What drives the impact of future support policies for energy efficiency in buildings?

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Abstract

Policy makers face the challenge to design and test support policies for nearly zero energy buildings (nZEB) – and in general energy efficiency policies – in a real-life laboratory. Model based scenarios are expected to reduce the uncertainties. However, rather than trying to exactly predict the future or the impact of a certain instrument (which will never succeed), the core objective is to understand the drivers affecting the impact of policies on future energy demand in buildings. We will draw nearer to this objective by a comparative analysis of policy scenarios in 9 EU Member States (MSs) and EU-28 as a whole. Thus, the key research questions of this paper are: **(1)** What impact on energy demand, CO_2-emissions and public costs do various policies trigger in scenarios for EU MSs and the EU-28? **(2)** What drives the differences between the scenarios in various countries and policy settings? **(3)** How do the policies compare in terms of their consistency with long-term targets of energy savings and CO_2-reductions? We build this research on three policy sets which were developed in the IEE project ENTRANZE in an interactive discussion process with policy makers: one policy set reflecting current policy instruments and two others with more innovative and ambitious approaches. The potential effect of these policy sets was analysed with the techno-socio-economic bottom-up model Invert/EE-Lab. The model is based on a disaggregated description of the building stock, and its building and HVAC components. The investment decision for various retrofit measures and HVAC systems is modelled under consideration of the characteristics of various country specific agent groups (e.g. low-income households, elderly people, ownership types etc.). The results show a wide range of energy savings for space heating, hot water, cooling and lighting of less than 10 % to more than 30 % from 2008–2030. Remarkably, the highest energy savings were not achieved in those scenarios and countries with the highest public expenses. It turns out that at least a minimum level of regulatory measures increasing "nZEB renovation" activities and renewable heating (RES-H) systems should be added to economic incentives and strong supply – side measures.

Introduction

Policy makers face the challenge to design and test nZEB support policies – and in general energy efficiency policies – in a real-life laboratory. Model based scenarios are expected to reduce the uncertainties. However, rather than trying to exactly predict the future or the impact of a certain instrument (which will never succeed), the core objective is to understand the drivers affecting the impact of policies on future energy demand in buildings. We will draw nearer to this objective by a comparative analysis of policy scenarios in 9 EU Member States (MSs) and EU-28 as a whole.

Thus, the **key research questions** of this paper are:

- What impact on energy demand, CO_2-emissions and public costs do various nZEB support policies trigger in scenarios for EU MSs and the EU-28?
- What drives the differences between the scenarios in various countries and policy settings?
- How do the policies compare in terms of their consistency with long-term targets of energy savings and CO_2-reduction?

After this introduction we document the main pillars of the methodology, i.e. the selection of policies and the policy discussion process, the modelling framework and sources of key input data. This is followed by the scenario results and evaluation. Finally, we draw conclusions and recommendations for future policy making in this field on national and EU level.

Methodology

We build this research on the policy sets which were developed in the IEE project ENTRANZE[1] in an interactive discussion process with policy makers: one policy set reflecting current policies and two others with more innovative and ambitious approaches. Policy instruments include regulatory (e.g. building codes), economic (e.g. subsidies, taxes) and accompanying measures like information campaigns, and last but not least research and technology development. The potential effect of these policy sets was analysed with the techno-socio-economic bottom-up model Invert/EE-Lab. Thus, we start with a description of the policy process and the investigated policies. Consequently, we provide a short overview on the methodology of the model Invert/EE-Lab. The data regarding building stock, techno-economic data, prices etc. are based on the database developed in the project ENTRANZE (corresponding reports and data tools: www.entranze.eu/pub/pub-data). Some key elements of this data collection process and relevant sources are also documented.

POLICY DISCUSSION PROCESS AND INVESTIGATED POLICY INSTRUMENTS

Nine countries have been in the focus of this analysis: AT, BG, CZ, DE, ES, FI, FR, IT, RO. These countries were selected to cover more than 60 % of the EU building stock and to represent a broad range of western, eastern, southern, northern and central European countries. For these countries, detailed policy discussion processes and data collection have been carried out in the project ENTRANZE (see e.g. (Georgiev et al., 2014), (Zahradnik et al., 2014), (Steinbach et al., 2014), (Fernandez-Boneta et al., 2014), (Heiskanen et al., 2014), (Sebi et al., 2014), (Pietrobon et al., 2014), (Atanasiu et al., 2014). For the other EU-28 countries, a generic harmonised policy set has been assumed.

The policy discussion process carried out in the project ENTRANZE (Kranzl et al., 2014c) was based on a continuous exchange with a policy group in every ENTRANZE target country (see list of countries in the previous paragraph). These discussion rounds met four times during the project duration (April 2012–September 2014) and were designed as small groups of policy makers allowing an in-depth discussion of crucial questions of policy making in the corresponding country. One of the key objectives of these meetings was the selection of policy packages to be quantitatively assessed by the model Invert/EE-Lab. The results of the corresponding scenarios were discussed in the policy groups and with other national experts in each target country. The outcome of this discussion process was used to revise the policy and modelling assumptions in an iterative process leading to revised and well based scenario results, broadly accepted by the involved policy makers.

1. For a summary of results see Kranzl et al., (2014c), more reports on policy analyses: www.entranze.eu/pub/pub-policies.

The overall concept was to define three policy scenarios:

1. Policy scenario 1 corresponds to current policies, remaining in place until 2030 or being further developed according to officially adopted plans, as far as such plans exist in a country.
2. Policy scenario 2 introduces new, more innovative policy approaches.
3. Policy scenario 3 increases the ambition level and/or introduces other, innovative policy instruments.

This concept was used as a general framework. However, the very interactive policy discussion led to country specific definitions of policy packages which were considered to be most relevant and interesting for policy makers to be further investigated in the model based analysis. The country specific policy sets included instruments like strengthening building codes (all countries), energy performance dependent real estate taxes (AT), improving economic incentives like investment subsidies or soft loans (BG, CZ, IT, RO), measures how to increase compliance (DE), information and qualification campaigns (BG, DE, FR, RO), obligation for building renovation (FR, ES), energy and CO_2 taxes (FI, FR).

