentage-points higher in the *PAU-Scenario*. Never the less, all scenarios exceed the 14% target for 2020, concerning the residential heating market.

The higher renewable requirements in the *RE Plus-Scenario* result in additional six percentage-points renewable share until 2050. By 2020, the year of the policy inception, higher renewable requirements substantially increase the renewable share despite the hampering effect of low constructions rates.

The *RE OB-Scenario* reveals a better effectiveness pushing the renewable share to 50% until 2050. Renewable requirements are less rigorous than in the *RE Plus-Scenario*, but include the whole building stock, leading to results more in line with political desires. The *RE OB Plus-Scenario* is the only scenario in which the regulation is adequate to stimulate a heating market that is dominated by

⁸ Yet, this is a question of definition as Figure 4 also shows environmental energy. If solar and other environmental energy used in heat pumps were excluded, the 2020 target would be reached.

renewable heat. The consideration of the building stock and rising requirements towards the share of renewables have an amplifying effect in the course of time. A renewable share of 72% in 2050 makes the *RE OB Plus-Scenario* the only scenario that seems appropriate to come close to a climate neutral building stock.

4.3 CO₂ Emissions

The household sector has so far widely been spared when direct measures for emission reduction were addressed. Yet, existing regulations focussing on the energy demand and energy sources used for heating both affect CO₂ emissions indirectly. Variations of existing regulation as depicted in the five main scenarios therefore still deliver different results and show the effectiveness of heating market regulation concerning the households' contribution to emission reduction targets. Figure 5 shows the emission reductions until 2050 over all five main scenarios as well as the target values for 2020, 2030, 2040 and 2050.

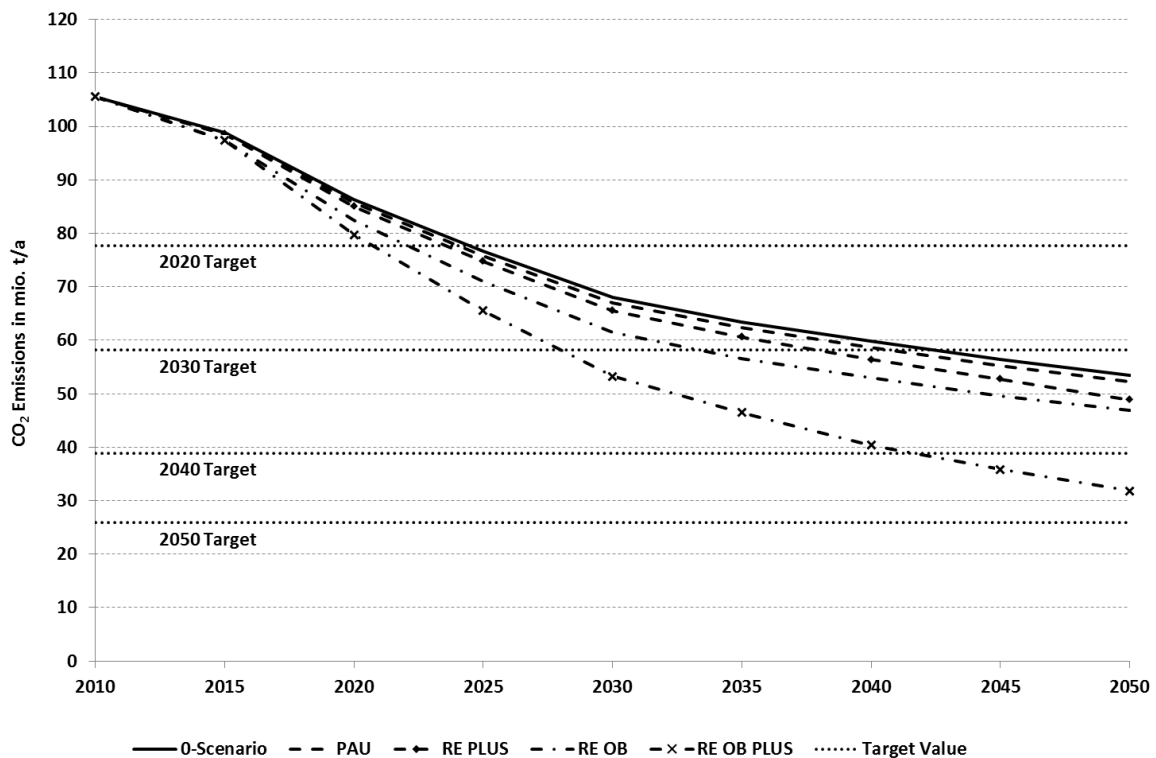


Figure 5 CO₂ emissions of the residential heating market in Mio. t/a until 2050 over all five main scenarios

In terms of emission reductions, recent regulation performs fairly incapable as emission reductions nearly equal the *0-Scenario* results. Even the higher requirements towards the share of renewables do not substantially put downwards pressure on emissions. The limiting factor of an already low but still declining rate of new constructions, leads to inefficient regulation results.

Better results are attained if the building stock is incorporated into regulation. The *RE OB-Scenario* delivers significantly better results. The distance to the *RE Plus-Scenario* narrows after 2030 due to the late impact of rising renewable shares, yet results remain favourable. All of the three scenario results fail to reach the target values for emission reductions in particular after 2030. The only scenario that attains the target value for 2030 and 2040 is the *RE OB Plus-Scenario*. Its two regulatory amendments mutually amplify and deliver a much better reduction result. Despite the fact that, due

to the later growing share of renewables, the highest reduction yields compared to the recent regulation (*PAU-Scenario*) are attained from 2050, when almost 525 m t of CO₂ could be saved by 2050.

