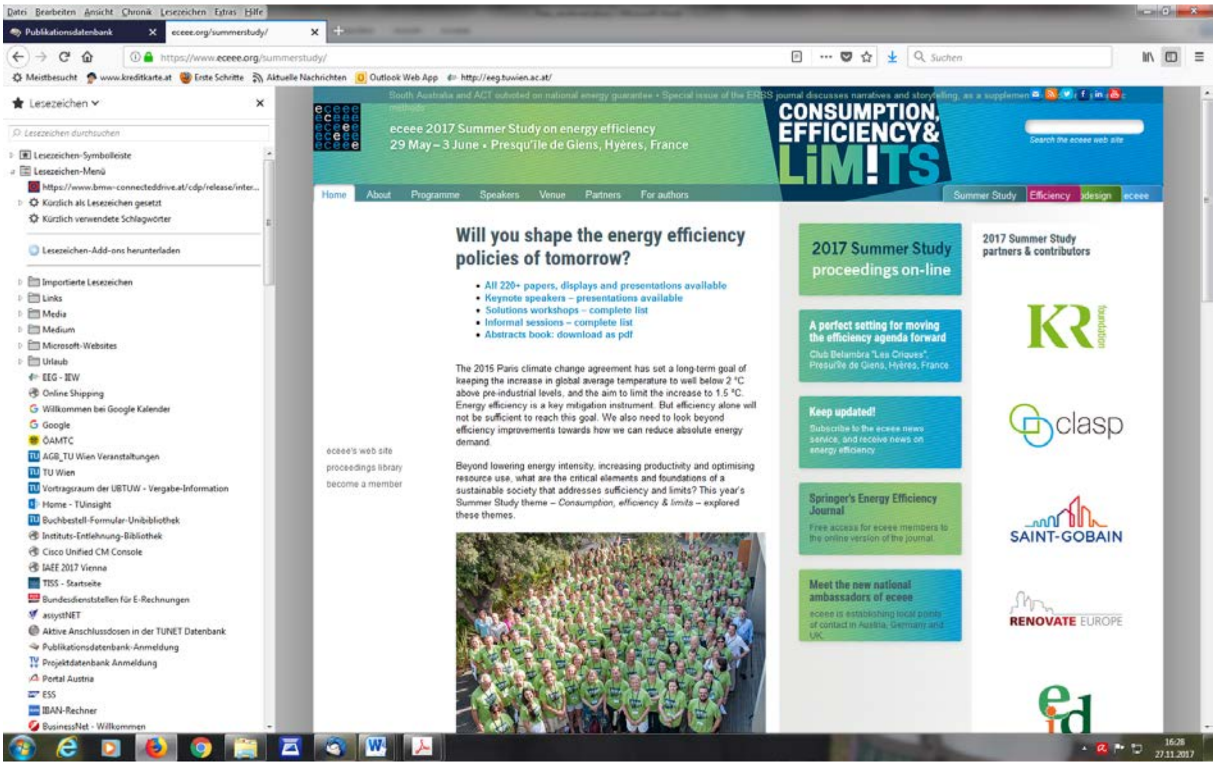
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To what extent do “ambitious” scenarios of energy demand in the building stock reflect COP21 Paris targets?

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Abstract

COP21 led to an agreed target of keeping the increase in global average temperature below 2°C compared to pre-industrial levels. The EU-contribution to this target will require GHG-emission reductions of at least 80-95% from 1990-levels until 2050. Due to the high potential for decarbonisation, the building stock will have to achieve at least the same level of reduction. Policy makers are asked to develop a corresponding framework. Important for assisting decision makers in this context are policy driven scenarios.

The research questions of this paper are: (1) Do long-term scenarios (and in particular those labelled as ambitious) of energy demand in buildings reflect the COP21 target? (2) If not: What are reasons for the gap? (3) What can we learn for policy making?

The method builds on following steps: (1) Analysis of GHG-emission reduction in scenarios from the policy driven bottom-up model Invert/EE-Lab carried out recently for various European countries in several EU and national projects (e.g. ZEBRA2020, progRESsHEAT, Tender for DG Energy on Mapping of Heating/Cooling, etc); (2) compare scenarios among each other and analyse whether the scenarios lead to an achievement of GHG-emission reductions in the range of 80-95% until 2050; (3) identify reasons for possible gaps in GHG-emission reductions like insufficient stringency of building codes, deficient economic incentives etc and (4) derive conclusions regarding policy making.

Results show that scenarios labelled as being “ambitious” e.g. in ZEBRA2020 for several EU MSs achieve GHG-emission reductions of 56% - 95% until 2050, but only three of them above 85%. The reason is that policies have been developed together with policy makers, who were not willing to go beyond certain stringency of modelled instruments. In particular, this was the case for regulatory instruments which turn out to be essential for achieving ambitious climate targets.

Introduction

COP21 led to an internationally agreed target of “holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels” (UNFCCC, 2015). The EU-contribution to this target will require GHG-emission reductions of at least 80-95% from 1990-levels until 2050. Due to the high potentials for decarbonisation, the building stock will have to cover at least the same reduction (see e.g. European Commission, 2011). Thus, policy makers face the challenge to develop a corresponding framework.