For the other EU-28 countries (covering the remaining 40 % of space heating and hot water energy demand), we assumed harmonised policy packages, with increased, but still moderate ambition in policy scenario 2. They involve intensified information, qualification and training, implementation of RES-H use obligation[2], a moderate increase in energy taxation and a slight increase in budgets for subsidies. In Policy scenario 3 we assume a stronger enforcement of these instruments and assumed the stepwise reduction of barriers, e.g. regarding split incentives.

The scenario results which we will present below exactly refer to this definition of three policy packages.

More information on the details of investigated policy packages is included in Kranzl et al., (2014a).

THE MODEL INVERT/EE-LAB

Invert/EE-Lab is a dynamic bottom-up simulation tool that evaluates the effects of different policy packages (economic incentives, regulatory instruments, information and advice, research and technology development) on the total energy demand, energy carrier mix, CO_2 reductions and costs for space heating, cooling, hot water preparation and lighting in buildings. Furthermore, Invert/EE-Lab is designed to simulate different scenarios (energy prices, renovation packages, different consumer behaviours, etc.) and their respective impact on future trends of energy demand and mix of renewable as well as conventional energy sources on a national and regional level. More information is available e.g. in Müller, (2012), Kranzl et al., (2013) or Kranzl et al., (2014a) The model has been ex-

2. RES-H use obligations should be implemented by the end of 2014 according to the renewable energy directive, Article 13 (4): “By 31 December 2014, Member States shall, in their building regulations and codes or by other means with equivalent effect, where appropriate, require the use of minimum levels of energy from renewable sources in new buildings and in existing buildings that are subject to major renovation.” However, real implementation is still vague. See e.g. Atanasiu et al., (2013).

tended by an agent specific decision approach documented e.g. in (Steinbach, 2013a), (Steinbach, 2013b).

The key idea of the model is to describe the building stock, heating, cooling and hot water systems on highly disaggregated level, calculate related energy needs and delivered energy, determine reinvestment cycles and new investment of building components and technologies and simulate the decisions of various agents[3] (i.e. owner types) in case that an investment decision is due for a specific building segment.

The model Invert/EE-Lab up to now has been applied in all countries of **EU-28 (+ Serbia)**. A representation of the implemented data of the building stock is given in the online ENTRANZE – Data Tool (http://www.entranze.eu/tools/interactive-data-tool). Invert/EE-Lab covers **residential and non-residential buildings**. Industrial buildings are excluded (as far as they are not included in the official statistics of office or other non-residential buildings).

The **core of the simulation model** is a myopical[4] approach which optimizes objectives of agents under imperfect information conditions and by that represents the decisions concerning building related investments. It applies a nested logit approach in order to calculate market shares of heating systems and energy efficiency measures depending on building and investor type.

The model allows the definition of **different owner types** as instances of predefined investor classes: owner occupier, private landlords, community of owners (joint-ownership), and housing association. The structure is motivated by different perspectives regarding building related investments. For instance, energy cost savings are only relevant for those owners which occupy the building. The corresponding variable relevant to landlords is a refinancing of energy savings measures through additional rental income (investor-tenant dilemma).

Owner types are differentiated by their investment decision behaviour and the perception of the environment. The former is captured by investor-specific weights of economic and non-economic attributes of alternatives. The perception relevant variables – information awareness, energy price calculation, risk aversion – influence the attribute values. The modelling of agents has been done country specific, according to the characteristic situation, the relevance of various groups and data availability. The groups of agents can also take into account e.g. low-income households, elderly people. More information on specific selection and description of these groups is documented in Heiskanen and Matschoss, (2012) and Heiskanen et al., (2013). For more details on the modelling of these aspects in Invert/EE-Lab see Steinbach, (2013a) and Steinbach, (2013b).

Invert/EE-Lab models the decision making of investors regarding building renovation and heating, hot water and cooling systems. **Policy instruments** may affect these decisions (in reality and in Invert/EE-Lab) in the following ways:

3. For details regarding the modelling and clustering of agents please see the description in this chapter below.

4. The myopical approach implies that the model does not include a perfect foresight optimisation. We assume that investors optimize over the whole considered depreciation time. However, the investors are not (or only partly) aware that energy prices or investment costs might change over time.

- Economic incentives change the economic effectiveness of different options and thus lead to other investment decisions. This change leads to higher market share of the supported technology in the Invert/EE-Lab (via the nested logit approach).
- Regulatory instruments (e.g. building codes or renewable heat obligations) restrict the technological options that decision makers have; limited compliance with these measures can be taken into account by limiting the information level of different agents regarding this measure (see next bullet point).
- Information, advice, etc.: Agents have different levels of information. Lack of information may lead to neglecting of innovative technologies in the decision making process or to a lack of awareness regarding subsidies or other support policies. Information campaigns and advice can increase this level of information. Thus, the consideration of innovative technologies, knowledge about support programmes and compliance with regulatory standards increases.
- R&D can push technological progress. The progress in terms of efficiency increase or cost reduction of technologies can be implemented in Invert/EE-Lab.

Standard outputs from the Invert/EE-Lab on an annual basis are:

- Installation of heating and hot water systems by energy carrier and technology (number of buildings, number of dwellings supplied).
- Refurbishment measures by level of refurbishment (number of buildings, number of dwellings).
- Total delivered energy by energy carriers and building categories (GWh).
- Total energy need by building categories (GWh).
- Policy programme costs, e.g. support volume for investment subsidies (M€).
- Total investment (M€).

Moreover, Invert/EE-Lab offers the possibility to derive more detailed and additional result evaluations.

DATA: BUILDING STOCK, TECHNO-ECONOMIC DATA ETC.

The model Invert/EE-Lab requires the following main categories of input data:

- Disaggregated description of the building stock: The scenarios presented in this paper are based on the building stock data documented in the ENTRANZE online data tool[5]. This takes into account data from Eurostat, national building statistics, national statistics on various economic sectors for non-residential buildings, BPIE data hub, Odyssee, which are finally summarized in the ENTRANZE database.