4.4 Efficiency and Household Costs

Having analysed the effectiveness of the five depicted scenarios, the question concerning economic policy efficiency arises. Efficiency in the course of economics can be analysed differently. In its most simple way, efforts and results are compared to obtain a performance indicator. For the heating market and its regulation, this can best be assessed by comparing subsidies for efficient and renewable heating systems and the development of CO₂ emissions. In the course of a political evaluation and discussion, the approach may differ due to a higher variety of targets. Figure 6 pictures the ratio between subsidies granted for efficient and renewable heating systems and reduced emissions of the heating sector until 2050. The more downright a scenario is positioned, the more efficient it is considered.

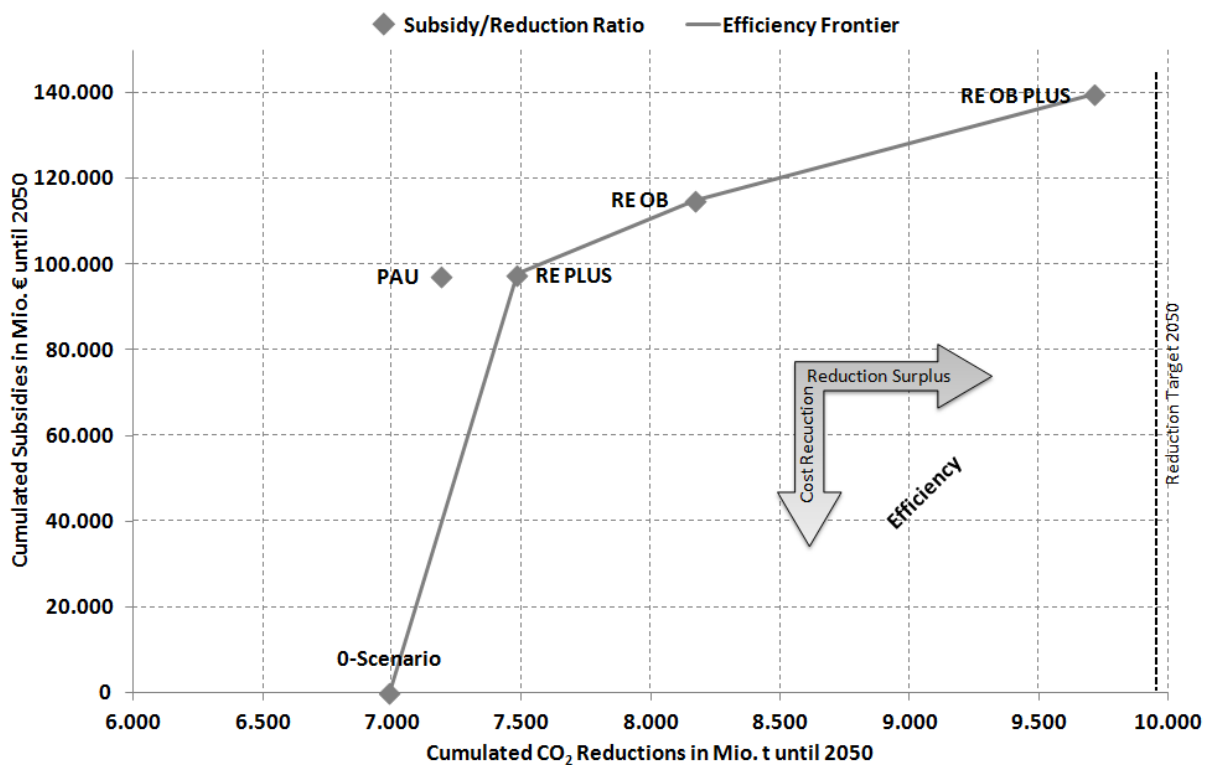


Figure 6 X/Y-diagram of cumulated subsidies and reduced CO₂ emissions until 2050

In terms of economic efficiency, we find all downright scenarios to form an efficiency frontier, with the PAU-Scenario performing worst. Marginal abatement costs are a frequently used policy tool that indicates efficiency in an illustrative manner (Kesicki, Strachan, 2011). With no further regulation and subsidies, the *0-Scenario* is superior to all other scenarios with respect to the sole objective of economic efficiency because of its free of cost carbon reductions. Yet, the policy maker is willing to influence the market development by regulation and financial support. Under that assumption, including windfall profits, Table 5 shows most favorable results for the *RE Plus-Scenario* (Simple Abatement Costs). In order to evaluate the real abatement costs, excluding the windfall profits represented by the *0-Scenario*, the four remaining scenarios perform differently (Additional Abatement Costs).

Table 5 Abatement costs for the five main scenarios

€/t	Simple Abatement Costs	Additional Abatement Costs as against 0-Scenario
0-Scenario	0,0	-
PAU	13,6	496
RE PLUS	13,1	198
RE OB	14,1	97
RE OB PLUS	14,4	51

The abatement costs differ by a factor nearly 10 between the four scenarios with a clear preference for the *RE OB PLUS-Scenario*. The results show two issues. First, that the tightening of renewable requirements is always cheaper than the recent low requirements, and second, that the expansion of the renewable use obligation into the building stock is always cheaper than only targeting new constructions. Yet, the additional abatement costs as against the *0-Scenario* show that the *PAU-Scenario* is neither effective nor efficient. Whereas the *RE OB PLUS-Scenario* is not only far more effective but also the only scenario that could be considered successful in terms of the achievement of politically intended emission reductions (e.g. Figure 6)

A comparably high political target achievement with low subsidies on the one side may be on the expense of households' budgets on the other side. Table 6 shows the development of the inflation adjusted, annualised full household heating costs. All scenarios reveal the effect of an increasingly energy efficient building sector and the growing share of free environmental energy that despite higher investment costs, results in declining heating costs in real terms.

