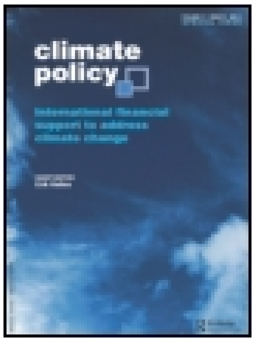

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Achievability of the Paris Agreement targets in the EU: demand-side reduction potentials in a carbon budget perspective

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ABSTRACT

Limiting global warming to 'well below' 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5°C is an integral part of the 2015 Paris Agreement. To achieve these aims, cumulative global carbon emissions after 2016 should not exceed 940 – 390 Gt of CO_2 (for the 2°C target) and 167 – −48 Gt of CO_2 (for the 1.5°C target) by the end of the century. This paper analyses the EU's cumulative carbon emissions in different models and scenarios (global models, EU-focused models and national carbon mitigation scenarios). Due to the higher reductions in energy use and carbon intensity of the end-use sectors in the national scenarios, we identify an additional mitigation potential of 26–37 Gt cumulative CO_2 emissions up to 2050 compared to what is currently included in global or EU scenarios. These additional reductions could help to both reduce the need for carbon dioxide removals and bring cumulative emissions in global and EU scenarios in line with a fairness-based domestic EU budget for a 2°C target, while still remaining way above the budget for 1.5°C.

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KEYWORDS
Paris Agreement; cumulative emissions; carbon budget; Europe; demand side; carbon capture and storage

Key policy insights

- Models used for policy advice such as global integrated assessment models or EU models fail to consider certain mitigation potential available at the level of sectors.
- Global and EU models assume significant levels of CO_2 emission reductions from carbon capture and storage to reach the 1.5°C target but also to reach the 2°C target.
- Global and EU model scenarios are not compatible with a fair domestic EU share in the global carbon budget either for 2°C or for 1.5°C.
- Integrating additional sectoral mitigation potential from detailed national models can help bring down cumulative emissions in global and EU models to a level comparable to a fairness-based domestic EU share compatible with the 2°C target, but not the 1.5°C aspiration.

1. Introduction

Net decarbonization in the second half of this century is an integral part of the Paris Agreement's goal to limit global warming to 'well below 2°C above pre-industrial levels' and 'pursue efforts to limit the temperature increase to 1.5°C' (UNFCCC, 2015). From a climate science perspective, emission budgets define the amount of emissions that are still permissible to meet a given temperature goal. In the case of a likely 2°C target (probability > 66%), the estimated global carbon budget for 2017–2100 is between 940 and 390 Gt of CO_2 (medium estimate 760 Gt), while it is between 167 and −48 Gt of CO_2 (medium estimate 59 Gt) for a 1.5°C-consistent target (probability > 50%) (see MCC, 2017; based on IPCC, 2014a, 2014b; Rogelj et al., 2015).

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The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) used a broad range of integrated assessment model (IAM) runs to derive reduction targets for specific years: for Annex I countries, the developed countries as listed in the United Nations Framework Convention on Climate Change (UNFCCC), a reduction of 80–95% below 1990 levels was found to be compatible with reaching the 2°C target (IPCC, 2007, Box 13.7). Recently, the political debate in Europe has been focussed on reduction targets for specific years, neglecting the role of cumulative emissions. The EU has expressed a target range of reducing emissions by 80–95% by 2050 (as discussed in EU COM, 2011). Its interim targets for 2020 and 2030 are GHG emission reductions of 20% and 40% below 1990 levels.

In the context of defining policies and measures to reach those targets, policy-makers use models to derive detailed transformation pathways for individual sectors. In the EU, this process is applied both at a European level (mainly by the European Commission) and at the level of the member states to derive national strategies. At the same time, international negotiations on climate change are highlighting the principle of equity when discussing how countries should share efforts and contributions to emission reductions.

The economic and techno-economic models applied at different levels differ significantly in their focus and level of detail. The global models assessed by the IPCC (mainly IAMs) cover all world regions and make it possible to calculate cost-efficient effort sharing between regions endogenously within the models. Besides the economic perspective, these models integrate the effects on the climate, although in a much less complex way than climate science models (e.g. ICON-earth system model). In contrast, economic and techno-economic models applied at the European or national level provide more details at the technology, country and sector levels. To cover the missing climate link, a carbon budget or carbon/GHG mitigation target that is assumed to be compatible with meeting a given temperature target (either 2°C or 1.5°C) ex ante is defined exogenously within these models.

Comparing the different models indicates that more aggregated models with a global or larger regional coverage may result in lower reduction potentials at the sector level (cf. Lucon et al., 2014; Pauliuk, Arvesen, Stadler, & Hertwich, 2017; Yeh et al., 2017). One obvious reason for the differences is carbon dioxide removal, e.g. due to carbon capture and storage (CCS) combined with bio-energy (BECCS). While the number of 1.5°C scenarios in IAMs is very limited at the moment, those scenarios meeting 1.5°C require large amounts of gross but also net carbon dioxide removals, in particular in the second half of the century (Rogelj et al., 2015). Gross carbon dioxide removal amounts to −3.2 Gt annually with net emissions reaching −1.6 Gt per annum in 2100. Kartha and Dooley (2016) point out that there is a substantial risk that emission removals may not be realized to the extent required in these scenarios due to possible technical infeasibility and unacceptable ecological and social impacts. Solano Rodriguez, Drummond, and Ekins (2017) find that the important role of BECCS in European low-carbon scenarios results from the lack of sectoral mitigation options in the underlying models, in particular the buildings and transport sectors. They conclude that it is necessary to update the models regularly to include newly available mitigation options. In the IPCC's Fifth Assessment Report (AR5) (see Section 9.9.3 of Lucon et al., 2014), the IPCC Working Group 3 states that sectoral bottom-up models cover mitigation options in the buildings sector in more detail and thereby achieve higher mitigation rates than the global IAMs.