5. Available at www.entranze.eu. State of data June 2014.

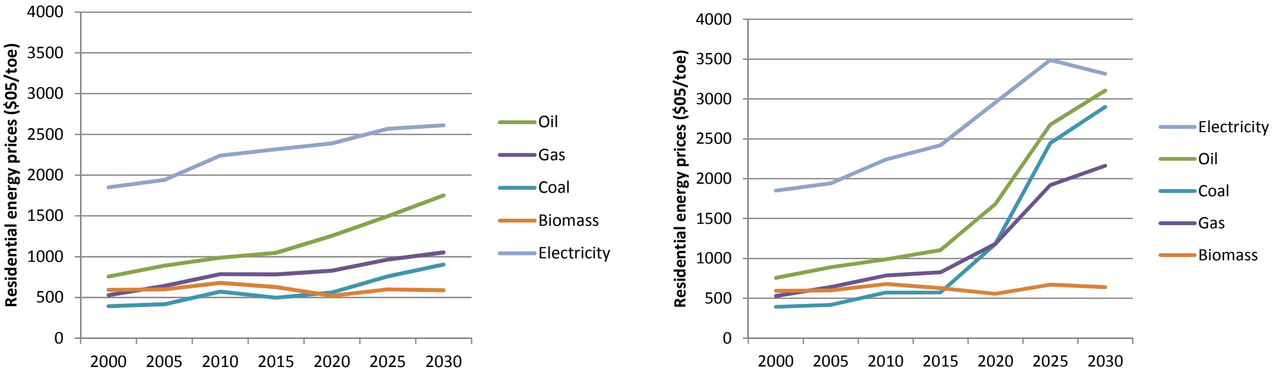

Figure 1. Residential and tertiary energy price scenarios for EU27 average reference scenario (left) and ambitious scenario (right). Source: POLES-Enerdata, (Sebi et al., 2013).

- As efficiency technologies Invert/EE-Lab models the uptake of different levels of renovation measures (country specific) and the diffusion of efficient heating, hot water, cooling and lighting technologies. Related cost data and techno-economic data (e.g. efficiencies, U-values etc.) are based on (Fernandez-Boneta, 2013) and (Pietrobon et al., 2013). These reports document the collection of cost data for these technologies in various countries in Europe as well as cost-optimality calculations of building renovation measures.
- For those measures leading to a reduction of the energy need (e.g. renovation of building envelope or heat recovery systems) Invert/EE-Lab requires a set of pre-defined renovation packages from which agents may select. The selection and definition of these renovation packages was done based on the cost-optimality calculations in the project ENTRANZE (Pietrobon et al., 2013) and the derived energy-cost matrices (Fernandez-Boneta, 2014). Based on these calculations, three packages have been selected: The standard renovation package more or less reflects the current practice of thermal building renovation, the “good” renovation package reflects a set of measures near the cost-optimality point whereas the “ambitious” renovation package refers to a level of renovation which is near the “minimum primary energy” level as indicated in Pietrobon et al., (2013). According to our understanding of the EPBD-recast’s intention we call this ”nZEB renovation”, being well aware that this term is yet vague and even not existing in most EU Member States.
- Energy prices are based on POLES scenarios, see Figure 1.

Results

Based on the data sources and assumptions outlined above, we used the model Invert/EE-Lab to develop six scenarios: The three policy sets described above (chapter “Policy discussion process and investigated policy instruments”) under two energy price scenarios. Figure 2 indicates the energy carrier mix for space heating, hot water, cooling and lighting as well as PV generation for EU-28 in all calculated scenarios. Due to high fuel costs, heating oil systems are more and more being phased out in all scenarios[6]. However, natural gas still plays a crucial role up to 2030, though with different intensities in various scenarios. Almost 50 % of final energy demand for heating and hot water is covered by natural gas in 2008, (about 1,900 TWh or 165 Mtoe). According to the scenarios presented here, the business-as-usual framework could reduce natural gas demand in 2030 by about 21–31 % and under policy scenario 3 by 36–45 %. Thus, energy dependency regarding natural gas could be halved by 2030. All scenarios show a significant growth of solar and ambient energy. Ambient energy[7] is accounted according to the reporting requirements of Member States for the renewable energy directive (see Kranzl et al., 2014a).

Besides the overall economic attractiveness of renewable heat (RES-H) compared to other heating systems, the growth of renewable heat in the model is mainly driven by the following policy instruments:

- Economic incentives, e.g. CO_2- and fossil energy prices or investment subsidies for RES-H systems
- RES-H use obligations according to the renewable energy directive Art 13 (4), see footnote 2.
- Research and technology development affecting possible future cost development.

In our scenarios, RES-H use obligations are in place in many countries in scenario 2 and 3 (see also chapter “Policy discussion process and investigated policy instruments”) as well as economic incentives (investment subsidies for most countries and CO_2-taxes in selected scenarios for FI and FR).

This leads to the result that the share of RES-H increases from about 12 % in 2008 to about 25–29 % in 2030 under policy scenario 1 (under low and high energy prices respectively) and to 28 %–33 % under more ambitious policies. However, considerable uncertainties remain, e.g. regarding the growth of solar thermal.

6. It remains an open question, to which extent the currently lower heating oil prices might affect this development. However, in most countries we can observe a significant and steady decline in heating oil consumption during the last years.

7. Ambient energy is the energy which is extracted with heat pumps from the environment (ground, air or water) and thus reflects a renewable part of the energy used by heat pumps.