Table 6 Annualised full household heating costs until 2050 indexed to the 0-Scenario in real terms

	2010	2015	2020	2025	2030	2035	2040	2045	2050
0-Scenario	100	101	101	100	96	94	93	90	88
PAU	98	99	99	97	94	92	90	88	86
RE PLUS	98	99	100	98	94	92	90	88	85
RE OB	98	95	90	89	83	87	89	88	87
RE OB PLUS	98	95	93	91	88	94	98	97	97

The higher 2010 value of the *0-Scenario* reflects the effect of the missing subsidies. We find a positive influence of higher renewable requirements in the *RE PLUS-Scenario*, carefully indicating that these might also be beneficial to households in the course of time if compared to recent regulation (*PAU-Scenario*). The *RE OB-Scenario* shows a lucid positive effect on household heating bills until 2040 if renewable obligations were transferred into the building stock. Yet, the combination of higher renewable requirements that are also mandatory in the building stock lead to higher household heating costs in the *RE OB PLUS-Scenario*. Poorly insulated buildings appear to be confronted with expensive heating solutions if they are to meet the severe renewable obligations of the *RE OB PLUS-Scenario*. Hence the most favourable scenario in terms of budgetary efficiency and the achievement of political objectives imposes higher heating costs to the households.

4.5 Alternative Policy Approach – CO₂ Tax

The taxation of emissions offers an alternative to policy targeting heating demand and technologies in order to lower the carbon footprint of the household sector. A carbon tax on fuels increases the price of fossil heating energy, leaving the heating system decision to the house owner. As the

improvement of insulation is not a subject to this study, the effect of a CO₂ tax on the heating system choice is presented, leaving room to further research approaches.

The CO₂ tax scenarios imply that households pay for their heating emissions. No subsidies for renewable heating systems are granted as the heating market in these scenarios is regulated by prices only. In order to comprehensively evaluate the effect of a CO₂ tax, three different price paths are modelled (Table 7). These price paths are solely chosen to show the impact of a CO₂ tax that in turn depends on the CO₂ price itself. Therefore different CO₂ price targets for 2040 are assumed and annual growth rates linearly interpolated.

Table 7 CO₂ price paths until 2050 for the three CO₂ tax scenarios in €/t

	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO ₂ Tax	8	5	28	32	37	43	50	58	67
CO ₂ Hightax	8	5	30	38	49	63	80	102	130
CO ₂ Superhightax	8	5	57	72	92	118	150	191	244

The introduction of a CO₂ tax affects the household heating market similarly to the previously calculated regulation measures. Rising costs for heating are now directly linked to the use of fossil fuels due to the higher CO₂ emissions and make renewable systems economically more attractive. The strength of this effect depends on the CO₂ price level. Table 8 shows the development of the renewable share in the final energy demand for heating until 2050. All calculated scenarios show a higher renewable share in 2050 if compared to the *0-* (38%), and *PAU-Scenario* (40%), while only the *Superhigh-Scenario* delivers a higher share from 2030 on. The rising CO₂ prices lead to a slow but more constant development towards renewable systems. The reason is twofold. Current regulation stimulates households that are interested in renewable heating systems anyhow and fosters the installation of partly renewable heating systems in new constructions. Whereas the regulatory framework of a CO₂ tax with rising prices strengthens fully renewable systems in the course of time as they become comparably more attractive.

Table 8 Share of renewable energy for heating and annual CO₂ emissions until 2050 over the three CO₂ tax scenarios

Renewable Share	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO ₂ Tax	9%	11%	17%	22%	27%	31%	34%	38%	41%
CO ₂ Hightax	9%	11%	17%	23%	28%	31%	35%	40%	45%
CO ₂ Superhightax	9%	11%	18%	24%	30%	35%	40%	46%	53%
CO ₂ Emissions	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO ₂ Tax	106	99	86	75	66	61	57	53	49
CO ₂ Hightax	106	99	86	75	66	61	56	52	47
CO ₂ Superhightax	106	99	85	75	65	59	54	49	43

Unlike the recent heating market regulation, the CO₂ tax directly penalises emissions. Hence, in terms of emission reductions, the CO₂ tax scenarios perform even better than in terms of growing the renewable share of final heating demand. Even the lowest *Tax-Scenario* reaches 49 Mio. t/a of carbon emissions in 2050, the level of the *RE PLUS-Scenario*. The *Hightax-Scenario* performs as good as the *RE OB-Scenario*, and the *Superhigh-Scenario* shows that a further rising CO₂ price leads to further and earlier emission reductions. However, the *RE OB PLUS-Scenario* value is attained by none of the CO₂ tax scenarios.

As the CO₂ scenarios replace existing regulation and subsidies by the introduction of a new tax, it is on the expense of households, while it reduces the burden on the public purse. Table 9 shows the

development of the inflation adjusted, annualised full household heating costs, indexed again to the *0-Scenario*. Contrary to the previous results, the 2010 value jumps up due to the additional taxes paid by households. As expected, all CO₂ scenarios lead to comparably high household costs until 2050.

Table 9 Annualised full household heating costs until 2050 indexed to the *0-Scenario* in real terms

	2010	2015	2020	2025	2030	2035	2040	2045	2050
CO₂ Tax	102	102	108	106	103	102	100	98	97
CO₂ Hightax	102	102	108	108	106	105	105	105	105
CO₂ Superhightax	102	102	114	115	114	115	116	117	119

The high CO₂ prices in the *Hightax-* and *Superhightax-Scenario* exceed the efficiency gains by refurbishments and free environmental energy, leading to rising heating costs in real terms. Although households have to pay the bill, it has to be considered, that the environmental taxes relieve the national budget between 29 and 81 billion € until 2050. The CO₂ tax as an alternative policy instrument proves to be as effective as recent policy measures. Yet, its effectiveness strongly depends on the CO₂ price. However, the question of efficiency is difficult to answer as the success is bought on the expense of households. According to the “polluter-pays” principle, a CO₂ tax can still be valued an efficient instrument.