Important for assisting decision makers in this context are policy driven scenarios. There are numerous scientific reports and academic journals assessing long-term energy demand in the building sector using different scenario frameworks including energy price development, climate change, policy measures and technological change (Olonscheck et al, 2011, Asimakopoulos et al, 2011, McKenna et al, 2013, Töglhofer C. et al, 2012, Ó Broin et al, 2013, Steinbach, 2015). These papers show identical future trends, namely a decrease in heating energy demand in winter and increase in cooling energy demand in summer. Decreasing heating energy demand is affected by better thermal performance resulting from mandatory efficiency standards for new buildings and building renovation whereas the increasing cooling energy demand is led by a warmer climate and rising comfort standards. Although many studies show a decrease in the energy demand for space heating, many papers conclude that in a reference case, the targets for 2020 or 2030 are not met and further political intervention is required. McKenna et al, 2013 modelled energy demand scenarios for the German building sector by 2050 showing that in the reference scenario which leads to 17% of energy savings for space heating and hot water from 2010 to 2050, the target for 2020 is not met. Policy instruments are required leading to higher renovation rates to achieve higher energy savings. (Ó Broin et al., 2013) shows the impact of energy efficiency increase by 2050 in EU-27 building stock. The authors of this paper also contributed to the literature of scenarios of energy demand and CO2-emissions in several studies, e.g. Kranzl et al., (2014), Müller, (2015), Kranzl and Müller, (2015).

However, despite this wide range of scenarios and modelling work, the authors are not aware of a rigorous check to what extent these scenarios are consistent with the Paris targets. Even though some of these scenarios identified above have been classified as "ambitious scenarios" or "climate mitigation scenarios" or "high policy intensity scenarios", it remains unclear how far their "ambition level" goes. Given the huge relevance of the Paris targets on the one hand and the building sector's energy demand and related CO2-emissions on the other hand, we believe that it is essential to test energy demand scenarios in the building sector towards their consistency with strong, or indeed almost complete, decarbonisation targets until 2050.

Hence, the research questions of this paper are: (1) Do long-term scenarios (and in particular those labelled as ambitious) of energy demand in buildings reflect the COP21 target? (2) If not: What are reasons for the gap? (3) What can we learn for policy making?

The scope of this paper are long- (2050) and medium (2030) term scenarios of the building stock's energy demand, in particular energy demand for space heating, hot water and cooling, the applied mix of technologies and energy carriers and resulting CO2-emissions. We focus on scenarios for different European countries, derived with the model Invert/EE-Lab (see chapter "Methodology" for more details).

We start with a more detailed description of our methodology, i.e. which scenarios were selected, a description of the model Invert/EE-Lab and which indicators we selected to test the consistency with Paris targets. The results chapter presents the selected indicators for a wide range of scenarios in different countries. From this, we derive conclusions and discuss policy implications.

Methodology

The method builds on the following steps:

1. Analysis of GHG-emission reduction in scenarios from the policy driven bottom-up model Invert/EE-Lab carried out recently for various European countries in several EU and national projects;
2. compare scenarios among each other by various indicators and analyse whether the scenarios lead to an achievement of GHG-emission reductions in the range of 80-95% until 2050;
3. identify reasons for possible gaps in GHG-emission reductions like insufficient stringency of building codes, deficient economic incentives etc and
4. derive conclusions regarding policy making.

In the following, we will first explain the system boundaries and scope of our study, subsequently we explain the model on which the scenarios considered in this paper are built, i.e. Invert/EE-Lab, and finally we will discuss the approach of comparing scenarios and selecting indicators for this comparison.

System boundaries, scope of the study and selected scenarios

We focus on space heating, hot water and cooling energy demand in both the residential and non-residential building stock. Since the main focus of this paper is on the achieved level of greenhouse-gas (GHG) reductions, we also need to take into account the applied mix of technologies and energy carriers and resulting CO2-emissions.

We restrict our analysis to the building sector as such and do not explicitly include scenarios and modelling of the electricity and district heating generation mix. This leads to some implications on the selected indicators and also some limitations, which we will discuss below.

The scope of the paper are long- (2050) and medium (2030) term scenarios for different European countries, derived with the model Invert/EE-Lab.

We select scenarios from different countries within the EU28 from several projects, which were to some extent labelled as "ambitious" efficiency, renewable and/or climate change scenarios.

The projects and scenarios which selected are:

- IEE-project ZEBRA 2020: "ambitious policy scenarios" for 15 selected countries[1] (Bointner et al., 2016) In the project ZEBRA 2020, a current policy scenario and an ambitious scenario were developed. Compared to the current policy scenarios, the ambitious policy scenario is based on more intensive policies which lead to higher renovation rates and depths, more efficient new building construction, a higher share of renewable energy and corresponding CO2 and energy savings. The detailed policy settings have been discussed with national stakeholders and policy makers. In particular, building codes have been strengthened in 2017 for new buildings and building refurbishment. Public budgets for subsidies have been increased in the ambitious scenario compared to the current policy scenario. Finally, obligations to install RES-H systems have been implemented in a more stringent way in the ambitious policy scenario. However, the detailed settings are country specific, based on the stakeholder consultation. For more detailed documentation see Bointner et al., (2016). For the analysis in this paper, we selected only the "ambitious policy" scenarios.
- IEE-project ENTRANZE: "ambitious scenario, high energy prices", for 8 countries[2] (Kranzl et al., 2014) Although there are country-specific deviations and exemptions, the general logic for the scenarios derived in ENTRANZE is as follows: Scenario 1 refers to a moderate ambitious scenario according to current national and EU legislation, Scenario 2 and 3 are more ambitious, innovative and stringent policy packages. The decisions on policy packages to be modelled were made in policy group meetings, which resulted in country specific deviations. The time frame of the policy scenarios is from 2008-2030. More details are described in Kranzl et al., (2014). For the analysis in this paper we selected the scenarios with the highest energy savings and highest share of RES-H in each analysed country.
- Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables): unpublished sensitivities with higher support for RES-H/C, 28 European Countries[3] In this project, we developed a current policy scenario considering targets and measures concerning RES-H/C and energy efficiency which have been agreed or already implemented at the latest by the end of 2015. Within this scenario, all implemented instruments are assumed to be in place by 2030, including current financial support programs, without significant changes throughout the years. The time frame of the scenarios is 2030.
- Energy scenarios for Austria 2015. Heating demand of small scale consumers. A project in the frame of the reporting obligations for the monitoring mechanism (Müller and Kranzl, 2015).
  In this project, three scenarios have been developed: The scenario "with existing measures" takes into account the currently implemented policy framework. The scenario "with additional measures" considers also measures which are under preparation and expected to be in place very soon. The scenario "with additional measures – plus" assumed a high policy intensity towards energy efficiency improvement and RES-H/C implementation. These policy measures were discussed and agreed upon with stakeholders and policy makers. The scenarios have been developed until 2050.
  For the analysis in this paper, we took into account the scenario "with additional measures – plus".
- Long term scenarios and strategies for the expansion of renewable energy in Germany considering sustainable development and regional aspects. (Pfluger et al., 2017)
  This project provided two scenarios: A reference-scenario, assuming that relevant measures of the Energiewende" will not be further be in place, and a basis-scenario, assuming further enhancement of the Energiewende in all relevant sectors, including the building stock. We selected the latter, more ambitious "basis-scenario" for this paper.

A comparison with other scenarios from the literature would be interesting and relevant. However, at least for some work (e.g. global scenarios of building related energy demand in Ürge-Vorsatz et al., (2011) or the scenarios available at http://www.gbpn.org/) only part of the required information is available, i.e. energy demand development but no energy carrier mix. For this reason, we limited the analysis to scenarios derived with the model Invert/EE-Lab and intend to extend this work in future studies to other literature.

[1] Belgium, Germany, Denmark, Spain, France, United Kingdom, Italy, Lithuania, Luxembourg, Netherlands, Norway, Poland, Romania, Sweden, Slovakia

[2] Austria, Bulgaria, Czech Republic, Finland, France, Italy, Romania, Spain

[3] Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovenia, Slovakia,

For the objectives of this paper, we need long-term scenarios, if possible until 2050 or beyond. However, as explained above, some of the scenarios are available only until 2030. This will have some implications on the indicators to select (see below).

The model Invert/EE-Lab

The scenarios discussed in this paper have been developed by the model Invert/EE-Lab. It 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, CO2 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 extended by an agent-specific decision approach documented e.g. in (Steinbach, 2013a), (Steinbach, 2013b), (Steinbach, 2015). The model Invert/EE-Lab up to now has been applied in all countries of EU-28 (+ Serbia).

The key idea of the model is to describe the building stock, heating, cooling and hot water systems at a highly disaggregated level, calculate related energy needs and delivered energy, determine reinvestment cycles and new investment in building components and technologies and simulate the decisions of various agents[4] (i.e. owner types) in case that an investment decision is due for a specific building segment.

The core of the simulation model is a myopic[5] 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. 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 is country specific, according to the characteristic situation, the relevance of various groups and data availability. 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:

- Economic incentives change the economic effectiveness of different options and thus lead to other investment decisions.
- 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.
- 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.
- 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.

Input data regarding building stock data, economic and policy drivers etc are documented in the sources listed above for each of the scenario groups.

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

[5] The myopic 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.

Indicators to assess whether a scenario is in line with the Paris COP21 agreement

Since the objective of this paper is to assess the consistency of different scenarios with the Paris agreement, we need to define indicators for this assessment.

The first and probably most obvious indicator is the achieved reduction of GHG-emissions from the base year until 2050. Here, we face the problem of how to deal with GHG-emission factors for electricity and district heating. Since for the analysis in this paper we have decided to purely focus on the building stock as such, we decided not to distort results by assuming decreasing emission factors for these two sectors. This also would have to be distinguished between countries, making it difficult to identify key impact factors and drivers for decarbonisation. Thus, we apply the following two indicators:

- CO2 emission reduction assuming constant emission factors for district heating and electricity
- CO2 emission reduction excluding electricity and district heating.

This second indicator focuses on direct emissions in the building stock, and implicitly takes into account that also the electricity and district heating sectors will need to decarbonise. However, we should also need to know about the increasing share of electricity and district heating to cover the building stock's energy demand. This is covered in the additional two indicators:

- Increase district heating from base year (pp)
- Increase electricity from base year (pp)

Also the use of biomass as a decarbonisation option is of relevance, since biomass is expected to play a more and more crucial role in sectors where carbon energy carriers are more difficult to substitute (e.g. aviation, industry). This is taken into account with this third indicator:

- Increase biomass from base year (pp)

These three indicators are defined as difference of the market share in the base year and the years 2030 and 2050, respectively. We are aware that these three indicators above could be avoided if a fully sector coupled modelling approach would be chosen. On the other hand, we believe that they also provide additional insights, which often are not available in a transparent way in cross-sectoral modelling.