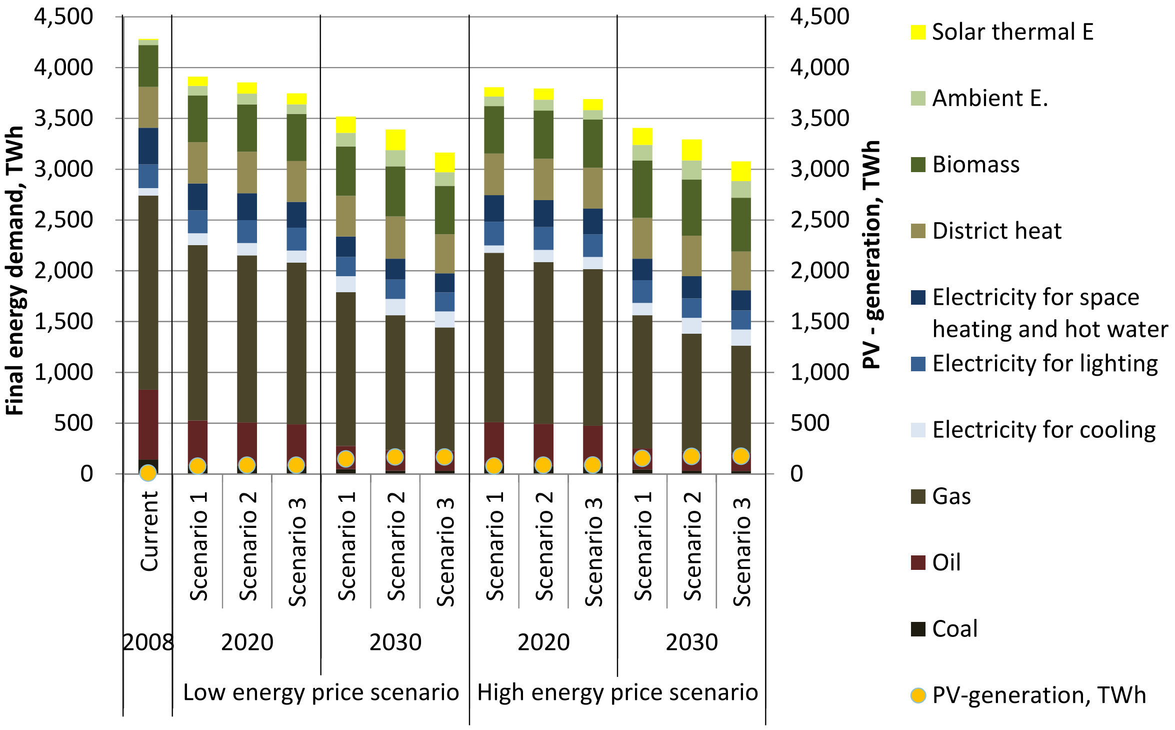

Figure 2. Final energy demand for space heating, hot water, cooling and lighting by energy carriers in EU-28 in policy scenarios 1, 2 and 3. Roof-top PV generation. Policy scenario 1 reflects current policies and business-as-usual developments. Policy scenarios 2 and 3 reflect more innovative and stepwise more ambitious policy packages.

In contrast to renovation of the building envelope, the growth of renewable heating technologies can happen faster since heating system change rates typically are higher than renovation rates.[8] This is one of the reasons why the growth of renewables is more sensitive regarding the level of energy prices than the renovation activities and overall energy demand.

The increasing energy performance of the building stock, the strong phase-out of heating oil and coal in the building sector, which could occur in the coming decades (partly due to environmental and climate policy considerations and partly due to higher comfort requirements and high fuel prices) and the expected move towards the decarbonisation of the electricity sector leads to a reduction of total CO_2-emissions for space heating, hot water, cooling and lighting from 43–50 % in policy scenario 1 and 50–57 % in policy scenario 3 from 2008 to 2030 under low and high energy prices, respectively.

The **renovation rate** of the building stock and thus the cumulated share of renovated buildings are often referred as the main indicator of effective policies[9]. Figure 4 shows that there is also a clear connection between renovation rate and energy savings in different scenarios, shown here for the nine target countries. However, it is not only the renovation rate which matters. Even more, and in particular in the period beyond 2030, **renovation depth**, i.e. the level of achieved energy savings in renovated buildings, matters. Shallow renovation activities lead to the fact that these buildings are probably lost for high energy performance standards until 2050 (and even beyond). Thus, shallow renovation leads to considerable lock-in effects.

Figure 4[10] shows that Germany achieves the highest savings (more than 30 %) of final energy demand for space heating and hot water with about 30 % of renovated floor area in the 22 years period in the most ambitious policy set, whereas the cases of Italy and Spain achieve even higher cumulated renovation rates (34 % and more than 40 %, respectively), however with lower energy savings (about 25 %). Reasons for these variations are different renovation depths, but also climatic differences and disparities in the existing building stock.

The figure also shows that except for Finland in all countries energy savings of at least 20 % from 2008–2030 can be achieved. So, it becomes clear that not only in countries with low tradition of energy performance standards (e.g. Bulgaria, Romania) high efficiency potentials exist, but also in countries like Germany and Austria.

8. Both heating system change rate and thermal renovation rate are endogenous results from the model Invert/EE-Lab, resulting from the vintage structure of buildings (and thus the average age of building components), historical renovation and heating system change activities and typical average life time distributions of building components. Thus, these rates vary between countries, scenarios and years. Figure 4 shows (cumulated) renovation rates for several scenarios and countries. Annual thermal renovation rates vary between below 0.5 % and about 1.8 %. Heating system exchange rates are typically in the range of 2 %–4.5 %.

9. This statement can be underlined by energy strategies which include targets to increase the thermal renovation rate without a clear statement on the renovation depth, see e.g. the Austrian energy strategy document 2010 (Bundesministerien für Wirtschaft, Familie und Jugend sowie Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2010).

10. Due to the fact that only about 10 % of the considered final energy demand account for lighting and cooling, we decided to focus on space heating and hot water in Figure 4–7.