4.6 Sensitivity Analysis

The previously shown results are all calculated under the assumption of an observable energetic refurbishment rate that remains below the governmental projection. In order to take account of the optimistic official assumptions, the sensitivity analysis presents some main results with regard to higher refurbishment rates (*REF*) as depicted in the energy concept. In the following, the recent regulation by the *PAU-Scenario* and the best performing *RE OB PLUS-Scenario* are calculated with higher refurbishment activities.

Table 10 shows the refurbishment rates as pronounced by the Federal Government. They reveal the expectation of an earlier increase and a higher maximum level, which is already reached in 2020.

Table 10 Annual full and partial refurbishment rates as used for the sensitivity analysis

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Partial Refurbishment	0.6%	0.8%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Full Refurbishment	0.2%	0.5%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%

The earlier and more widespread refurbishment of the building stock has a dampening effect on heating energy demand and emissions, as less energy is needed to heat up the buildings. Yet, it does not significantly influence the share of renewable energy for heating. Table 11 shows the economic effectivity of higher refurbishment rates. While there is no difference between the *PAU-* and the new *PAU REF-Scenario* results, two more percentage points in 2050 can be attained within the new *RE OB PLUS REF-Scenario*. To a large extent, this can be explained by a shift within the heat pump systems. The more energetically refurbished buildings are better suited for electric heat pumps that gain market share, while gas heat pumps become less economically advantageous and lose market share. As the electricity generation in 2050 is dominated by renewable energy, electric heat pumps deliver a higher share of renewable energy than gas heat pumps. Effects, based on the share of renewables appear unimpressive. However the only marginally higher share is based on less energy demand, hence presents a very welcome result in terms of target achievement.

Table 11 Share of renewable energy for heating and annual CO₂ emissions until 2050 over the REF scenarios

Renewable Share	2010	2015	2020	2025	2030	2035	2040	2045	2050
PAU REF	9%	12%	19%	26%	31%	34%	36%	39%	40%
RE OB PLUS REF	9%	14%	28%	40%	51%	58%	65%	69%	74%
CO ₂ Emissions	2010	2015	2020	2025	2030	2035	2040	2045	2050
PAU REF	106	99	85	73	63	58	54	50	47
RE OB PLUS REF	106	97	79	63	50	42	36	31	27

The effect on CO₂ emissions is more impressive, as the reduced final energy demand through refurbishments directly decreases the demand for CO₂ intensive fuels. If compared to the main scenario results, emissions are reduced by 5.5 Mio. t/a in the *PAU REF*- respectively 4.6 Mio. t/a in the *RE OB PLUS REF-Scenario* in 2050. Cumulated from 2010 to 2050, the higher refurbishment rates lead to an additional emission reduction of 9% in the *PAU REF*- respectively 6% in the *RE OB PLUS REF-Scenario*, compared to their equivalent scenarios with lower refurbishment rates. The better results for the *PAU REF-Scenario* can be explained by the higher share of fossil fuels, so that every reduced kWh saves more CO₂ than in a heating market with little CO₂.

In terms of efficiency, both *REF-Scenarios* perform better due to higher refurbishment rates and associated CO₂ emission reductions. Yet, the model-exogenous higher refurbishment rates are not a result of the heating market policy, focused on in this study. The effects of policy promoting energy efficient refurbishments have been subject to other studies, such as Koeppel, Üрге-Vorsatz, 2007; Uihlein, Eder, 2010; Schimschar et. al., 2011.

Compared to the main scenario results, the increased refurbishment rates reduce the final energy demand for heating by around 880 TWh or 4.2% between 2010 and 2050, while the 2050 final energy demand is 10% below the main scenario results, due to the multiplying effect of higher refurbishment rates in the course of time. Still, even the politically intended refurbishment rates of the *PAU REF-Scenario* that results in a demand reduction of almost 50% based on the 2008 values, the CO₂ reduction target value of 26 Mio. t/a in 2050 cannot be attained.

5. Discussion and Conclusion

The present study focuses on the impacts and limits of recent and conceivable residential heating market policy until 2050, using different scenarios for the residential heating market transformation. While doing so, the question of whether or not recent policy appears promising to achieve the postulated heating market targets and in how far conceivable policy alternatives can contribute to target achievement is addressed? The policy impact on the heating market structure, the renewable share and CO₂ emissions is examined in particular and policy effectiveness and efficiency is evaluated.

As the heating system decision is usually made based upon the energetic requirements of the building that determine the heating costs, a dual approach is applied. This approach combines a residential building model with a discrete choice model for the heating system decision. This dual approach differs from existing approaches for Germany (Schlesinger et. al., 2010, Schimschar et. al., 2011, Olonscheck et. al., 2011). It does not assume a general decline in heating energy demand due to energetic refurbishment activities nor calculates the consequences based on a forecasted heating market structure. The dual approach allows for the consideration of individual heating system

purchase decisions, based on the energetic requirements of each building category⁹ and their development until 2050. As a result, the heating market develops based on the households' decisions that in turn are based on the building stock development and the market political framework. This is the first integrated approach that investigates the effects of different policy measures on the development of the residential heating market, energy demand and CO₂ emissions and evaluates the efficiency of policy measures until 2050. It therefore is a considerable expansion of current approaches and helps to better understand the impact of heating market policy.