- Energy savings compared to the base year (%)

This indicator accounts for the share of final energy demand reduced from the base year until 2030 and/or 2050. We want to emphasize that this is not delivered energy, but final energy demand in the sense of the renewable energy directive, i.e. including solar thermal and ambient heat.

Another difficulty is that only some scenarios are available until 2050. So, the question arises as to which indicator could represent the future decarbonisation perspective best. For this purpose, we selected:

- Installation of fossil based heating systems.

Due to the long life time of heating systems (often even above 20-30 years) a high share of the heating systems installed e.g. in 2030 will still be in place in 2050. And also markets typically do not change very quickly. E.g. if the share of fossil heating systems in the installation of all new heating systems in the year 2030 is still very high, it would need really strong regulatory policy instruments including also a complete change of the manufacturer structure to reduce this market share quickly. Moreover, stranded investments could occur in case that heating system replacement would be required before the lifetime has ended.

Thus, this indicator allows an assessment also for those scenarios which have been modelled only until 2030.

Results

Figure 1 illustrates the range of direct greenhouse gas emissions in different scenarios and for various European countries. It shows that the reduction of these direct greenhouse gas emissions varies strongly across these scenarios and we need to understand better the reasons and drivers behind it.

Figure 2 presents an overview of the distribution of the main indicators, defined above. One of the most obvious results is that none of the 2050 scenarios achieve sufficient CO2-savings (i.e. > 80%) if constant CO2-emission factors for electricity and district heating are assumed. Assuming that decarbonisation efforts have to take place also in these sectors, the indicator of the direct CO2-emissions may be more relevant. However, also with respect to this indicator, only a very few targets achieve levels of more than 85-90% CO2-savings to 2050. This is a crucial outcome, because actually the intention of these scenarios in fact was to provide a significant increase in policy intensity. And the discussion processes carried out within the project ZEBRA2020 also showed that stakeholders and policy makers classified these measures as highly ambitious – in some cases even beyond what would be imaginable the current political framework.

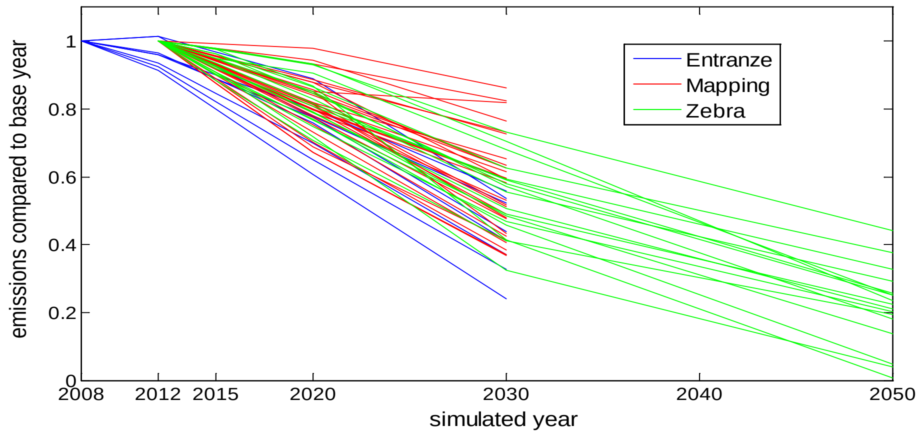

Figure 1.Scenarios of direct greenhouse gas emissions for space heating, hot water and cooling (i.e. excluding electricity and district heating) in selected scenarios in various European countries.