In this paper, we combine analyses using techno-economic bottom-up models with emission budgets provided by climate and IAMs and compare them with a focus on Europe. We address two questions: First, how consistent are the scenarios from global, but in particular EU and national models, with the carbon budgets based on equity considerations? Second, what can be learned from the more detailed EU and national models about the available mitigation potential and its effect on carbon budgets?

The analysis proceeds in three steps: first, we compare cumulative emission levels from the different economic and techno-economic models and burden-sharing approaches to identify consistencies and inconsistencies between different model groups. In a second step, based on this analysis and a more in-depth analysis of the sector abatement pathways, we identify the additional mitigation potential based on carbon intensity and energy use in different sectors. In a final step, we bring together the results from the sector-level analysis and the overall analysis of cumulative emissions and show the effects the additional mitigation potential can have on meeting the carbon budgets for the 2°C or 1.5°C target. This paper builds upon the results of a companion paper by Wachsmuth and Duscha (2018).

The structure of the paper is as follows: in the next section, we introduce the scenarios analysed within the paper. Section 3 provides details of the data preparation necessary to conduct the further analyses. Section 4 shows the results concerning the overall carbon emissions. Sections 5 and 6 provide the results of the detailed sector analysis. Section 7 brings together the results, and Section 8 concludes, drawing attention to policy implications.

2. Decarbonization scenarios and models

The paper builds upon in-depth analyses of decarbonization scenarios from different economic and techno-economic model groups and combines these with a budget approach based on complex climate science models. For the budget approach, we include two different approaches reflecting different fairness concepts.

For the first approach, we build upon the calculations by Gignac and Matthews (2015). Their budget approach is based on the most recent IPCC global carbon budgets (Collins et al., 2013) and applies Meyer's contraction and convergence framework for the allocation of emission allowances (Meyer, 2000). The basic underlying concept for allocating the remaining carbon budget is that all countries should converge to equal global per capita emission shares. Gignac and Matthews base their allocation on a global carbon budget of 1000 Gt from 2013 onwards, which is compatible with the upper case for the 2°C target. We calculate further burden-sharing based on their approach in order to be able to analyse scenarios compatible with a 1.5°C target.

Note that according to Gignac and Matthews (2015), the contraction and convergence approach does not correct for historic and existing emissions inequality. The latter requires mechanisms for an international transfer of emissions like trading schemes or financial compensation, which are not reflected in the domestic emissions that are specified by the evaluated scenarios. We therefore refer to the budget based on Gignac and Matthews (2015) as *fairness-based domestic carbon budgets/shares*. For the second approach, we include an EU share that is calculated based on allocating the remaining carbon budget equally among all people on earth from now on (equal cumulative per capita emissions) (Matthes, Blanck, Greiner, Zimmer, & Cook, 2018).

For the decarbonization scenarios, we choose from a variety of studies available for Europe as a whole or for individual countries or regions within Europe. Major factors for including or excluding a study include a level of ambition compatible with at least the 2°C goal and even better the 1.5°C goal, as well as the coverage of sectors and gases; the studies need to cover at least all emissions from the energy system, i.e. electricity, heat, industry and transport. Among others, the following studies were considered suitable:

- global mitigation scenarios from the databases of the projects AME, AMPERE and LIMITS (see the AR5 scenario database[1] for links);
- European mitigation scenarios from the databases of the AMPERE project (see the AR5 scenario database for links);
- national mitigation scenarios with a GHG reduction of 80–100% for France, Germany, Italy and the UK (négaWatt, 2014; Repenning, Braungardt, & Ziesing, 2015; Virdis et al., 2015; Allen et al., 2013, respectively).

For these studies, we collected and analysed sector-specific results. Where studies do not focus on the EU as a whole, but rather on individual regions and countries, we apply the figures to construct rough estimates of reduction pathways for the EU as a whole. The EU estimates are calculated based on the development of per capita emissions. We calculate the changes in per capita emissions for all available time steps (10-year steps) between 2010 and 2050. The percentage changes are then used to calculate the development of EU per capita emissions. We obtain EU emissions between 2010 and 2050 from multiplying the resulting EU per capita emissions by EU population. For national scenarios, we exclude emissions from land use, land-use change and forestry (LULUCF) because scaling up based on per capita LULUCF emissions is not possible. To be compatible with Gignac and Matthews, we look at CO_2 emissions only.

3. Data preparation

For our analysis, we compiled three groups of scenarios: those developed using models with a global focus covering all regions of the world ('global scenarios'); those developed using models with a European focus that do not consider other world regions ('EU scenarios'); and those developed using models or model systems with a national focus ('national scenarios'). The main difference between the groups is that, for the European and national models, a target has to be set exogenously that is deemed compatible with the 2°C/1.5°C target. Depending on the type of model, either a carbon budget of 90.6 Gt CO_2 is applied for 2010–2050 or GHG emission reduction targets are applied for each decade, which result in 80% reduction in 2050 compared to 1990 (see Capros et al., 2014) in the EU models and up to 100% reduction in 2050 compared to 1990 for the national models. In contrast, most of the global models, in particular the global IAMs, allow endogenous determination of the reduction amounts for the different regions. An exception is the POLES model, for which the overall reduction needs to be defined due to the missing link between the economy and the climate.[2] Other differences concern the time horizon of the scenarios and the figures provided. While the scenarios based on EU and national models end in 2050 (with the exception of the UK scenario that ends in 2030), the timeline for the scenarios based on global models extends until 2100.

The evaluated databases contain the following sets of scenarios based on global models that provide EU-specific data until 2050 and show no overshoot of the 2°C target up to 2100:

- AME: 4 scenarios from 2 models (GCAM 2.0, IMAGE 2.4);
- LIMITS: 15 scenarios from 5 models (GCAM, IMAGE, REMIND, TIAM-ECN, WITCH);
- AMPERE (Work package 2/3): 49 scenarios from 5 models (DNE21+, IMAGE, MERGE-ETL, POLES, WITCH).

Sector-specific data, however, are not available for the AME scenarios and the scenarios based on WITCH and MERGE-ETL, and only transport is available for the REMIND model. Therefore, we included these models only in the global assessments but not in the sector assessments.