Despite the different approach, the results align with a number of national and international publications that also predict a slow transformation of the heating market and less contribution to emission and demand reductions than politically desired (Schäfer et. al., 2000, Koepfel, Ürges-Vorsatz, 2007, Bürger et al., 2008, Olonscheck et. al., 2011, Schimschar et. al., 2011, Weiss et. al., 2012, Kranzl et. al. 2013). The main findings are:

- Current heating market policy leads to an insufficient heating market development, that is not adequate to induce the politically desired climate neutral building stock
- The share of renewables used for heating is likely to remain inferior to the share of fossil fuels used for heating until 2050
- The residential heating market fails to make its contribution to the achievement of the national 80% CO₂ reduction target until 2050
- The recent regulation turns out to be inefficient and not effective if compared to the calculated alternatives
- Rising renewable requirements as well as the expansion to the building stock contribute to the target achievement and prove to be more efficient
- If requirements are carefully increased this efficiency does not only lead to less subsidies paid but also to less household expenditures for heating

Briefly, the model results lead to the conclusion that the heating market policy in place does not fit the postulated targets. Recent policy does not suffice to tap into the huge reduction potentials of the residential heating market. Even with higher refurbishment rates, contributing to the first pillar of regulation - a lower energy demand - policy in place does not sufficiently stipulate the use of renewable, hence not supporting the second pillar. If regulation is not expanded to existing buildings, none of the Energiewende targets for the residential building sector will be met.

The heating market development under current regulation is carried out only very slowly, because buildings erected before the heating market regulation via EEWärmeG, still dominate the heating market in 2050. If regulation is not expanded to existing buildings in every case of a heating system installation, the heating market transformation is not likely to advance. The heat supply by fossil fuels still occurs to be economically beneficial to many households, while the restraints towards new technologies the peoples' inertia remain high, resulting in a sluggish market transformation.

The same holds for the share of renewable energy used for heating. The combination of the current subsidy level and the comparably low renewable share requirements does not substantially push the renewable energy share. The small differences between the recent regulation (*PAU-Scenario*) and the unregulated (*0-Scenario*) scenario suggest that besides decision makers interested in renewable

⁹ The building category entails information about the building type, its construction age, size and energetic requirements. For more information, see: Bauermann, Weber, 2013

heating technology, only few are affected by regulation and subsidies in particular. Such free-rider effects have repeatedly been identified and help to understand the low impact of existing regulation (Schäfer et. al., 2000; Koeppel, Ürge-Vorsatz, 2007; Weiss et. al., 2012).

The final energy demand reduction primarily depends on refurbishment rates that are held constant over the main scenarios. The sensitivity analysis reveals the impact of increased refurbishment rates. Their increase solely results in a reduction of 880 TWh until 2050, or more than 1/3 of the 2011 overall German final energy demand. As refurbishment effects amplify over time, the 2050 final energy demand drops by 50% below the initial demand in 2010, while the reduction with lower rates is only 34%. Again, the building stock proves to be the key factor, while the well regulated construction sector contributes only little. Olonscheck et. al. (2011) find even higher reductions than 50% until 2050, but calculate higher refurbishment rates and consider the effect of less heating degree days due to global warming.

For the CO₂ emission reductions it can be found that only rising renewable share obligations expanded to the building stock can contribute to a really substantial reduction surplus. Recent regulation and all other alternative scenarios fail to substantially decrease carbon emissions of the residential building sector. The combination of targeting the existing building stock and rising renewable requirements prove to be the only way to decarbonise the building stock.

As regards efficiency of policy measures, it appears that the policy maker fails to legislate an efficient regulation. This may be due to political target plurality that makes it difficult to the policy maker, if measured against only one target – CO₂ reductions. Yet, the ambitiousness of targets itself in combination with the disregard of the existing building stock have created a policy framework, that cannot efficiently regulate the energy use which is finally responsible for emissions. It can thus be concluded that policy measures in place are only little efficient. Yet, if CO₂ emissions are measured, the most austere scenario turns out to be the most efficient and also the only one delivering satisfying emission reductions. However, to the expense of households.

Recapitulating the results and their interpretation, the conclusion becomes obvious. The recent heating market policy has little impact on meeting targets. The results reveal that a general obligation for the use of renewable heating systems, like already installed in the Federal State of Baden-Württemberg, is needed to overcome the decision makers' reluctance and to come close to a heating market dominated by renewables. These results correspond to Kranzl et. al. (2013) who argue that use obligations lead to higher renewable penetrations than economic incentives. This also stresses the importance of the building stock, the key parameter for the transformation of the heating market. Weiss et. al. (2012) also pronounce the importance of the building stock as they identify the limitation to new constructions as one main reason for the limited effect of existing regulation and pronounce the strong need for improvements to the heating standards for existing structures. While the sole expansion of renewable obligation on existing buildings already delivers a 50% renewable share until 2050, a politically desired renewable share can only be attained if renewable requirements rise until 2050. The same applies to emission reductions, where only the inclusion of the building stock in combination with rising renewable obligations delivers results close to the policy target. This means, as regards effectiveness, the policy maker can only aggravate his policy measures or adapt and lower his targets for the heating market. Olonscheck et. al. (2011) also raise doubts about the feasibility of the official reduction goals, although they calculate ambitious refurbishment rates. The target plurality of the policy maker and his eagerness to win coming

elections often hinder efficient regulation. However, the heating market offers the opportunity for a more effective regulation and an additional win-win-situation. The inclusion of the buildings stock does not only lead to better results envisaging the decarbonisation of the building stock, if carried out carefully it can also be done more efficiently and to the benefit of household heating costs. Bürger et al. (2008) offer an alternative to the here followed general renewable share, as they ask for rising, but lower renewable shares in the building stock than in new constructions. Additionally costs and effectiveness of measures also depend on the energy prices assumed. Their influence in particular could well be subject to further research. Yet, the question remains whether official targets are too ambitious, or politicians overestimated the measures' impact.