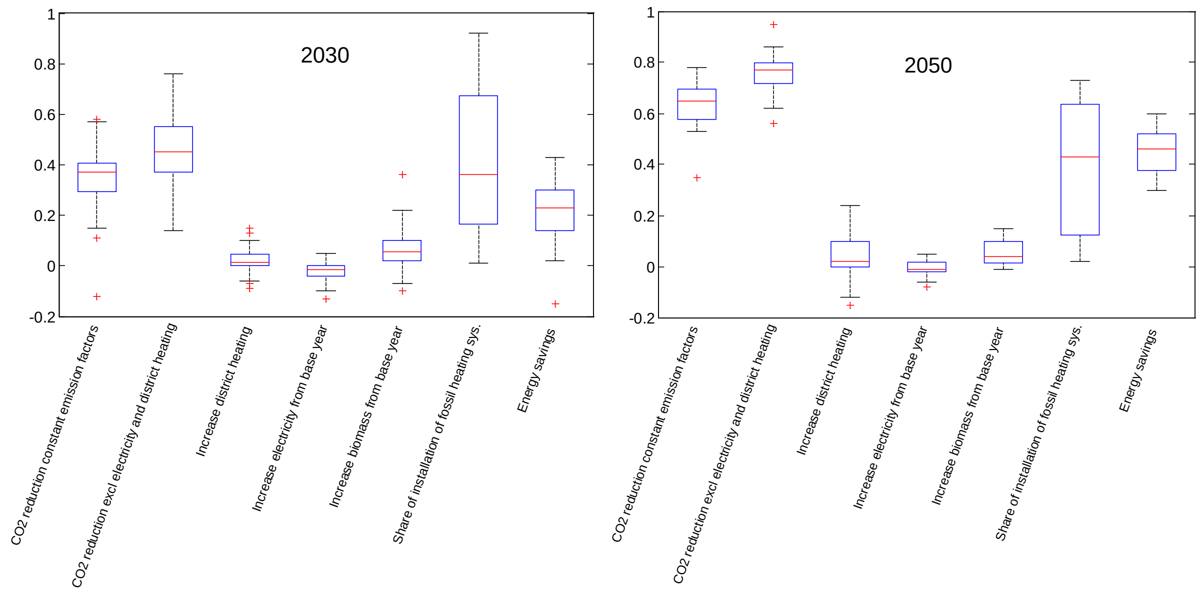

Figure 2.Box plots of indicators to assess the Paris-consistency of selected scenarios.

The following tables indicate all indicators explained in the methodology section for all analysed scenarios.

Table 1. Comparative assessment of scenarios regarding CO2-emission reduction, installation of fossil based heating systems and increase of district heating, electricity and biomass. Bold: Values indicating towards consistency with Paris targets.

Cou ntry	Project	CO2 reduction assuming constant emission factors		CO2 reduction excl electricity and district heating		Increase district heating from base year (pp)		Increase electricity from base year (pp)		Increase biomass from base year (pp)		Share of installation of fossil based heating systems		Energy savings (reduction of final energy demand from base year)	
		2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
FR	ENTRANZE	58%		67%		7%		-5%		8%		39%		33%	
AT	ENTRANZE	40%		76%		15%		-1%		7%		**10%**		30%	
BG	ENTRANZE	-69%		56%		1%		-10%		3%		21%		23%	
CZ	ENTRANZE	15%		59%		1%		1%		9%		25%		28%	

Country	Project	CO_2 reduction assuming constant emission factors 2030	CO_2 reduction assuming constant emission factors 2050	CO_2 reduction excl electricity and district heating 2030	CO_2 reduction excl electricity and district heating 2050	Increase district heating from base year (pp) 2030	Increase district heating from base year (pp) 2050	Increase electricity from base year (pp) 2030	Increase electricity from base year (pp) 2050	Increase biomass from base year (pp) 2030	Increase biomass from base year (pp) 2050	Share of installation of fossil based heating systems 2030	Share of installation of fossil based heating systems 2050	Energy savings (reduction of final energy demand from base year) 2030	Energy savings (reduction of final energy demand from base year) 2050
ES	ENTRANZE	24%		63%		3%		-4%		9%		26%		27%	
FI	ENTRANZE	-12%		48%		1%		-4%		-1%		**4%**		14%	
IT	ENTRANZE	38%		44%		1%		1%		6%		66%		30%	
RO	ENTRANZE	41%		46%		-9%		1%		9%		18%		31%	
FR	Mapping	36%		37%		2%		-2%		8%		40%		9%	
AT	Mapping	21%		57%		13%		-4%		1%		31%		19%	
BE	Mapping	39%		42%		5%		-2%		10%		76%		23%	
BG	Mapping	44%		51%		-3%		-6%		12%		21%		10%	
CH	Mapping	11%		14%		1%		0%		-10%		70%		2%	
CY	Mapping	17%		62%		0%		5%		12%		18%		-15%	
CZ	Mapping	37%		52%		2%		-2%		22%		27%		6%	
DE	Mapping	39%		38%		1%		-1%		0%		84%		33%	
EE	Mapping	54%		57%		-2%		-6%		13%		6%		22%	
ES	Mapping	57%		59%		0%		-5%		36%		15%		4%	
FI	Mapping	23%		48%		4%		-9%		5%		7%		2%	
GB	Mapping	37%		40%		9%		-2%		3%		75%		30%	
GR	Mapping	55%		59%		1%		0%		15%		42%		35%	
HR	Mapping	39%		63%		10%		-1%		19%		15%		8%	
HU	Mapping	39%		47%		4%		-1%		14%		48%		23%	
IE	Mapping	29%		27%		0%		-2%		3%		92%		19%	
IT	Mapping	39%		37%		0%		-1%		9%		57%		23%	
LT	Mapping	38%		49%		4%		-1%		-2%		18%		34%	
LU	Mapping	25%		27%		4%		-2%		8%		78%		9%	
LV	Mapping	28%		18%		1%		-2%		-7%		51%		29%	
MT	Mapping	44%		52%		2%		-13%		17%		18%		24%	
NL	Mapping	30%		35%		5%		0%		4%		83%		24%	
NO	Mapping	32%		41%		0%		0%		-2%		1%		13%	
PL	Mapping	26%		18%		-6%		-1%		3%		73%		11%	
PT	Mapping	30%		23%		1%		-5%		1%		67%		14%	
RO	Mapping	39%		41%		-9%		1%		16%		7%		12%	
SI	Mapping	48%		63%		7%		-4%		18%		6%		14%	
SK	Mapping	35%		36%		-1%		-1%		8%		71%		24%	
AT	MonMech	31%	65%	32%	75%	4%	6%	-4%	-2%	1%	-4%	34%		19%	52%
DE	Long-term scenarios	40%	71%	45%	**85%**	6%	11%	-1	4%	-1%	0%	58%	34%	29%	56%
FR	ZEBRA	38%	65%	42%	75%	5%	10%	-2%	-1%	2%	-1%	38%	38%	17%	31%
BE	ZEBRA	47%	72%	53%	80%	10%	15%	-1%	-1%	10%	12%	66%	62%	33%	53%
DE	ZEBRA	50%	70%	51%	78%	1%	2%	0%	4%	1%	1%	76%	71%	43%	59%
DK	ZEBRA	34%	53%	59%	80%	3%	0%	-2%	-3%	8%	11%	25%	16%	17%	30%
ES	ZEBRA	46%	78%	51%	**86%**	0%	0%	0%	-2%	3%	4%	25%	38%	28%	43%
GB	ZEBRA	45%	65%	49%	79%	9%	24%	-2%	-2%	4%	6%	68%	66%	34%	46%
IT	ZEBRA	45%	67%	44%	71%	0%	1%	-1%	1%	4%	4%	54%	43%	30%	48%
LT	ZEBRA	40%	68%	54%	**95%**	5%	6%	0%	0%	-3%	4%	7%	3%	36%	55%