In the AMPERE database (Work package 5), there are 22 scenarios from 3 EU models (PRIMES, GEM-E3, Times_PanEU) that provide sectoral data on carbon emissions and energy use. All the European scenarios have projections for the period 2015–2050 in 5-year time steps.

Some data preparation was necessary to compare the cumulative data for CO_2 emissions and gross negative CO_2 emissions due to CCS among all the scenarios.

For the global models, data from 2015 to 2100 are available in 10-year steps for the scenarios of the models GCAM, IMAGE, REMIND and WITCH. For the scenarios of the models TIAM-ECN, MERGE-ETL, GCAM, IMAGE, REMIND and WITCH, data are present in 5-year steps starting in 2010. Of the global models, only DNE21+ provides short-term data only from 2010 to 2050 in 5-year steps.

Where intermediate data steps are missing, we interpolate linearly between the data points available. To provide an assessment up to 2100 for the European and national models (as well as for the DNE21+ model), we extrapolate those scenarios ending in 2050 to the year 2100 as described below. According to the 2014 UNEP Emissions Gap Report (UNEP, 2014), the scenarios from the IPCC AR5 database that stay below the 2°C limit with a probability of at least 66% reach zero net CO_2 emissions between 2055 and 2070. Therefore, we consider a future scenario that decreases emissions linearly from the year 2050 (or the last year for which data are available) to zero by 2070. After 2070, emissions are kept at zero and no net carbon dioxide removals are considered. This can be seen as a conservative realization of the goal of net zero emissions without overly ambitious assumptions about carbon dioxide removals.

In the second step, we calculated cumulative emissions for all scenarios for both periods 2015–2050 and 2015–2100 by applying simple linear interpolation between time steps. In cases where information for 2015 was missing, we used the arithmetic mean of years 2010 and 2020.

The UK 'Zero Carbon Britain 2030' scenario forecasts reaching net zero emissions already by 2030. The comparison includes the original scenario as well as an adapted version, in which we assume net zero emissions are reached by 2050.[3] Not all the necessary sector-level data were publicly available for the French, Italian and UK scenarios. However, the designers of all three scenarios kindly provided additional sector-level data. In a few cases, we had to complete the data by interpolating missing time steps linearly and calculating carbon emissions from fossil fuel use based on standard carbon factors.

While all the available scenarios that met our criteria were included for global and European scenarios, only one scenario was included in the analysis for national models even if more than one scenario with emission reductions larger than 80% was available. There are two main reasons: first, data from the national models had to be collected manually and in many cases needed intensive preparation, which limited the number of studies that could be evaluated. Second, due to the high level of detail within the models and their continued updating and improvement, scenario results can differ significantly between different applications. In many cases, in-depth knowledge of the model is necessary to understand the differences, reasons for which are normally not found within the studies. For national models, we chose to include the most ambitious scenario from the most recent studies available.

4. Decarbonization scenarios and carbon budgets

The starting point for our analysis is the comparison of the carbon budgets for the selected scenarios for the periods 2015–2050 and 2015–2100. As models usually rely on similar databases even between different model runs and scenario calculations, we group the scenarios by model for the analysis. As there are only two scenarios that are compatible with limiting the temperature increase to 1.5°C,[4] we decided to show these scenarios[5] separately and independent of the model used to calculate them. Figure 1 shows the