Appendix

Table 12 Inflation adjusted wholesale energy prices 2010-2050 as used for the residential building & heating model

		2010	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	€/MWh	44,6	41,3	63,8	67,2	71,2	75,8	81,1	87,2	94,2
Gas	€/MWh	19,4	26,8	30,6	31,6	32,4	33,2	34,0	34,8	35,6
Oil	€/MWh	52,4	53,2	54,8	55,9	56,6	57,3	57,9	58,6	59,2
Coal	€/MWh	10,0	12,2	10,7	10,8	10,9	11,0	11,1	11,2	11,3
EEG Charge	€/MWh	0,6	6,1	7,1	7,9	8,4	8,8	9,2	9,7	10,2

Table 13 Inflation adjusted technology cost decrease between 2011 and 2050

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Gas Boiler	100%	99%	98%	97%	95%	94%	93%	92%	90%
Oil Boiler	100%	99%	98%	97%	95%	94%	93%	92%	90%
Solar-Thermal Components	100%	73%	68%	66%	65%	63%	62%	60%	59%
Wood Boiler	100%	98%	97%	95%	92%	90%	87%	85%	84%
Electric Heat Pump (Air)	100%	81%	67%	64%	61%	59%	57%	56%	55%
Electric Heat Pump (Ground)	100%	88%	79%	75%	71%	68%	64%	61%	59%
Gas Heat Pump	100%	81%	67%	64%	61%	59%	57%	56%	55%
Cogeneration	100%	99%	98%	97%	95%	94%	93%	92%	90%

Source: BMU, 2010 and own amendments

References

Bauermann K., Weber C., Eickholt, V., 2010. Gesetzliche Änderungen: Wirtschaftlichkeit von Heizungssystemen neu hinterfragen. *Energiewirtschaftliche Tagesfragen* Nr. 4/2010, pp. 29-33

Bauermann, K., Weber, C., 2013. Individual choice in a residential building & heating model – An application case for Germany. Working Paper 2/2013, Lehrstuhl für Energiewirtschaft, Essen

Bjørnstad, E., 2012. Diffusion of renewable heating technologies in households. Experiences from the Norwegian Household Subsidy Programme. *Energy Policy*, 48, pp. 148-158

Bemelmans-Vidéc, M.-L., Rist, R.C., Vedung, E., 2010. Carrots, sticks, and sermons: policy instruments and their evaluation. Transaction Publishers, New Brunswick

BDH, 2012. Erhebung bei Mitgliedsunternehmen zu regionalspezifischem Absatz von Heizungsanlagen für 2008 bis 2011. Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V., Köln

BMU, 2010. Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global – Leitstudie 2010. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin.

BMU, 2011. The Energy Concept and its accelerated implementation. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin. Available at: <http://www.bmu.de/en/topics/climate-energy/transformation-of-the-energy-system/resolutions-and-measures/>

BMU, 2012a. Erfahrungsbericht zum Erneuerbare-Energie-WärmeGesetz (EEWärmeG-Erfahrungsbericht). Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin. Available at: <http://www.bmu.de/service/publikationen/downloads/details/artikel/erster-erfahrungsbericht-zum-erneuerbaren-energien-waermegesetz-eewaermeg-beschlossen/>

BMU, 2012b. Richtlinien zur Förderung von Maßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Berlin.

BMWi, 2010. Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. Federal Ministry of Economics and Technology, Berlin

BMWi, 2013. Zahlen und Fakten - Energiedaten – Nationale und Internationale Entwicklung. Referat III C 3, Federal Ministry of Economics and Technology, Berlin. Available at: <http://www.bmwi.de/DE/Themen/Energie/energiedaten.html>

Born, R., Diefenbach, N., Loga, T., 2003. Energieeinsparung durch Verbesserung des Wärmeschutzes und Modernisierung der Heizungsanlage für 31 Musterhäuser der Gebäudetypologie - Studie im Auftrag des Impulsprogramms Hessen - Endbericht. Darmstadt

Braun, D., Giraud, O., 2009. Politikinstrumente im Kontext von Staat, Markt und Governance. In: Schubert, K., Bandelow, N. (Eds.), Lehrbuch der Politikfeldanalyse 2.0, Oldenbourg, München, pp. 159-187

Bundesgesetzblatt, 1976. Gesetz zur Einsparung von Energie in Gebäuden (Energieeinsparungsgesetz – EnEG). Jahrgang 1976, Teil I, pp. 1873, Bonn

Bundesgesetzblatt, 1977. Verordnung über einen energiesparenden Wärmeschutz bei Gebäuden - (Wärmeschutzverordnung – WärmeschutzV), Jahrgang 1977, Teil I, pp. 1554-1565, Bonn

Bundesgesetzblatt, 1978. Verordnung über energiesparende Anforderungen an heizungstechnische Anlagen und Brauchwasseranlagen (Heizungsanlagen-Verordnung - HeizAnV), Jahrgang 1978, Teil I, p. 1581, Bonn

Bundesgesetzblatt, 2001. Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung - EnEV). Teil I, Nr. 59, p. 3085, Bonn

Bundesgesetzblatt, 2008a. Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich (Erneuerbare-Energien-WärmeGesetz – EEWärmeG). Jahrgang 2008, Teil I, Nr. 36, pp. 1659-1665, Bonn

Bundesgesetzblatt, 2008b. Gesetz zur Neuregelung des Rechts Erneuerbarer Energien im Strombereich und zur Änderung damit zusammenhängender Vorschriften. Teil I, Nr. 49, pp. 2074-2100, Bonn