Country	Project	CO2 reduction assuming constant emission factors		CO2 reduction excl electricity and district heating		Increase district heating from base year (pp)		Increase electricity from base year (pp)		Increase biomass from base year (pp)		Share of installation of fossil based heating systems		Energy savings (reduction of final energy demand from base year)	
		2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
LU	ZEBRA	35%	55%	38%	62%	3%	9%	-2%	-2%	11%	15%	75%	73%	19%	34%
NL	ZEBRA	36%	57%	41%	67%	5%	14%	0%	2%	5%	7%	79%	62%	30%	48%
NO	ZEBRA	32%	67%	41%	74%	1%	-1%	-3%	-8%	2%	1%	3%	6%	21%	46%
PL	ZEBRA	33%	60%	27%	56%	-6%	-15%	0%	1%	0%	3%	65%	64%	22%	46%
RO	ZEBRA	33%	60%	29%	77%	-7%	-12%	1%	5%	4%	4%	14%	11%	24%	49%
SE	ZEBRA	20%	35%	29%	76%	4%	5%	-5%	-6%	3%	0%	3%	2%	22%	36%
SK	ZEBRA	39%	72%	43%	82%	2%	0%	0%	5%	6%	12%	62%	46%	30%	60%

Three scenarios showed **reduction of direct CO2-emissions of at least 85% until 2050. This is the case for the presented ZEBRA - ”ambitious policy scenarios” in ES and LT and the ”basis-scenario” for Germany from the project ”long-term scenarios”**.

For the case of **Spain**, we see a mix of different drivers leading to this result. Firstly, currently, there is a relatively high share of fuel oil in the energy carrier mix. In all countries and scenarios we see a strong shift from fuel oil to other energy carriers – both in the past and in our scenarios. Thus, there is a high potential for decarbonisation, which is exploited in this scenario. Secondly, compared to other countries, the discussion process in the project ZEBRA2020 led to more ambitious policy packages than in other countries. In particular, renewable heat obligations and obligatory efficiency improvement, combined with advice and proper econoimc side conditions were implemented. Thirdly, the share of solar thermal energy in the total final energy demand is much higher than in other countries and scenarios, reaching more than one third in 2050. Due to the fact that solar thermal collectors partly are still combined with fossil heating systems, the share of fossil based installations in the heating system market of 2050 is still surprisingly high. However, due to building renovation and the high share of solar thermal energy, the resulting GHG-emissions from these remaining fossil fuels are moderate.

In **Lithuania** the largest part of the heating demand in the year 2012 is covered by district heating (43%) and biomass (37%). The scenarios lead a strong increase of both of them (in particular district heating) to an overall share of almost 90%. Despite the fact that solar thermal and ambient heat show only very moderate market growth in our scenario, the reduction of the remaining direct GHG-emissions is very high, also due to a considerable share of coal in the base year 2012 (7%). Moreover, the reduction achieved final energy demand with 55% from 2012-2050 is among the highest of the considered scenarios.

Finally, what can be seen from the selected scenario for **Germany** are high energy savings of 56% until 2050. Remarkably, the share of biomass does not increase which means that in absolute terms biomass use for heating in the building sector is reduced. However, the market share of district heating increases quite substantially by 11 percentage points. What might be striking is the relatively high share of 34% of fossil based heating systems still in the boiler market in 2050. The reason why this is in line with a high reduction of direct CO2-emissions is that there is a substantial share of solar energy in the final energy carrier mix, i.e. many of the solar supported heating systems still use fossil based energy carriers as a back up.

On the contrary, the **lowest reductions in CO2-emissions until 2050 take place in the ZEBRA scenarios for Poland (56%) and Luxembourg (62%)**. For the case of Poland, the current political framework does not show any ambition to strongly reduce the high share of coal. This led to the fact that even in the ambitious policy scenario the stakeholders and policy makers involved in the ZEBRA discussion process did not consider it as realistic to implement really strong RES-H policies. Even though the share of coal reduces, this is mainly the case in favour of natural gas. Moreover, our scenario continued the current trend regarding the decreasing role of district heating.