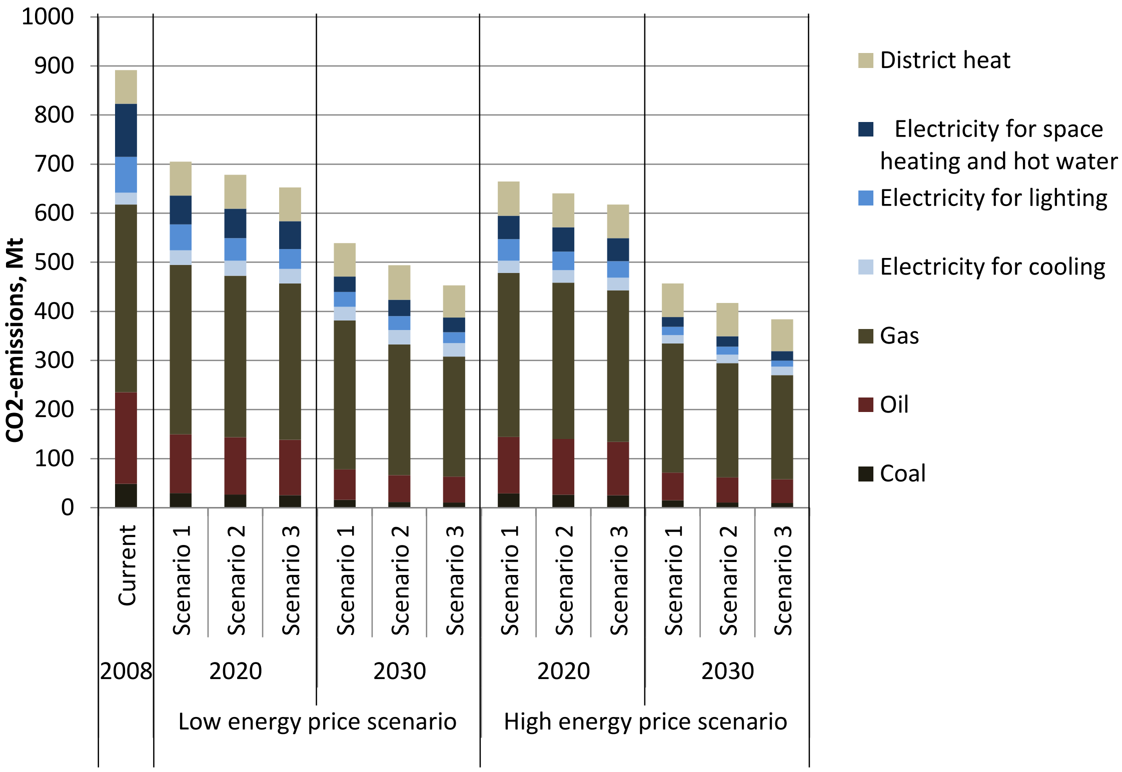

Figure 3. CO_2-emissions caused by energy demand for space heating, hot water, cooling and lighting by energy carrier in EU-28, in policy scenario 1, 2 and 3, low and high energy price scenarios.

What are the reasons for different energy savings in the countries in detail?

On the one hand, the **market share of different renovation depths** provides an explanation for the different energy savings in different countries. On the other hand, there is also a difference in the definition renovation depths between the countries.[11] For each country, we defined three renovation packages according to cost-optimality calculations. Thereby, our approach for the definition of these renovation packages followed the following approach (for details see Kranzl et al., 2014a):

- "Standard renovation": reflects current practice of renovation activities.
- "Good renovation": reflects measures near the cost-optimal point.
- "nZEB renovation": reflects measures near the "minimum primary energy" level as indicated in (Pietrobon et al., 2013). Thus, we decided to label this ambitious level of renovation as "nZEB renovation", although we are aware that this term is not (yet) clearly defined in most Member States and that existing definitions might also deviate from our approach.

Thus, the different climatic conditions and different reference buildings which are typical for different countries also lead to different definitions of most economic renovation packages for achieving certain energy performance levels.

11. See: http://www.entranze.eu/pub/pub-scenario.

So, in a similar way as we defined country specific policy packages in discussion with national policy makers, we also defined country specific renovation packages based on cost-optimality calculations. The sum of all country scenarios were aggregated to EU28 results, thus reflecting the different country specific conditions and constellations which we also observe in reality.

Overall, the cumulated share of buildings with "nZEB renovation" for each of the countries varies between 15 % e.g. in the least ambitious policy scenario 1 (low energy prices) for Bulgaria and up to 60 % and beyond in the most ambitious policy scenario 3 (low energy prices) for the cases like Spain, Czech Republic or Romania. This indicates that in the latter examples, the policy group decided to analyse either more rigorous regulatory schemes including compliance measures for building renovation or specific incentives for "nZEB renovation". Where the impact of "nZEB renovation" might only partly be visible in the scenario results for 2030, previous studies have shown their essential impact for avoiding lock-in effects and for achieving ambitious energy and GHG saving targets in the building stock until 2050, e.g. Ürge-Vorsatz et al., (2011), Henning et al., (2013), Müller et al., (2010), IEA, (2013).

The share of "nZEB" renovation in the overall renovation activities increases in our scenarios to only about 25 % under BAU-policies and to about 50 % under policy scenario 3 for the EU28. Although 50 % of "nZEB" renovation would be a strong improvement compared to the current state, we want to emphasise that the remaining 50 % are locked-in for more substantial improvements until the middle of the century. Thus, the activities to improve high quality renovation, leading

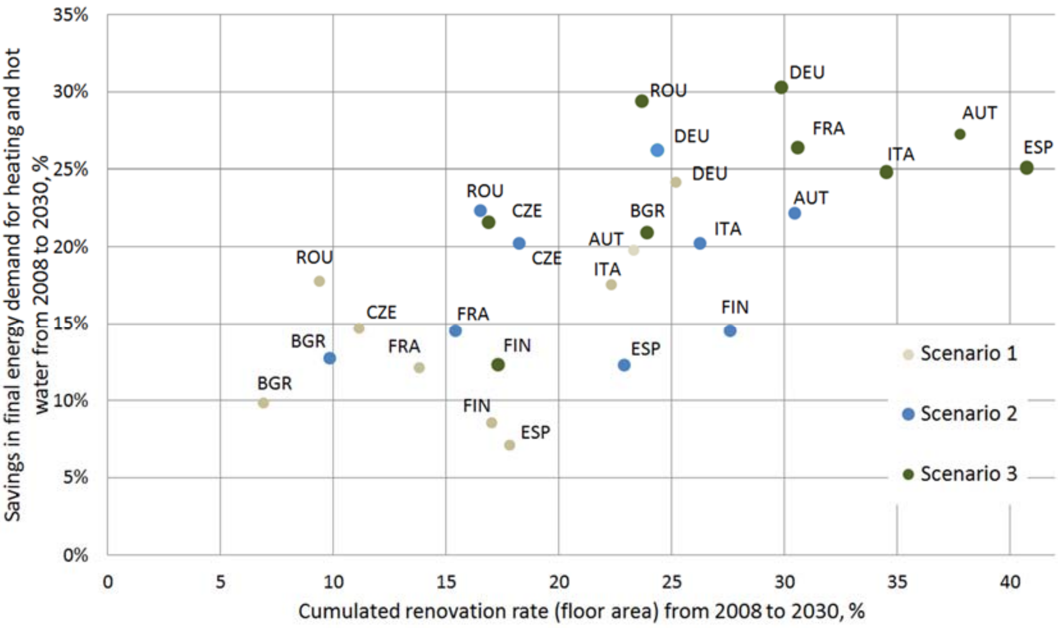

Figure 4. Savings in final energy demand for space heating and hot water from 2008 to 2030 and cumulate renovation rate from 2008 to 2030, low energy price scenario.

to substantial savings per floor area, have to be substantially increased.