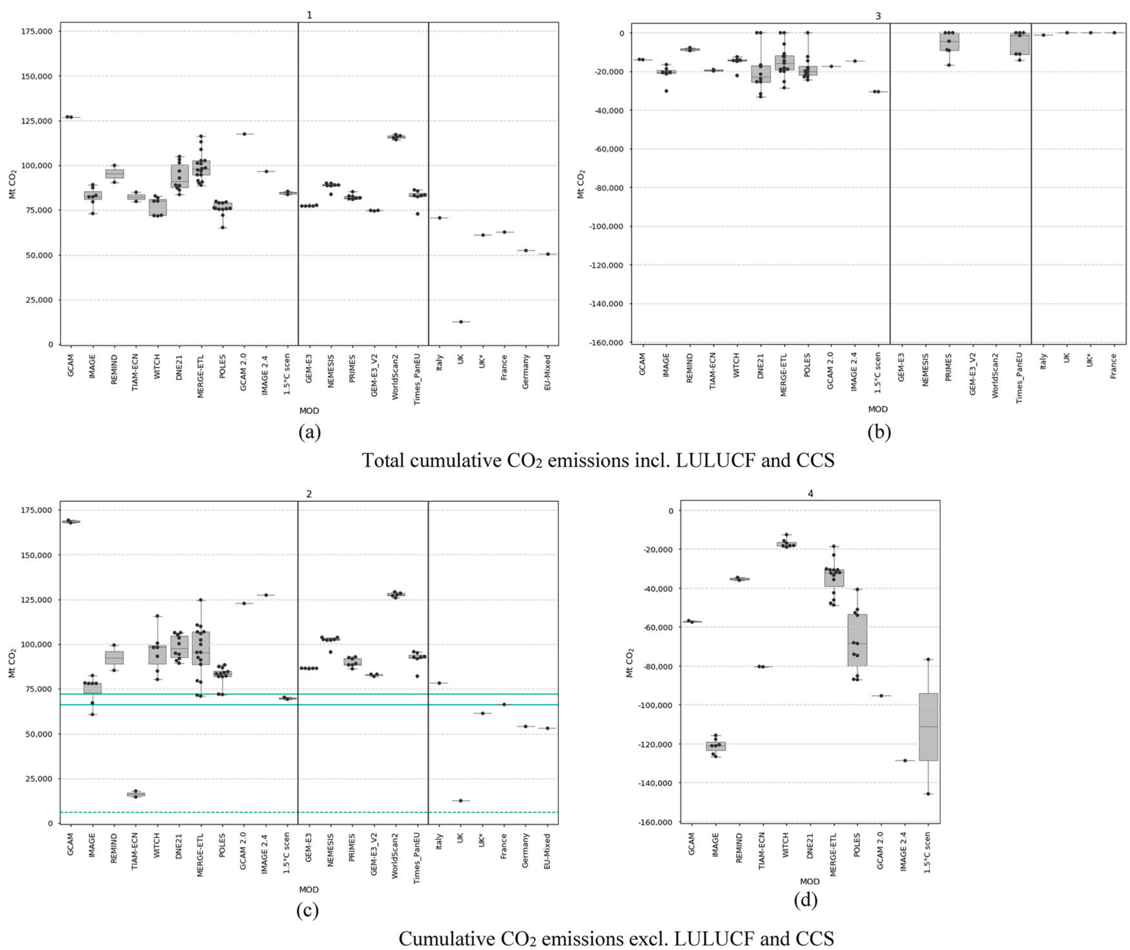

Figure 1. Cumulative emissions in Gt CO_2 for the periods 2015–2050 (a,c) and 2015–2100 (b,d) by model. Scenarios are grouped into three segments: global, European and national scenarios. Boxplots indicate the quartiles of model results. The solid horizontal line represents the fair carbon budget for the EU for the 2015–2100 period, ranging from 48 to 72 Gt CO_2 for a 2°C target (medium case) in line with Gignac and Matthews (2015) and Matthes et al. (2018). The horizontal dotted line shows the fair carbon budget for the EU of 6–27 GtCO2, which is consistent with the 1.5°C target. Source: Own calculations.

cumulative emissions for both periods 2015–2050 and 2015–2100 for the scenarios analysed. Figure 1(a,b) shows cumulative emissions, including LULUCF and CCS; Figure 1(c,d) shows cumulative emissions excluding LULUCF and CCS.

As expected, the cumulative emissions (including as well as excluding) LULUCF and CCS from EU scenarios show significantly less variation than the cumulative emissions calculated from global scenario runs. This results from the need to define overall European CO_2 emission reductions exogenously for the calculations made using EU models. Despite those differences, our analysis shows that cumulative carbon emissions (including LULUCF and CCS) are mainly in the range of 75–100 Gt CO_2 for both global as well as EU models for 2015–2050. Only a small number of scenarios based on global models result in cumulative emissions including LULUCF and CCS above 100 Gt CO_2 between 2015 and 2050. In contrast, cumulative CO_2 emissions including LULUCF and CCS from the national scenarios are significantly lower, ranging from 50 to 75 Gt CO_2. Due to the significantly higher level of ambition of the original UK study, which reaches zero carbon emissions already by 2030, cumulative emissions in this scenario remain at around 22 Gt CO_2.

To compare the scenarios analysed with the fairness-based carbon budgets for Europe, we extended the period of the scenarios and analysis to 2100. For those scenarios not providing data until 2100, we extended the GHG emissions until 2100 as described in the previous section. In general, the effects are similar for the periods 2015–2100 and 2015–2050. Slightly more scenarios, in particular from the global models, reach cumulative emission levels above 100 Gt for the longer time frame. Again, the national studies' cumulative emissions are lower compared to the global and European scenarios; only one of them (Italy) reaches cumulative emissions above 75 Gt for the longer period.

Two interesting effects are visible when comparing the 2015–2050 and the 2015–2100 periods. First, the scenarios of TIAM-ECN show moderate cumulative values for the 2015–2050 period, which drop to the minimum level among the global and European scenarios for the 2015–2100 period. This is due to both strong emissions reductions and a high level of net removals of CO_2 by CCS technologies in the second part of the century (see also Figure 1(c,d)). Second, for some of the global models – not all of them – our analysis shows lower cumulative CO_2 emissions over the 2015–2100 period than over the 2015–2050 period. Again, this development can be explained by the important role of gross carbon dioxide removals due to CCS and LULUCF in the second half of the century, which results in net negative CO_2 emissions for a number of models and scenarios. Due to the significance of carbon dioxide removals, the next section focuses on the role of CCS in the different scenarios and models. LULUCF is not considered in detail in the further analyses within this paper due to the significant differences between natural emission sinks and sources and technology-based ones.

Figure 1(b) also shows Europe's fairness-based (domestic) share in the global carbon budget that is compatible with the 1.5°C or 2°C target based on the work by Gignac and Matthews (2015) and Matthes et al. (2018). The EU's share is 48 (Matthes et al., 2018) and 72 Gt (Gignac & Matthews, 2015) for the 2°C target and approximately 27 and 6 Gt CO_2 for the 1.5°C target. Comparing the scenarios' cumulative carbon levels for the time period 2015–2100 shows that only one of the scenarios – the original UK scenario – manages to stay within the fairness-based EU budget for the 1.5°C target despite considerable carbon dioxide removal in the second half of the century, in particular. Most of the national studies are within the range to meet the 2°C target (despite neglecting LULUCF as a natural sink). However, only six of the scenarios based on global or EU models plus the two scenarios compatible with the 1.5°C target comply with the fairness-based domestic EU budget of cumulative CO_2 emissions, but are only close to the fairness-based EU budget based on Matthes et al. (2018). This reflects that target setting within the global models is normally based on least-cost considerations. In contrast, target setting in the EU scenarios shown is based either on a given level of cumulative emissions (and model-endogenous allocation over time) or by a given pathway for emission development over time, resulting in similar cumulative emissions (Capros et al., 2014). In both cases, lower reductions within the EU compared to the EU's fair share require higher reductions outside the EU.

To develop a better understanding of the mechanisms underlying the different scenarios and resulting in the CO_2 emission reductions and cumulative CO_2 emissions, the following sections provide an in-depth analysis of different sectors' emissions. The analysis focuses on the role of emission reductions due to the application of CCS and on the demand side of energy end-uses. Supply-side emissions are briefly touched upon while emissions from LULUCF – due to the significant difference in nature – are not addressed in the following in-depth analyses.