Bundesgesetzblatt, 2009. Verordnung zur Änderung der Energieeinsparverordnung. Teil I, Nr. 23, pp. 954-989, Bonn

Bürger, V., Klinski, S., Lehr, U., Leprich, U., Nast, M., Ragwitz, M., 2008. Policies to support renewable energies in the heat market. Energy Policy, 36, pp. 3150-3159

Cansino, J. M., del P. Pablo-Romero, M., Román, R., Yñiguez, R., 2011. Promoting renewable energy sources for heating and cooling in EU-27 countries. *Energy Policy*, 39, pp. 3803-3812

Council of the European Union, 2008. Energy/Climate Change – Elements of the final compromise. Council of the European Union, Brussels. Available at:

<http://www.consilium.europa.eu/uedocs/cmsUpload/st17215.en08.pdf>

Diefenbach, N., Born, R., 2007. Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie. Institut Wohnen und Umwelt, Darmstadt

Diefenbach, N., Cischinsky, H., Rodenfels, M., Clausnitzer, K.-D., 2010. Datenbasis Gebäudebestand Datenerhebung zur energetischen Qualität und zu den Modernisierungstrends im deutschen Wohngebäudebestand. Institut Wohnen und Umwelt/Bremer Energie Institut, Darmstadt

Dieckhöner, C., Hecking, H. 2012. Greenhouse Gas Abatement Cost Curves of the Residential Heating Market – a Microeconomic Approach. *EWI Working Paper*, No.12/16, Köln

Diefenbach, N., Cischinsky, H., Rodenfels, M., Clausnitzer, K.-D., 2010. Datenbasis Gebäudebestand - Datenerhebung zur energetischen Qualität und zu den Modernisierungstrends im deutschen Wohngebäudebestand. Institut Wohnen und Umwelt (IWU), Bremer Energie Institut (bei), Darmstadt

Diekmann, J., Hopf, R., Ziesing, H.-J., Kleemann, M., Krey, V., Markewitz, P., Martinsen, D., Vögele, S., Eichhammer, W., Jochem, E., Mannsbart, W., Schломann, B., Schön, M., Wietschel, M., Matthes, F., Cames, M., Harthan, R., 2005. Klimaschutz in Deutschland bis 2030 - Endbericht zum Forschungsvorhaben, Politikszenerarien III, Studie im Auftrag des Umweltbundesamtes. Deutsches Institut für Wirtschaftsforschung (DIW), Forschungszentrum Jülich, Fraunhofer-Institut für System- und Innovationsforschung (ISI) und Öko-Institut

Ebert, M., Bohnenschäfer, W., 2008. Vollkostenvergleich Heizsysteme - Informationen für Verbraucher vom IE Leipzig. Leipzig

Ericsson, K., 2009. Introduction and development of the Swedish district heating systems - Critical factors and lessons learned. *RES-H Policy*, Lund. Available at:

http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_%28D5%29_final.pdf

European Commission, 2011. Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the regions – Energy Efficiency Plan 2011. European Commission, Brussels. Available at:

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0109:FIN:EN:PDF>

European Parliament, 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. *Official Journal of the European Communities*, Brussels. Available at: <http://eur-ex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF>

European Parliament, 2012. Directive 012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing directives 2004/8/EC and 2006/32/EC. *Official Journal of the European Communities*, Brussels. Available at:

<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:EN:PDF>

Federal Statistical Office, 2006. Bevölkerung Deutschlands bis 2050. 11. Koordinierte Bevölkerungsvorausberechnung, Wiesbaden

Federal Statistical Office, 2011. Bevölkerung und Erwerbstätigkeit – Entwicklung der Privathaushalte bis 2030 – Ergebnisse der Haushaltsvorausberechnung. Wiesbaden

Federal Statistical Office, 2010. Fachserie 5 Heft 1, Bauen und Wohnen Mikrozensus – Zusatzerhebung 2010, Bestand und Struktur der Wohneinheiten, Wohnsituation der Haushalte. Wiesbaden. Available at:

<https://www.destatis.de/DE/Publikationen/Thematisch/EinkommenKonsumLebensbedingungen/Wohnen/WohnsituationHaushalte2055001109004.pdf?blob=publicationFile>