Figure 5[12, 13, 14] shows final energy demand for space heating per useful floor area with and without climate correction[15]. In the base year, Finland, Austria and Czech Republic have the highest specific final energy consumption (without climate correction) amongst the ENTRANZE target countries. This top position results from the countries' climate conditions, user behaviour, mix of installed heating systems and overall energy performance of the building stock. However, the climate corrected values show that the Finnish building stock is among the most efficient ones, whereas Italy and France have the highest specific energy demand. This Finnish success, is the effect of early introduction of energy performance requirements in the Finnish building codes (Heiskanen et al., 2014). Subsequently, the potential for efficiency improvement is lower compared to that in other countries with the remaining potential being less economic than in other countries.

Since the graph does not show energy needs but total final energy consumption (for 2008) and total final energy demand (for the scenario years), it also implicitly includes user behaviour, and comfort levels (and corresponding changes of comfort levels until 2030). The low values of specific climate corrected energy demand in 2008 in countries like Bulgaria and Spain are mainly due to low comfort level and not due to high energy performance of the building stock. Thus, it is most likely that in these countries increasing comfort requirements in the coming years will compensate for the energy efficiency gains (e.g. by higher effective indoor temperature after building envelope insulation). Also the share of local room heaters plays a strong role. This share is particularly high in Bulgaria, Spain (and to some extent Romania). Due to the fact that the comfort level (service factor) of room heating systems in practice is significantly lower than for central heating systems, the shift from room heating (like solid fuel single stoves) to central heating systems may lead to an increase of final energy demand, since the increasing comfort outweighs the efficiency gains of the heating systems. Besides the different policy ambition levels, this is also one of the reasons for lower energy efficiency gains in the Bulgarian policy scenario 1 compared to countries like Italy or the Czech Republic.

The case of Bulgaria also reveals that the current policies have a very low impact due to high barriers and transaction costs (see Kranzl et al., 2014c, chapter 8).

Energy efficiency measures are typically associated with corresponding investments. Figure 6 shows the energy savings from 2008–2030 and the related specific investments per total floor area for each target country and scenario. Within the scenarios for each country we see a clear trend of higher investments leading to higher energy savings. The differences between countries are due to differences in climatic conditions, cost structure and quality of the existing building stock and, thus, existing energy efficiency potentials, rebound effects, change of heating systems etc. The contrasting results between countries to some extent also reveal different policy settings. For example, in the Czech Republic, policy makers were interested to see the effect of implementing mandatory standards for building renovation a few years earlier in policy scenario 3 as in policy scenario 2. The result was that this measure alone only

12. Specific final energy demand is calculated by dividing total final energy demand through useful floor area. Useful floor area in general is about 20 % lower than total building floor area.

13. Climate correction has been done on the basis of mean heating degree days in EU-27 from 2000–2009. See also explanation in footnote 15.

14. Due to constraints in the length of the paper we only show the low energy price scenario results here.

15. Climate corrections enable to compare European countries without the influence of the climatic conditions. The calculation of climate corrected final energy demand is based on the specific energy demand in a certain country, HDD (heating degree days) in EU-27 and HDD in the estimated country. Mean HDD are taken from the Eurostat statistic which provides mean HDD in EU-27 and in each European country from 2000 to 2009 (Eurostat 2014).

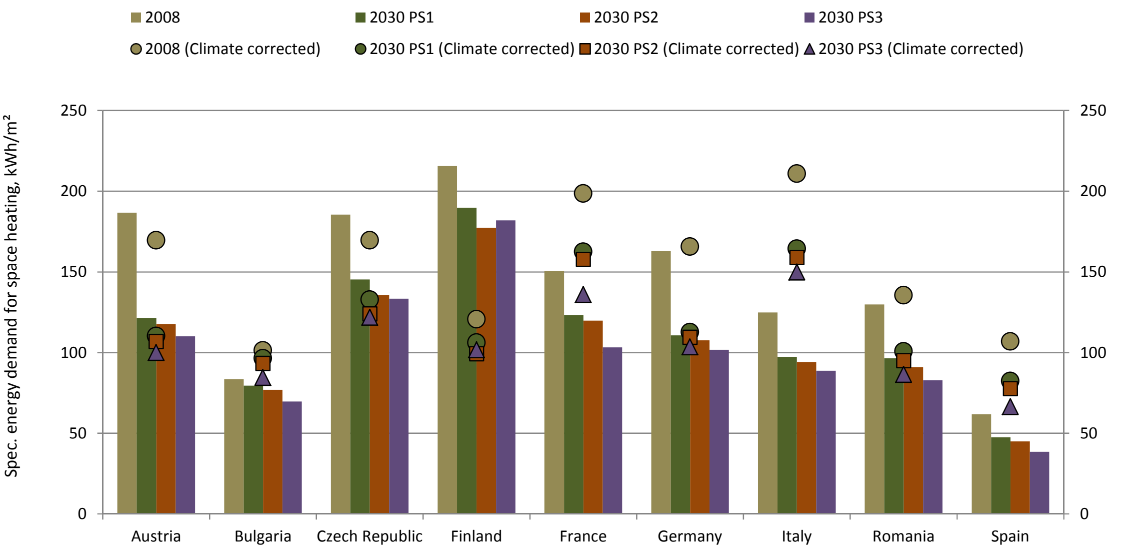

Figure 5. Specific final energy demand per floor area for space heating and climate corrected specific final energy demand per floor area for space heating in target countries in 2008 and 2030 in policy scenario 1 (PS1), policy scenario 2 (PS2) and policy scenario 3 (PS3), low energy prices.

leads to limited additional energy savings (and also only limited additional investments), because of low renovation rates and the high inertia of the building stock. On the other hand, the French policy makers designed a very ambitious policy package as policy scenario 3.This scenario is mainly based on strong regulatory measures like renovation obligations in case of real estate transactions, accompanied with economic incentives, information and qualification measures. This package of measures induced a much stronger effect than an increase in energy taxation in policy scenario 2 (Sebi et al., 2014).