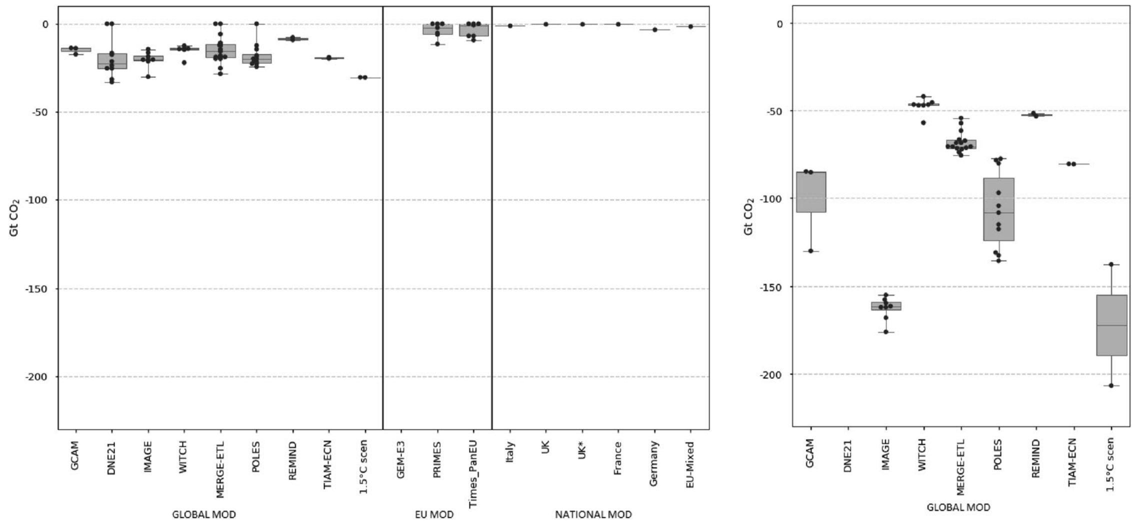

Figure 2. Cumulative carbon dioxide removal due to CCS in Mt CO_2 grouped by model for the period 2015–2050 for all scenarios, sorted into three segments: global, European and national scenarios (left) and 2015–2100 – only for global scenarios (right). Boxplots indicate the range and distribution of model results. Source: Own calculations.

5. Role of CO_2 emission reductions via CCS in meeting the carbon budget

Our first analysis of cumulative CO_2 emissions already indicated that emission reductions from CCS play an important role, in particular for the EU and global model scenarios. The following analysis focuses on CCS as a technological option to keep CO_2 out of the atmosphere or remove CO_2 from the atmosphere, including CCS in combination with fossil fuels as well as BECCS (referred to as 'CO_2 emission reductions').

Figure 2 shows CO_2 emission reductions due to CCS for the different scenarios. All of the global scenarios include CCS technologies in the projections up to 2100; most of them already before 2050. For the EU models, two out of six provide information on the use of CCS before 2050; the cumulative carbon dioxide removal due to CCS ranges from 0 to −20 Gt CO_2 by 2050.

The two 1.5°C scenarios differ in their cumulative CO_2 emission reductions due to CCS. The GCAM scenario projects a medium range of emission reductions of −20 Gt CO_2, while the IMAGE scenario is in the upper range with −30 Gt CO_2.

In contrast, there are very limited CO_2 emission reductions due to CCS in the national studies. In particular, the very ambitious UK scenario reaches its targets without using CCS technology at all. A limited amount of emission reductions due to CCS can be found in the German KS95 scenario, amounting to −4 Gt CO_2 by 2050.

For the period 2015–2100, information on CCS is only available from the global scenarios. In contrast to the 2015–2050 period described above, the values are widely scattered and range from −17 to −145 Gt CO_2. These figures reinforce the finding that CCS plays an important role in the global models for meeting the 2°C target. The 1.5°C scenarios are among the scenarios with the highest absolute values for cumulative CO_2 emission reductions due to CCS until 2100.

6. Demand-side reduction rates

As seen in the previous section, cumulative CO_2 emissions in the national scenarios are significantly lower than most projections in the scenarios based on global and EU models. Due to the significant use of CCS in the global and EU scenarios in contrast to the national scenarios, the difference is more prominent when looking at cumulative CO_2 emissions excluding CO_2 emission reductions due to CCS and LULUCF.

Figure 3 shows the cumulative CO_2 emissions for energy supply and energy demand, divided into the sectors industry, transportation, buildings and other. The figures include CO_2 emission reductions by CCS, but not

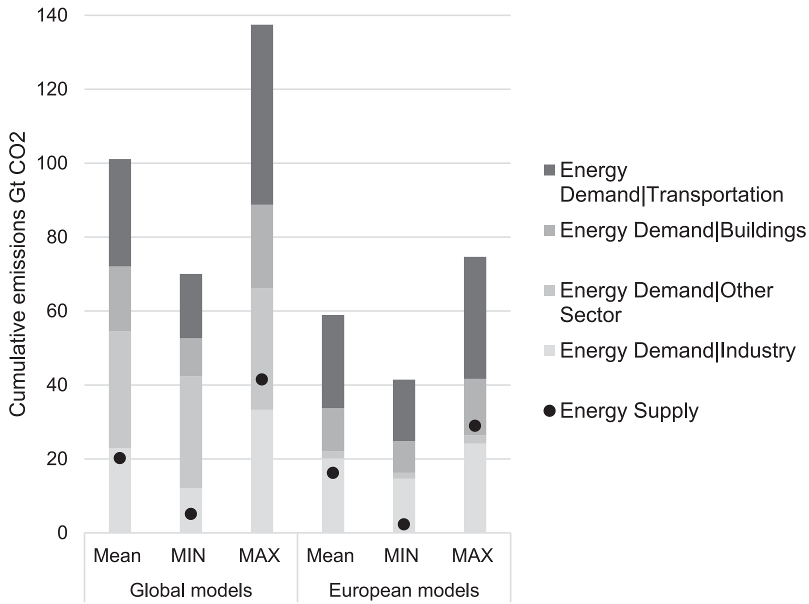

Figure 3. Minimum, mean and maximum cumulative emissions by energy sector for the evaluated scenarios for 2015–2050 (left: global, right: European). Source: Own calculations.

LULUCF. To limit the number of scenarios, we constructed three scenarios for both the global and EU models: a maximum emission scenario ('max'), a minimum emission scenario ('min') and a mean emission scenario ('mean') from all the scenarios available in the respective category.

