

Ariadne-Analysis

Optimal allocation of the EU carbon budget: A multi-model assessment



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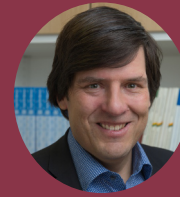
Authors



» Dr. Jan Abrell
ZEW - Leibniz-Zentrum für
Europäische Wirtschaftsforschung



» Süheyb Bilici
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Prof. Dr. Markus Blesl
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Dr. Ulrich Fahl
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Felix Kattelmann
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Lena Kittel
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Dr. Mirjam Kosch
Potsdam-Institut für
Klimafolgenforschung



» Prof. Dr. Gunnar Luderer
Potsdam-Institut für
Klimafolgenforschung



» Drin Marmullaku
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung



» Dr. Michael Pahle
Potsdam-Institut für
Klimafolgenforschung



» Dr. Robert Pietzcker
Potsdam-Institut für
Klimafolgenforschung



» Dr. Renato Rodrigues
Potsdam-Institut für
Klimafolgenforschung



» Jonathan Siegle
Universität Stuttgart – Institut für
Energiewirtschaft und Rationelle
Energieanwendung

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Corresponding Author: Dr. Mirjam Kosch, mirjam.kosch@pik-potsdam.de

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Abstract

The European Union (EU) has pledged to reduce greenhouse gas (GHG) emissions until the year 2030 by 55% compared to 1990. Currently, a central debate within the EU institutions concerns the introduction of a new Emission Trading System for road transport and buildings (ETS2) in addition to the current EU ETS. Contested design features are the split of the carbon budget between the EU ETS and the remaining sectors regulated under the Effort Sharing Regulation (ESR), the carbon price level of the ETS2, and the scope in terms of whether to initially regulate only commercial entities or all consumption. In this paper we conduct a multi-model assessment to shed light on the former two. We find that shifting the budget between EU ETS and ESR sectors in the discussed range seems to be favorable from an economic efficiency point of view. However, the impact on overall welfare is relatively low, given current knowledge about abatement costs. We also find that if carbon prices are the only instruments used, the carbon prices that would be necessary to reach the emission targets range from 130 to 210 €/tCO₂ in the EU ETS and from 175 to 350€/tCO₂ for the energy-related ESR (ESR-E) emissions – depending on technology development and baseline assumptions of the different models. Our results imply that if the ETS2 price were capped at 50€/tCO₂ as discussed by the European Parliament, the abatement target will not be reached with a carbon price alone. The remaining abatement would need to come from complementary policies like technology standards or subsidies, and abatement costs from these policies would be above 50€/tCO₂. In this case, effective costs for consumers would very likely exceed the costs of carbon pricing alone due to inefficiencies that arise from the lack of flexibility to mitigate emissions where it is cheapest.

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1. Introduction

The European Union (EU) has pledged to reduce greenhouse gas (GHG) emissions until the year 2030 by 55% compared to 1990. The resulting carbon budget is allocated mainly to two different sectoral categories: First, the EU Emissions Trading System (EU ETS) regulates energy intensive industries, air, and water transport. It imposes a single cap on carbon emissions in the EU, defining the annual emission budget. Second, the Effort Sharing Regulation (ESR) and the Land Use, Land-Use Change and Forestry (LULUCF) regulation regulate the remaining emissions. For these emissions there is an individual carbon budget for each member state (MS), i.e., the ESR regulates allocation of the emission budget across countries. The ESR allows, however, that MS partly trade these emission rights. In addition, the European Commission has proposed to introduce a new Emission Trading System for road transport and buildings (ETS2).

The EU therefore needs to decide how to allocate the carbon budget across sectors and MS. Two major options exist. First, extending the EU ETS to cover all sectors leading to one EU-wide cap and a uniform European carbon price. This delegates the final allocation of the fixed carbon budget across sectors, countries and installations to the market. Second, maintaining the current sectoral scopes and deciding about the respective carbon budgets for the EU ETS and the ESR sectors.

In the short term, a full European trading system is politically unlikely. Therefore, the EU needs to decide about the carbon budget under the EU ETS and under the ESR, respectively. This decision will impact the cost of reaching the climate targets. In the current proposal, the European Commission (EC) suggests to attribute 64% of the remaining 2030 GHG emissions budget to the ESR sectors and the rest to the EU ETS. According to the EC's impact assessment, this split results in EU ETS and ETS2 price estimates of around 50€/tCO₂ for a scenario with strong additional measures in complement to carbon pricing (*MIX*). For a scenario with less stringent additional measures (*MIX-CP*) the ETS2 price estimate increases to 80€/tCO₂.