For the indicator on the x-axis in Figure 6[16, 17, 18], total floor area includes the *total* useful building stock floor area, not only the renovated floor area, in order to allow for a proper comparison between the scenarios and countries.[19] Thus, this amount is substantially lower than investments per *renovated* floor area.

A key element of investigated policy packages is investment subsidies for thermal building renovation. Figure 7[20, 21] links savings in final energy demand with public expenses. These subsidies are granted for energy efficiency improvement of building envelopes in different scenarios. Again, please note that we relate the costs to the *total* floor area, not to the *renovated* floor area.

The figure shows that those countries and scenarios with the highest public expenses per total floor area not necessarily achieve the highest savings. There are several drivers for the results in this graph: (i) regional differences as explained above for the case of investments and savings; (ii) different designs of policies and the relevance of economic support instruments in the policy packages. Obviously, policy packages with a strong regulatory element may achieve substantially higher energy savings with the same amount of public expenses for investment subsidies.

Examples for such policy scenarios are the ambitious policy scenario 3 in France, which accomplishes energy savings of about 27 % from 2008–2030 with public expenses for subsidies of less than €2/m² total floor area. This is achieved with a mix of regulatory instruments (obligation to renovate the least efficient buildings in case of real estate transactions), moderate subsidies and strong target oriented information instruments and coaching (Sebi et al., 2014). Thus, the case of the French policy scenario 3 indicates a strong potential impact of regulatory measures: Due to the introduction of a renovation obligation in case of real estate transactions (Sebi et al., 2014), renovation activities and corresponding energy savings are strongly increased (in particular because the obligation is targeted on the least efficient buildings) with very limited public expenses (although much higher investments as shown in Figure 6). It remains open, to which extent such a policy instrument would be realisable.

The German scenarios show the impact of stepwise increasing compliance and information measures to ensure a high effectiveness of regulatory instruments (Steinbach et al., 2014). These examples are in strong contrast to scenarios e.g. for Austria. Scenario 2 leads to 22 % energy savings from 2008–2030 with about €16.5/m² public expenses per total floor area. Sce-

16. Please take into account that total floor area includes the whole building stock floor area, not only the renovated floor area, in order to allow for a proper comparison between the scenarios and countries.

17. There is one outlier indicating results for Finland excluded from the graph. Policy scenario, saving in energy demand for space heating and hot water from 2008 to 2030 and cumulated public expenses in building renovation from 2008 to 2030 are as follows: Policy Scenario 2, 15 % and €197/m² for Finland.

18. Results for the high energy price scenario are shown in the annex.

19. The investments per renovated floor area would be mainly an indicator of the specific investment costs in the different countries. However, what we want to show here is the overall cumulated investments in relation to the overall size of the building stock of a country.

20. Due to constraints in the length of the paper we only show the low energy price scenario results here.

21. There are two outliers indicating results for Austria and Finland excluded from the graph. Policy scenario, saving in energy demand for space heating and hot water from 2008 to 2030 and cumulated public expenses in building renovation from 2008 to 2030 are as follows: Policy Scenario 3, 25 % and €27/m² for Austria and Policy Scenario 2, 15 % and €27/m² for Finland.

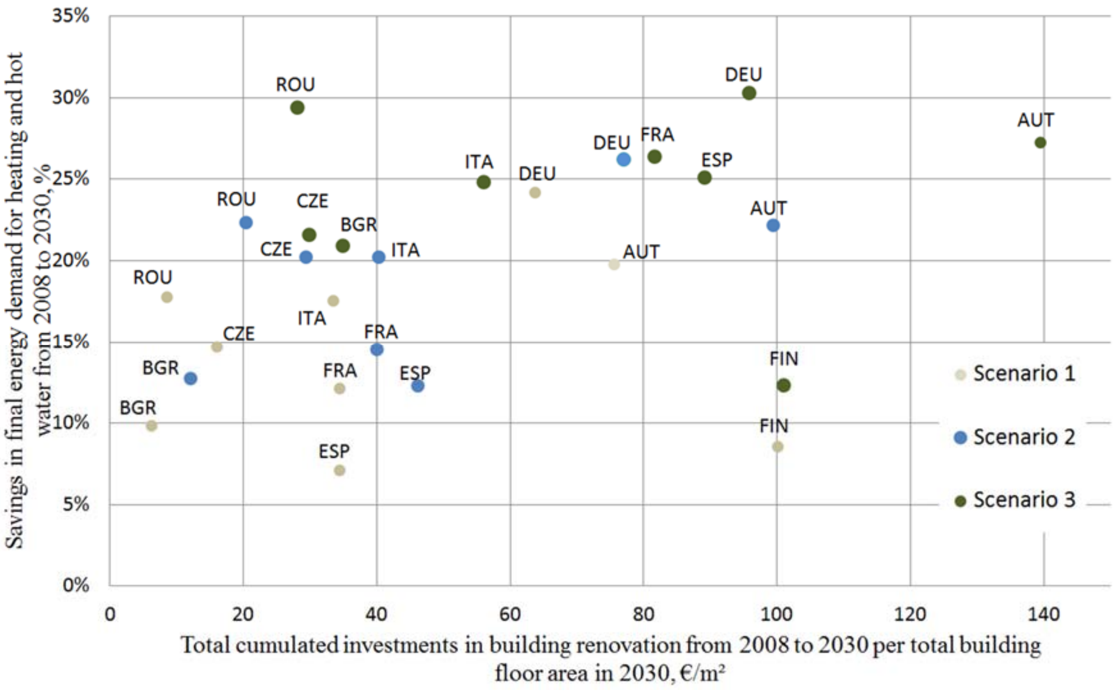

Figure 6. Savings in final energy demand for space heating and hot water from 2008 and 2030 and total investments in renovation per total building floor area from 2008 to 2030, low energy prices.