As shown in Figure 3, the cumulative emissions of the supply sector are already relatively low compared to the energy demand sectors for the period up to 2050. Further CO_2 reductions are achieved in the second half of the century, including net carbon dioxide removals in the energy sector due to CCS. In the scenarios analysed, energy demand sectors account for a dominant share of the cumulative CO_2 emissions from fossil fuels. Hence, in our further analysis, we focus on these sectors and try to identify further mitigation potentials based on scenarios with a higher disaggregation of the demand side.

CCS technology is not used to achieve significant emission reductions or carbon dioxide removals in the national models. Instead, additional emission reductions are achieved in the end-use sectors in these scenarios.

To analyse the differences within sectors between the different scenario groups, we split the development of sector emissions into two indicators: the carbon intensity of energy (i.e. carbon emissions per unit of final energy used), on the one hand, and final energy use per capita, on the other hand. While per capita is not the optimal reference value for all demand sectors, population is the only reference value available for all studies and therefore used for the following analysis.

Figure 4 shows the development of carbon intensity (left part) and energy use per capita (right part) within the different model groups based on the example of the transport sector.

In the transport sector, carbon intensity reduces at a similar rate in both the EU and the global models in the first half of the twenty-first century. The reduction in the national scenarios is in line with the most ambitious EU models in the German and French cases, is even more ambitious in the UK case and at least average in the Italian case. Noticeably, the significant decrease in carbon intensity in the national studies as well as in the EU model studies in the transport sector only occurs after 2030 or even 2040. This also applies to the scenarios based on global models, although to a lesser extent.

At the same time, the EU models show a significantly broader range compared to the global models and reach significantly higher levels for carbon intensity at the beginning of the period as well as by 2050.

Compared to carbon intensity, the range for the energy use per capita is significantly wider in the global models than in the EU models. At the same time, energy use per capita decreases significantly faster in the

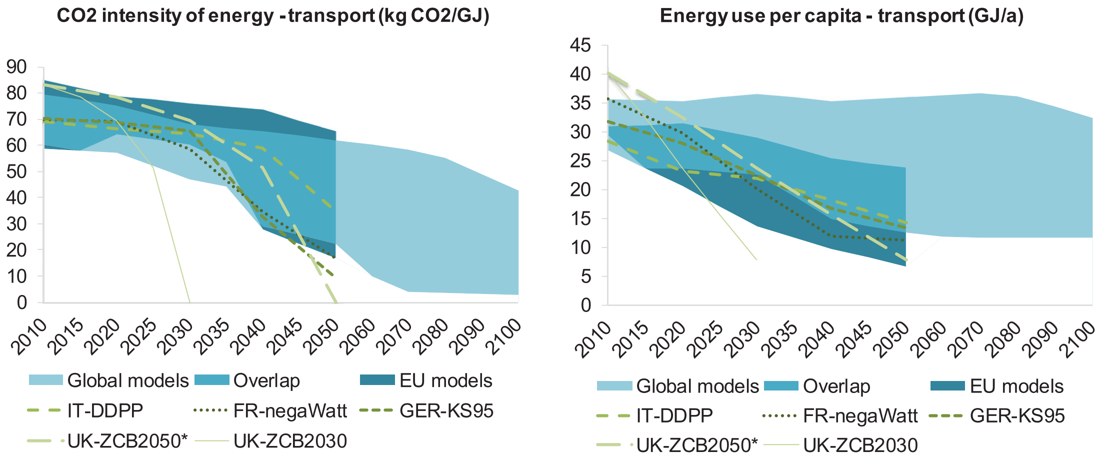

Figure 4. Development of carbon intensity of energy and energy use per capita in the transport sector in the different scenarios, grouped by study types. Source: Own calculations.

EU models than in the global models, which show only moderate reductions. For the national studies, energy use per capita decreases even faster than in the EU scenarios in the French and the UK scenarios, while the Italian and the German scenarios show developments comparable with the EU models; i.e. they are still more ambitious than the scenarios based on global models.

Similar analyses were conducted for the two demand sectors: industry and buildings (see Appendix). Once again, energy use per capita values in the national studies decrease as strongly or even more strongly than in the most ambitious global and EU models. Energy use per capita remains stable for the global models in the buildings sector, while it mainly decreases in the EU models. In the industry sector, it is the other way round with energy use per capita on average decreasing in the global models and not changing substantially in the EU models. For carbon intensities, the picture is more diverse. In general, the development of carbon intensities in industry and buildings is smoother over time than in the transport sector. In industry, the carbon intensity in the national scenarios in 2010 is more in line with the global models' range. Over time, the national scenarios realize a significantly higher reduction of carbon intensity compared to the global models; in some cases, even higher than in the EU models. In particular, the German KS95 scenario reaches a negative carbon intensity in the industry sector by 2050 due to the application of CCS to bio-energy and fossil fuels in the cement, chemicals and steel sectors.

In the buildings sector, it is striking that most of the national studies start at significantly higher levels of carbon intensity compared to both EU and global models. Over time, carbon intensities in the buildings sector in scenarios based on EU models decrease as rapidly as in the ambitious global models, while they decrease even faster in national scenarios so that these reach the lowest values in 2050 despite beginning above the EU average.

Overall, the comparison indicates that certain mitigation potentials, in particular for energy use per capita, but also with regard to carbon intensities, are not taken into account in the global and EU models in contrast to the national scenarios. This finding serves as the starting point for the final step of the analysis.

7. Identifying additional mitigation potentials

In a final step, we estimate the additional reduction potentials of mitigation options apparently neglected in the global and EU models. To do so, we applied the reduction rates of the sectoral carbon intensity and energy use per capita from the German 'Climate protection scenario 2050, KS95 run' to all the global and European scenarios. The KS95 was chosen for two reasons: (i) it is very ambitious and should therefore be a good match to the analysed global and EU scenarios that comply with a 2°C target. (ii) It is the only national scenario that includes all the relevant sector-level data in the publicly available report and is therefore more transparent about the

Table 1. Changes in cumulative mean emissions due to changes of carbon intensity and final energy use.