The results for the indicator ”share of installations of fossil based heating systems” reveal that the change in the boiler market will be a crucial challenge in the coming years. The scenarios of the project ”Mapping” (Fleiter et al., 2016) highlight that under current policy conditions, the share of fossil heating systems in the boiler market of 2030 is by far not consistent with reasing Paris targets. The share of fossil heating systems in new installations in most scenarios and countries is beyond 50%. However, in the scenarios of the project ENTRANZE, labelled again as ”ambitious policy” scenarios, this share is significantly lower at least for some countries. The main reason is that, in particular for the cases of Austria and Finland rigorous fossil-phase out policies were implemented in the policy scenarios. Moreover, the share of fossil heating sytems in these countries already in the base year is substantially lower than in other countries. Overall, it turns out that only a few scenarios in selected countries achieve market shares of fossil heating systems below 50% in 2030. This shows that the model based scenarios do not only indicate a high inertia in the existing heating system stock but also in the boiler market. It is evident, that high shares of fossil heating systems in the newly installed stock contradicts ambitious climate targets. However, surprisingly, there are also cases of scenarios achieving more than 85% of GHG-emission reductions with fossil heating system market shares of more than 30% even in 2050. This is only possible if high energy savings (at least 50% of final energy demand reduction) and high shares of solar energy limit the energy demand supplied by these fossil heating systems.

Discussion, conclusions and outlook

Overall, despite the fact that the analysed scenarios show significant climate change mitigation progress, under current policies the (almost) complete decarbonisation of the building sector is far out of reach until 2050. Even in the scenarios labelled as “ambitious policy scenarios” in different projects listed above, the speed of change, in particular in the market of newly installed heating system is not fast enough.

Key challenges for achieving a strong decarbonisation scenario

A further reduction achieving 95% of greenhouse gases reduction is possible from a technical point of view. To achieve this goal, no new technology development in the building sector is necessary. **This means that technologies are currently available on the market; however they have to be entirely implemented assuring a high-quality in different phases of the renovation process** (e.g. higher renovation rate and depth, high quality in construction ensuring high-quality workmanship).

To achieve a higher reduction as it was calculated and presented in this paper, the following challenges occur:

Due to the long life time of the heating systems (some over 40 years), ambitious measures must be implemented at an early stage. Additionally, there are only limited options to use renewable heating systems in apartment buildings especially. A specific challenge will be switching from gas heating systems (which is “accepted” in an 80% reduction scenario) to central heating systems in combination with low carbon heat generation. Strict regulatory interventions can be a suitable measure to tackle this challenge but might also lead to problems of acceptance from building occupants.

This leads to the key challenge 1: transition in the boiler market – How can a complete phasing out of fossil fuel heating systems be achieved by the year 2025?

Both, the renovation rates and renovation depths have to be further increased compared to an 80% reduction scenario. Energy need reductions of 70% after renovation are technically feasible and renovation rates should be increased to 2.5% or even more to 3% earlier than in an 80% reduction scenario. Here, too, public acceptance problems are expected, especially in the case of financing and economic feasibility of renovation measures in buildings with low-income households in both rental dwellings and owner occupied single-family homes.

This leads to the key challenge 2: How can high renovation depth be implemented in accordance with policy requirements and social acceptance?

The supply sectors (electricity, district heating) have to be completely decarbonized for a 95% reduction, such that the use of efficient district heat and heat pumps lead to reduced emissions in the full energy supply chain. Even the reduction of direct CO2-emissions (i.e. excl. GHG-emissions from electricity and district heating) to a level beyond 90% is extremely challenging. If substantial emissions from district heating and electricity remain, decarbonisation is not possible.

In this context, **it should be noted that the energy demand for heating often does not correlate with the availability of the renewable energy (solar, wind).** The use of heat pumps can increase the peak load which can lead to capacity bottlenecks in the power supply. The demand peaks caused by electrical heat pumps can be relevant for the design of distribution networks due to the relatively high simultaneousness. A certain controllability of the heat pumps is almost indispensable with such a high share and targeted emissions reductions. Note that this effect is less relevant in district heating networks with multiple supply options. **Due to**

the potential flexibility in supply (combination of cogeneration, power-to-heat and peak-load boilers), heating networks could provide a balance between heat and electricity demand and supply peaks. Additionally, there is a need for a re-conceptualization of heating networks (temperature levels and integration of waste heat, solar heat, and ambient heat). The optimal share of district heating in an almost carbon free heat supply system is still an open issue and will need to be clarified in further research. All these aspects can only be addressed in a sector coupled model, which is of high relevance, but out of scope of this paper.

It is clear however that efficiency improvements leading to reductions of heat demand of more than 50% are realistic with acceptable measures. Due to the major challenges with regard to the decarbonisation of the electricity sector and the limited availability of biomass, it is likely that a cost-effective CO_2 reduction pathway will go beyond a 50% heat demand reduction and will more likely be in the range of up to a 60%-70% reduction. However, it strongly depends on the cost development of the renewable energy sources in the electricity sector (for example, the technological progress in wind and solar energy) and the costs of renewable and alternative heat sources and in particular also the availability of biomass. Even in an emission reduction scenario of 80%, the question of efficient allocation of biomass between different sectors arises. In a 95% reduction scenario this issue becomes even more relevant since biomass is even more used in the mobility sector, industry and the conversion sector. **Consequently, in the case of a complete decarbonisation of the building sector, there is rather less biomass available than in less ambitious scenario.** Thus there is a need for a cross-sectoral analysis of the potential and efficient allocation of biomass.