- Federal Statistical Office, 2012a. Umweltnutzung und Wirtschaft - Tabellen zu den Umweltökonomischen Gesamtrechnungen - Teil 3: Luftemissionen. Wiesbaden
- Federal Statistical Office, 2012b. Bauen und Wohnen - Baugenehmigungen / Baufertigstellungen von Wohn- und Nichtwohngebäuden (Neubau) nach Art der Beheizung und Art der verwendeten Heizenergie, Lange Reihen ab 1980. Wiesbaden. Available at: <https://www.destatis.de/DE/Publikationen/Thematisch/Bauen/BautaetigkeitWohnungsbau/BaugenehmigungenHeizenergie.html>
- Federal Statistical Office, 2012c. Mikrozensus – Zusatzerhebung 2010 Bestand und Struktur der Wohneinheiten Wohnsituation der Haushalte. Wiesbaden. Available at: <https://www.destatis.de/DE/Publikationen/Thematisch/EinkommenKonsumLebensbedingungen/Wohnen/WohnsituationHaushalte.html>
- Howlett, M., Ramesh, M., 1995. Studying public policy: Policy cycles and policy subsystems. Oxford University Press, Don Mills
- IEA, 2012. World Energy Outlook 2013. Part A Global Energy Trends, Understanding the scenarios, International Energy Agency, Paris, p. 41
- Kesicki, F., Strachan, N., 2011. Marginal abatement cost (MAC) curves: confronting theory and practice. Environmental Science & Policy, Volume 14, Issue 8, December 2011, pp. 1195-1204
- KfW, 2013. Energieeffizient Sanieren. Kreditanstalt für Wiederaufbau. Available at: <https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilien/Energetische-Sanierung/>
- Kirchner, A., Matthes, F.C., 2009. Modell Deutschland - Klimaschutz bis 2050 – Vom Ziel her denken. WWF Deutschland, Basel, Freiburg
- Koepfel, S., Ürge-Vorsatz, D., 2007. Assessment of policy instruments for reducing greenhouse gas emissions from buildings. Report for the UNEP-Sustainable Buildings and Construction Initiative, Central European University, Budapest
- Kranzl, L., Hummel, M., Müller, A., Steinbach, J., 2013. Renewable heating: Perspectives and the impact of policy instruments. Energy Policy 59, pp. 44-58
- Labandeira, X., Linares, P., 2010. Second-best Instruments for Energy and Climate Policy. Working Paper 06/2010, economics for energy, Vigo. Available at: <http://www.eforenergy.org/en/publicaciones.php>
- Langniß, O., Schüller, M., Wülbeck, H.-F., 2009. Evaluierung von Einzelmaßnahmen zur Nutzung erneuerbarer Energie im Wärmemarkt (Marktanreizprogramm) für den Zeitraum 2009 bis 2011 – Evaluierung des Förderjahres 2009 – Zwischenbericht Dezember 2010. Ausarbeitung im Auftrag des Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
- Michelsen, C.C., Madlener, R., 2012. Homeowners' Preferences for Adopting Innovative Residential Heating Systems: A Discrete Choice Analysis for Germany. Energy Economics, 34(5), pp. 1274-1283
- Neitzel, M., Lindert, R., 2012. Teilbericht A, in: Ökologische und ökonomische Optimierung des Wärmemarktes unter besonderer Berücksichtigung des Endenergiebedarfs und von Biogas/Bioerdgas, biogasrat, Stuttgart, pp. 27-107
- Newell, R.G., Pizer, W.A., 2008. Indexed regulation. Journal of Environmental Economics and Management. 56, pp. 221-233

- Olonscheck, M., Holsten, A., Kropp, J.P., 2011. Heating and cooling energy demand and related emissions of the German residential building stock under climate change. *Energy Policy* 39, pp: 4795–4806
- Paar, A., Ochse, S., Huther, H., 2013. Transformationsstrategie von fossiler zentraler Fernwärmeversorgung zu netzen mit höheren Anteilen erneuerbarer Energien. Endbericht, Heidelberg, Leimen, Frankfurt am Main
- Pigou, A.C., 1920. *The Economics of Welfare*. 4th ed. Macmillan and Co., London
- Schäfer, C., Weber, C., Voss'-Uhlenbrock, H., Schuler, A., Oosterhuis, F., Nieuwlaar, E., Angioletti, R., Kjellsson, E., Leth-Petersen, S., Togeby, M., Munksgaard, J., 2000. Effective policy instruments for energy efficiency in residential space heating : an international empirical analysis (EPISODE), IER, Stuttgart
- Schimschar, S., Blok, K., Boermans, T., Hermeling, A., 2011. Germany's path towards nearly zero-energy buildings – Enabling the greenhouse gas mitigation potential in the building stock. *Energy Policy*, 39, pp. 3346-3360
- Schlesinger, M., Hofer, P., Rits, V., Lindenberger, D., Wissen, R., Bartels, M., 2007. *Energieszenarien für den Energiegipfel 2007*. Bundesministeriums für Wirtschaft und Technologie, Berlin
- Schlesinger, M., Lindenberger, D., Lutz, C., 2010. *Energieszenarien für ein Energiekonzept der Bundesregierung – Projekt Nr. 12/10 des Bundesministeriums für Wirtschaft und Technologie*, Berlin, Basel, Köln, Osnabrück
- Schmid, E., Knopf, B, Pahle, M , 2012. *Renewable Electricity Generation in Germany: A Meta-Analysis of Mitigation Scenarios*. Working Paper, Potsdam Institute for Climate Impact Research, <http://www.pik-potsdam.de/members/schmid/schmid/schmid-pahle-knopf-2012--metaanalysis-germany.pdf>
- Schuler, A., Weber, C., Fahl, U., 2000. Energy consumption for space heating of West-German households: empirical evidence, scenario projections and policy implications. *Energy Policy*, 28, pp. 877-894
- Tol, R.S.J., 2013. Carbon Tax: Still the Best Way Forward for Climate Change. *Intereconomics*, 48, pp. 70-71
- Tuominen, P., Klobut, K., Tolman, A., Adjei, A., de Best-Waldhober, M., 2012. Energy savings potential in buildings and overcoming market barriers in member states of the European Union. *Energy and Buildings*, 51, pp. 48-55
- Uihlein, A., Eder, P., 2010. Policy options towards an energy efficient residential building stock in the EU-27. *Energy and Buildings*, 42, pp. 791–798
- Voß, A., Zech, D., 2012. *Dokumentation Heizkostenvergleich*. Institute of Energy Economics and the Rational Use of Energy, Stuttgart
- Wagner, U., 2009. *Energiezukunft 2050 Teil I und II*. Endbericht der Forschungsstelle für Energiewirtschaft e.V. (FfE) in Zusammenarbeit mit dem ifo Institut für Wirtschaftsforschung, München
- Weiss, J., Dunkelberg, E., Vogelpohl, T., 2012. Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany. *Energy Policy*, 44(0), pp: 406-415
- Weitzmann, M.L., 1974. Prices vs. Quantities. *The Review of Economic Studies*, 41, No. 4, pp. 477-491