Given the multitude of factors and assumptions that influence the optimal budget allocation and carbon prices, such an assessment should preferably be grounded on multiple model assessments covering a broad range of methodological, technological,

and behavioral assumptions. We thus conduct a multi-model assessment using four different models to put the EC's proposal in perspective by addressing the two questions: First, what is the optimal allocation of the EU carbon budget to EU ETS and ESR sectors? Second, what are the resulting carbon prices? Our answer to these questions is not a number, but a range representing best guesses based on different approaches.

As several of the models contributing to this study focus exclusively on CO₂ emissions, we convert the EC's proposed GHG-based ESR share of 64% into an *energy-related* CO₂-based ESR-E share of 62-63%. This implies that our ESR-E sector has a rather high overlap with the ETS2 sectors as proposed by the EC. We find that optimally between 60 and 70% of the total carbon budget should be allocated to the ESR-E sectors. The EC's choice of 62-63% thus lies at the lower end of the optimal allocation. However, our assessment also shows that within a range of around 55-70%, varying the split between ESR-E and EU ETS shares does not significantly affect total welfare.

Regarding the second question, for the proposed split of the carbon budget, our models provide EU ETS price estimates of 130 to 210€/tCO₂ that would be necessary to reach the emission targets in the absence of new additional policies. For the ESR-E sectors, carbon prices between 175 and 350€/tCO₂ would be necessary to reach the targets if a carbon price is the only new instrument used to reach the target. These price estimates depend on technology development and baseline assumptions of the different models. However, they all clearly lie above the EC's estimates of 50 to 80€/tCO₂. Importantly, we assume that MS trade their carbon budgets, i.e., countries do not necessarily reach their individual ESR targets but the EU-wide ESR target is met. This assumption implies that trade of Annual Emission Allocations (AEA) between MS works without constraints. However, in practice, AEA trade seems to face significant political barriers, leading to heterogeneous carbon prices across MS and, thus, higher total abatement costs.

Our results have two implications for the current policy debate: First, if the ETS2 price were capped at 50€/tCO₂ – as discussed by the European Parliament – the abatement target cannot be reached with a carbon price alone. The remaining abatement would require complementary policies like technology standards or subsidies, and abatement costs from these policies would be exclusively above 50€/tCO₂. In this case, effective costs for consumers would very likely exceed the costs of carbon pricing alone due to the

inefficiencies that arise from the lack of flexibility to mitigate emissions where it is cheapest. Second, whereas the EC has proposed to reduce EU ETS emissions by 61%, the EU Parliament currently discusses to increase the EU ETS ambition. In contrast to our analysis, a corresponding reduction of ESR targets is not discussed in the EU parliament. Yet, we find that such a shift seems to be favorable from an economic efficiency perspective. However, shifting the budget between EU ETS and ESR sectors in the discussed range has a relatively low impact on overall welfare, given current knowledge about abatement costs.

2. Numerical Approach

We use four different models to examine the cost implications of allocating the EU carbon budget between the EU ETS and the ESR-E sectors. The models differ in several dimensions including the model type and assumptions on technological developments, energy efficiency potentials, and political measures along the baseline path (see Table 1 and Table 2 in Appendix). We interpret these differences as uncertainty about future outcomes and therefore do not aim to harmonize these assumptions. Besides the scenario specifications and harmonization of outcome measures to ensure comparability of the results, we thus keep model harmonization at a minimum.

2.1 Models

We use four different models¹:

- REMIND-EU (Regional Model of Investments and Development; Baumstark et al., 2021; Luderer et al., 2020, Pietzcker et al. 2021) is a global multi-regional energy-economy-climate model combining an economic growth model with detailed modelling of the energy, agriculture, and climate system.
- TIMES-PanEU is a multi-regional model containing all countries of the European Union of 27 Member States (EU27) and UK, Switzerland and Norway. The model minimizes an objective function representing the total discounted system costs over the time horizon from 2010 to 2050 and assumes perfect competition among different technologies and pathways of energy conversion (Blesl et al. 2010; Blesl 2014; Kattelman et al. 2021).
- NEWAGE (National European Worldwide Applied General Equilibrium; Beestermöller, 2017, Fahl et al., 2019) is a global recursive-dynamic multi-region Computable General Equilibrium (CGE) model. It represents electricity production in a detailed manner using discrete generation technologies. Data sources include GTAP 9 (Aguilar et al., 2016), EXIOBASE 3 (Stadler et al., 2018), various IEA data and others.