		Further reduction potentials from EUC 2015–2050 [Gt CO_2]	Further reduction potentials from CI 2015–2050 [Gt CO_2]	Further reduction potentials from CI + EUC, 2015–2050 [Gt CO_2]
Global models	Demand-side	26.8	26.2	35.6
	Industry	8.2	8.4	10.8
	Buildings	9.2	9.1	12.2
	Transportation	9.4	8.8	12.5
	Energy supply	—	—	8.0
EU models	Demand-side	32.9	35.3	37.1
	Industry	11.4	13.0	13.9
	Buildings	7.1	7.5	8.3
	Transportation	14.4	14.8	15.0
	Energy supply	–	–	13.6

mitigation strategies chosen than the other national scenarios. As the KS95 scenario only covers the period up to 2050, we focused on the evaluation of the cumulative emissions for the period 2015–2050. We calculated three cases: in the first case, we adapted only the carbon intensity rates; in the second case, only the energy use per capita; and both in the third case.

As shown in Table 1, the effect of changing energy use per capita or carbon intensity is approximately of the same magnitude. In total, the mean cumulative emissions for 2015–2050 of all sectors are almost halved compared to the mean of the original data. In absolute figures, adapting energy use per capita and carbon intensity individually results in a reduction in the mean cumulative emissions of 26–35 Gt CO_2. Combining both effects reduces the mean cumulative emissions by 36–37 Gt CO_2. The difference in cumulative emissions is only slightly larger if both energy use per capita and carbon intensity are modified than if only one of the rates is adapted. This is because the impacts of reducing carbon intensity and energy use are interrelated. If energy use is already low, the impact of reducing carbon intensity is much smaller and vice versa. All end-use sectors hold significant potentials for emission reductions. These potentials are of a similar magnitude with the exception of the buildings sector, which offers slightly smaller potentials.

Table 2 brings together the additional reduction potential and the previously calculated cumulative emissions.

Cumulative emissions including LULUCF and CCS for 2015–2050 lie between 65 and 127 Gt CO_2 for the global and EU models, with mean cumulative emissions calculated at 96 Gt in the EU models and 90 Gt in the global models. This represents an additional 15–42 Gt of CO_2 compared to the EU's fairness-based share for reaching a 2°C target, which lies between 48 and 72 Gt of CO_2. According to our analysis, applying rates of carbon intensity or energy use per capita reductions similar to those in the national studies would allow additional emission reductions of between 26 and 35 Gt CO_2 by 2050; if both carbon intensity and energy use per capita were adapted in line with the national studies, reductions could even reach 36–37 Gt CO_2. The use of CCS is very limited compared to the global and EU scenarios. This suggests that adapting carbon intensity and energy use per capita[6] is not only able to compensate for the emission reductions due to CCS (between 0 and 32 Gt CO_2), but significantly overcompensates for them, almost doubling the total achievable emission reduction. It brings the constructed scenarios based on both global and EU models down to a cumulative emission level compatible with the 2°C target and comparable to the cumulative emission levels reached within the national studies.

A significant lever for decarbonization of the demand side in the German scenario is the use of electricity. Therefore, we also calculated the development of CO_2 emissions on the supply side based on the German

Table 2. Results from the analysis of cumulative emissions 2015–2050.

	Cumulative CO_2 emissions 2015-50 (mean) [Gt CO_2]	CO_2 emission reductions from CCS 2015–2050 [Gt CO_2]	Further reduction potentials from EUC 2015–2050 [Gt CO_2]	Further reduction potentials from CI 2015–2050 [Gt CO_2]	Further reduction potentials from CI and EUC 2015–2050 [Gt CO_2]
Global models	90 (65–127)	0 to −33	27	26	36
EU models	96 (85–101)	0 to −12	33	35	37
National models	52 (13–71)	0 to −4	n/a	n/a	n/a

Note: EUC = energy use per capita; CI = carbon intensity of final energy use.

scenario. We focus on the change in both carbon intensity and energy use per capita. In contrast to our expectations, the calculations show that in the German scenario the supply side decarbonizes very early and strongly. That leads to even lower cumulative emissions in the resulting global and EU scenarios when applying the German carbon intensity and energy use per capita change rates. The presumption of a stronger demand for electricity leading to a more carbon-intensive decarbonization path on the supply side is not confirmed based on our simple calculations for the ambitious German scenario.

Regarding the modification of the mitigation rates in the global and European scenarios, we note the following: In the national scenarios, we find more ambitious reductions of both carbon intensities and energy use per capita. However, lower energy use per capita and carbon intensities can be interlinked. More precisely, a reduction in energy use can lead to decreases in carbon intensity in an existing energy system. Also, lower energy use per capita reduces the need for investment in new generation capacity. For our exercise, this means a comparably much larger amount of non-fossil energy would have to be supplied, if energy use per capita remained constant and only the carbon intensities were aligned with the national scenarios (Lechtenboehmer, Schneider, & Samadi, 2017). On the other hand, modifying the energy use per capita while keeping the carbon intensities fixed can be seen as a conservative estimate of the impact of more ambitious energy efficiency improvements. The actual change of the non-fossil energy supplied will depend on the specific sector setting. While we provided a simple estimate based on figures available from the studies, a detailed analysis of these effects should be taken up in future work.

8. Conclusion

Our analysis showed that none of the scenarios based on global or EU models are able to reach the fair carbon budget for the EU compatible with a 2°C target in a contraction and convergence approach, while almost all of the national scenarios achieve this. This is not the case, however, for the 1.5°C target. Only one of the studies analysed in this paper is able to reach a fairness-based EU carbon budget for this target, the very ambitious UK study, which foresees net decarbonization for the UK already by 2030.

The analysis on the sector level revealed further structural differences between the global and EU models on the one hand, and the models applied within the national studies, on the other. For instance, CO_2 emission reductions due to CCS play a much more important role within the global and EU model scenarios, in particular after 2050, but also in the period 2015–2050. In contrast, the national studies for almost all sectors show higher reductions in carbon intensity as well as in energy use per capita. Applying these more ambitious reduction rates to the global and EU scenarios allows further reductions of cumulative emissions. These additional reductions not only cover the CO_2 emission reductions achieved by CCS, but also mean the scenarios can meet the fairness-based carbon budget for the EU to achieve the 2°C target. That could slightly increase carbon budgets for other parts of the world.