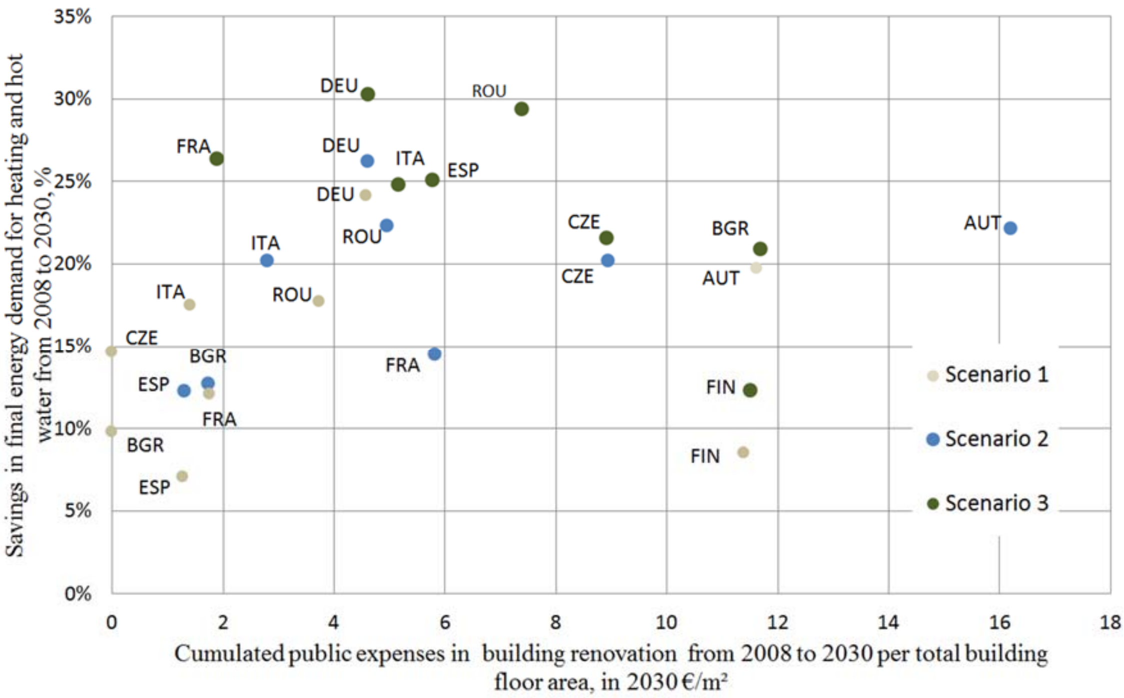

Figure 7. Savings in final energy demand for heating and hot water from 2008 to 2030 and cumulated public expenses in renovation per total building floor area from 2008 to 2030 (low energy price scenario).

nario 3 achieves 25 % of energy savings with public expenses of €27/m². Hence, this huge difference to the prior examples can be explained by (1) the higher specific investments in Austria, (2) a strong tradition in subsidies for building renovation (and new building construction) and (3) the type of investigated policy mix: the subsidies (which are counted here as public expenses) are financed through a property tax on low energy efficient buildings. In particular in the Austrian policy scenario 3, the additional revenues from the property tax would even overcompensate the expenses for subsidies (Kranzl et al., 2014b).

Conclusions and outlook

The results show a energy savings for space heating, hot water, cooling and lighting in different countries and scenarios ranging from less than 10 % to more than 30 % from 2008–2030. Remarkably, the highest energy savings were not achieved in those scenarios and countries with the highest public expenses. It turns out that at least a minimum level of regulatory measures increasing "nZEB renovation" activities and renewable heating systems should be added to economic incentives and strong supply-side measures. Even though there are regional differences in cost structure, policy traditions, climatic conditions and ways of financing public subsidies, a general conclusion can be drawn from Figure 7. The effectiveness of policy scenarios which are located on the right hand side of the Figure 7 could most likely be improved by giving more weight on measures which do not require high public expenses, i.e. stronger regulatory instruments (building codes, RES use obligation). Additional measures to increase compliance, building specific renovation roadmaps and more effective information activities, quality checks, training and coaching of building owners are crucial. Not only to do these measures address specific barriers but they also increase the acceptability and effectiveness of regulatory policy instruments.

The current conditions and building stock characteristics are very different across Europe. And so are behavioural patterns and comfort situation in buildings. In particular in some Eastern and Southern European countries, indoor conditions in the heating period are much less attractive than in some Western European countries. This is a strong indicator that increased economic welfare, but also the change from single stoves to central heating systems or increased energy performance of buildings may lead to a substantial comfort increase. While this is an important benefit of renovation activities this also leads to corresponding rebound effects with partly offsetting of theoretical energy savings. Although these effects were taken into account in the modelling approach, the concrete realisation of comfort gains and the rebound effect may be very different under various economic, climatic and cultural conditions. Thus, this question is left for further research.

We want to emphasize that even the more ambitious scenarios (policy scenarios 3) do not represent a maximum achievable policy impact or a technical or economic energy efficiency potential. Rather, the policy settings were the result of in-depth discussions with policy makers and their suggestions. In this sense, they can also be considered reality-proven or at least reality checked. Moreover, also the modelling approach in Invert/EE-Lab, in particular the Logit-approach in so far reflects reality, as not only the most attractive renovation solutions or heating systems are part of the scenario solutions. In reality, we observe that people do not always behave in a pure economic rational way when it comes to the decision making of building renovation and HVAC investments. Thus, even with high economic incentives for building renovation there might be investors who are not deciding for this option.

With this "realistic" approach, we end up with the same difficulties and challenges as in reality: Even though policy set 3 leads to a reduction of energy demand from 2008 to 2030 by more than 25 % to 30 % and even though CO_2-emissions decrease by more than 50 %, the share of "nZEB renovation" in most of the countries still does not reach a level of more than 60 %–70 %, in some countries not even more than 40 %. This is a strong indication that these scenarios are most likely still not in line with ambitious climate mitigation targets (reflecting e.g. the target of about minus 90 % GHG-emissions in the building sector 2050 according to the low carbon economy roadmap of the European Union, European Commission, 2011). In addition, the remaining buildings with "moderate renovation" activities will be locked for further efficiency improvement, thus creating corresponding lock-in effects. Leaving the targets achievable, if an even higher amount of RES can be realized in the building sector. Therefore, we consider the optimum split of energy efficiency measures and implementation of RES in buildings as well as the overall energy system in 2050 still an open question left for further research.

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