This leads to the key challenge 3: How much biomass is available for heating purposes and what is the electricity mix for the operation of heat pumps?
Since the presented scenarios do not include a holistic energy (and resource) system modelling but rather a detailed representation of the building stock, there is no clear answer possible. However, it is evident that a too high share of biomass allocated to the low-temperature heating sector may contradict reading climate targets in other sectors, in particular in industry or transport.

Which actions have to be taken now to stay on track for a 95% emission reduction until 2050?

Given the long life time of the building stock and heating systems, short-term action is required as it is very likely that buildings, which will be renovated in the coming years, won't be further renovated before 2050. This is also the case for the heating system exchange. In an 80% reduction scenario emissions stemming from older fossil fuel heating systems can be accepted to a certain extent which is not the case in 95% reduction world where the building sector needs to be fully decarbonized. Given the current market shares of heating systems in new installations of heating systems (still a high share of gas fired systems and also significant shares of oil fired systems), it is very likely that the European heat supply is not on track for a 95% reduction. **To reach that target a phase out of fossil heating systems within the next 10 to 15 years would be required.** This also means that current subsidies for efficient fossil heating systems (e.g. condensing gas boilers or gas-fired micro CHPs, also corresponding measures in the frame of the energy efficiency obligations, Art 7 of the EED) are not in line with a 95% emission reduction target. Consequently also the existing gas grid infrastructure needs to be addressed. If the gas supply cannot be substituted by "renewable gas" or hydrogen, a 95% emission reduction would also have to go hand in hand with a step wise removal of gas grids across European settlements.
Finally, as already addressed it is crucial to immediately take measures to increase renovation rates with the goal of achieving **average renovation rates across Europe of more than 2.5% by 2020 to 2025. In a 95% emission reduction scenario those renovation activities would have to lead to reductions of more than 70% of heat demand** on average across all renovated buildings across Europe which calls for significantly deeper renovation measures to be taken compared to current practice.

In summary we conclude that current measures in the building stock are not sufficient to reach a greenhouse gas emission reduction in Europe which is in line with the Paris targets. For that goal the building sector would have to be almost fully decarbonized which calls for even more ambitious measures to be taken now. While a full decarbonisation is feasible from a technical point of view at acceptable cost increases, there will be major challenges with regard to the acceptance by home owners, tenants, architects, builder and other stakeholders like fossil heating system or natural gas suppliers. With respect to that, a 95% reduction target is seen to be very ambitious. It will need to be accompanied by extensive information, education and consulting campaigns to get the necessary support and acceptance across the main stakeholders in the European building sector. (Pfluger et al., 2016)

Outlook and conclusions for modelling and scenario development

This paper is just a starting point for assessing how current scenarios, reflecting also expectations of policy makers and stakeholders, are in line with Paris targets. In addition to the work presented in this paper, a more comprehensive literature review would be interesting. Moreover, cross-sectoral effects in the electricity sector should be addressed. However, we believe that this would not substantially alter the overall conclusions derived in this paper.

Last but not least, the question arises as to what we as modellers and the modelling community in general should learn from these results.

First, **modelling and scenario development is always embedded in a certain institutional setting**. Clients, stakeholders and policy makers typically are involved in an interactive discussion process, which is essential to increase the impact of scenarios on real life policy making. At the same time we should be aware – and the results of this paper support this fact – that the involvement of these stakeholders can decrease the ambition level of scenarios bringing them to a level that – for these specific stakeholders – is in their interest or which they think is compatible with current policy decision making processes. Thus, often modellers are faced with a tension of their own intrinsic motivation to illustrate possible pathways of (almost) complete decarbonisation and the interests of clients, stakeholders and policy makers. This also leads to the question of the responsibility of the modelling community to also actively drive the discussion process and not only act as "recipients of orders".

Second, also methodological questions occur. **To what extent are models able to deal with really ambitious climate and policy targets?** In general, techno-economic bottom-up models as Invert/EE-Lab are better suitable for modelling more extreme transition pathways. However, there are also components in the model which reflect the inertia of changes in the stock of heating systems and buildings. Although this inertia is in line with what empirically can be observed, it cannot be completely ruled out that under a strong, joint societal effort towards decarbonisation also investment cycles and replacement rates of technologies could strongly change, even if this would be associated with higher private and societal costs.

We think that the energy modelling community, not only in the building sector has to adapt existing paradigms and working processes, partly also modelling approaches to better reflect the needs of the Paris targets also in the scenario results.

Finally, this paper also leads to the question: **To what extent do scenarios matter for the policy process?** Is it important that there are also Paris-consistent scenarios out there? We believe that scenarios at least should reflect the current reality of the discourse. If this is true, then the conclusions of this paper are alarming.

Moreover, we think that one objective of scenarios is to show the range of possible futures. So, as long as our energy demand scenarios do not at least include some examples of Paris consistent future pathways, the discourse does not even include this agreed and adopted target as a conceivable and possible future.

Thus, the modelling community – including the authors – and future projects in this field face the challenge to change this situation.

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