The analytical approach chosen in this paper is relatively simple. However, in its simplicity, it allows us to identify further mitigation potentials neglected in the global and EU models that could significantly increase the chances of meeting the 2°C target, or that aim at meeting the 1.5°C target. Since policy recommendations are often based on analyses using these types of global or EU models, it is worth knowing that these models neglect certain mitigation potentials and favour options such as CO_2 emission reductions using CCS, including the option of net carbon dioxide removal due to combining CCS with bio-energy. Our analysis, however, suggests it is worth considering these neglected mitigation potentials and developing policies and measures to tap them. This requires assessing the technologies and structural changes that underlie these additional potentials. This has been carried out by Wachsmuth and Duscha (2018). Findings in that paper suggest that current EU policies on demand-side driven mitigation need to substantially increase in both ambition and scope.

Notes

1. https://tntcat.iiasa.ac.at/AR5DB/dsd?Action=htmlpage&page=about.
2. Note that significant differences exist between the models within the groups used for our analysis. For further information on the models we refer the reader to http://themasites.pbl.nl/models/advance/index.php/Special:RunQuery/Models-

AttributesForm for information on the global models as well as to the reports and publications provided on the different scenarios.
3. The adapted version is included because the sector targets in the 'Zero Carbon Britain 2030' partly stem from a 2050 scenario and were shifted to 2030 for normative reasons only.
4. As in Rogelj et al. (2015), we define this as less than 50% chance of exceeding 1.5°C.
5. Those are 'GCAM 2.0-AME CO_2 price $50(5% p.a.)' and 'IMAGE 2.4-AME 2.6 W/m2 OS'.
6. Note that reducing energy use per capita can be reached in two ways: by efficiency increases (technological change) and by sufficiency, i.e. changes in behaviour that result in lower energy use.

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Appendix: Carbon intensities and energy use per capita in final energy, industry and buildings

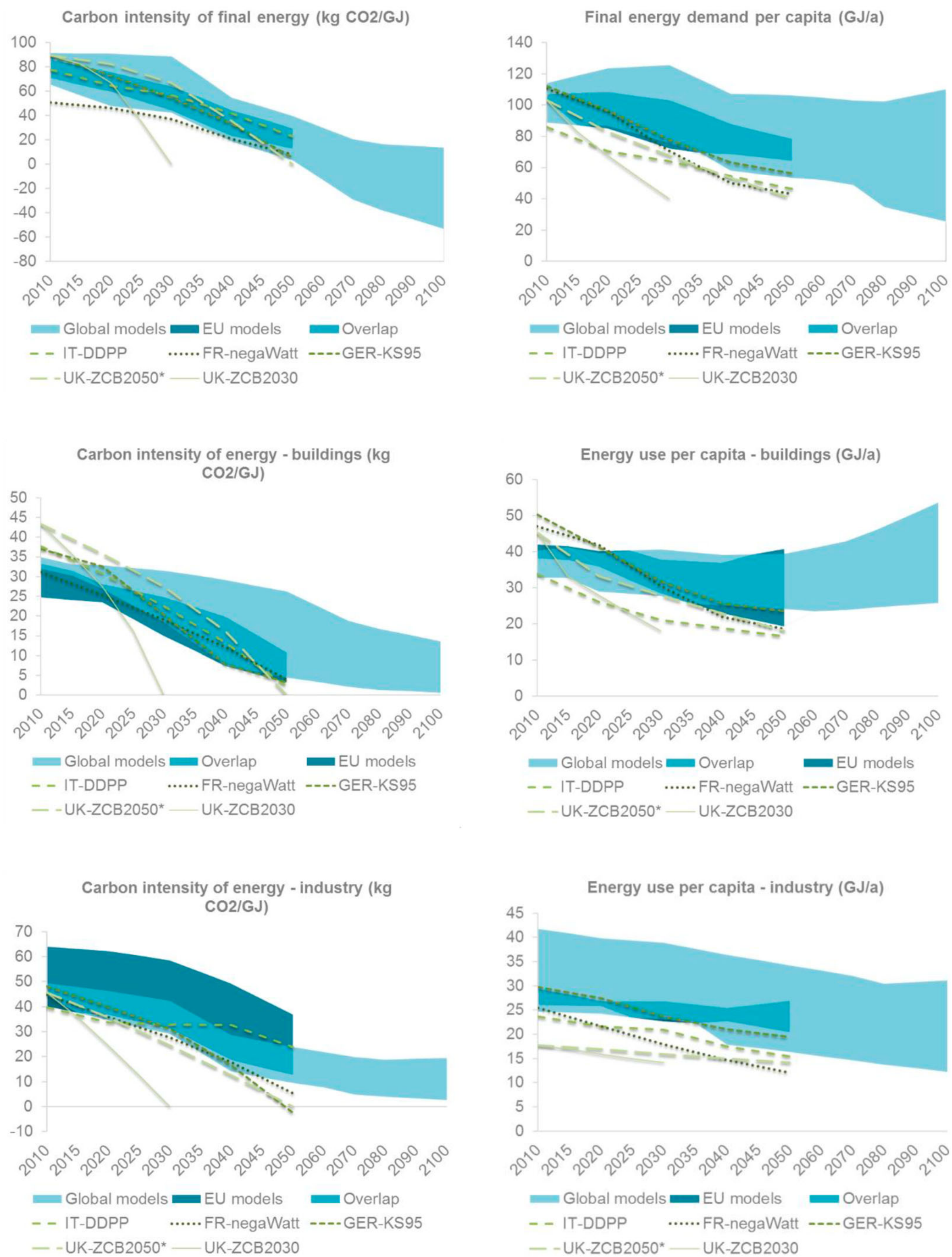

Figure A1. Development of carbon intensity and energy use per capita in final energy demand, buildings and industry in the different scenarios, grouped by study types. Source: Own calculations