¹ Detailed model overviews can also be found in the Scenario Report of Kopernikus-Projekt Ariadne (2021) (German only): https://ariadneprojekt.de/media/2021/10/Ariadne_Szenarienreport_Oktober2021_Appendix_Modellbeschreibungen.pdf

- ZEW CGE (Abrell and Rausch, 2021; Abrell et al., 2022) is a global static multi-region CGE model. It represents electricity production in a detailed manner using discrete generation technologies.

2.2 Scenarios

We examine the cost implications of allocating the EU carbon budget between the EU ETS and the ESR-E sectors in a common scenario framework. In all scenarios, we implement the 2030 target of 55% GHG reduction compared to 1990. We vary the allocation of the carbon budget between the EU ETS and ESR-E by varying the share of the ESR-E in the total EU carbon budget. We assume carbon trading under the EU ETS and under the ESR-E leading to two European carbon prices. In addition to the EU ETS/ESR-E system, we also model a *Fulltrade* scenario as reference point. The *Fulltrade* scenario implements a single EU carbon trading system resulting in a single carbon price.

Relation of Scenarios and Policy Proposals

While the models used in our analysis are well suited to assess the fundamental design choices of the current policy debate, they are not in all aspects an accurate reflection of the political reality. In particular, the following points need to be kept in mind for the interpretation of our results:

- *Sectoral and GHG coverage:* The analysis focuses on energy-related CO₂-emissions, i.e., we abstract from non-energy-related CO₂ as well as other GHG emissions.² This implies that our ESR-E sector has a high overlap with the ETS2 sectors as proposed by the EC.

In reality, the sectoral scope of the ESR and the ETS2 overlap to a lower extent: While the ETS2 would cover only emissions from buildings and road transport, the ESR covers all emissions that are not subject to the EU ETS except LULUCF emissions and removals, and thus includes emissions from agriculture, waste, domestic navigation and small industries on top of the emissions from buildings and road transport covered in the ETS2 (European Commission 2021). Currently, the EU parliament even discusses that at the beginning only emissions from commercial road transport and buildings are covered by the ETS2. However, as our analysis looks at 2030, we assume that by this time also private road transport and buildings will be regulated under ETS2.

- *Complementary instruments:* In our scenarios, carbon prices are the only new instrument to reach the 2030 targets. They are implemented mimicking cap-and-trade systems, i.e., we impose a quantitative limit on emissions and the models endogenously determine the according carbon price. Other than that, we do not implement additional policies to achieve the emission reduction relative to the baseline of the respective model. Some models, however, include additional policies in their baseline projection. Thus, part of the differences in results are driven by more optimistic baseline (policy) assumptions (see Appendix).

Carbon trading is likely continued to be supplemented by accompanying measures such as renewable support schemes, energy efficiency measures, and transport policies. The absence of additional policy measures in our scenarios has thus strong implications for the interpretation of our carbon prices: They should be regarded as implicit carbon prices or, likewise, marginal abatement cost. Complementary measures in the form of technology standards or subsidies would thus reduce these carbon prices but increase total abatement costs due to inefficiencies that arise from the lack of flexibility to mitigate emissions where it is cheapest.

- *AEA trade:* In our analysis we assume that countries make use of the existing flexibility option to trade their Annual Emission Allocation (AEA). I.e., countries that overachieve their annual ESR-targets sell their allowance surplus to countries that miss their targets. This is beneficial from an economic efficiency point of view as emissions are reduced where it is cheapest. This assumption also implies that in our models, AEA trade under the ESR-E leads to an equivalent abatement outcome as the ETS2 (assuming they cover the same sectors). However, in practice, AEA trade faces significant barriers, leading to heterogeneous carbon prices across MS and higher total abatement costs.

² Some models however do model total GHG emissions (see Appendix). However, to the sake of comparability, we focus on energy-related CO₂ emissions in our analysis.

3. CO₂-price ranges across models

Figure 1 shows carbon prices for the EU ETS and the ESR-E sectors depending on the share of the carbon budget allocated to the ESR-E sectors. The higher this share in the budget split, the more abatement needs to take place in the EU ETS sectors. As expected, the EU ETS prices (left panel) increase and ESR-E prices (right panel) decrease with a higher ESR-E budget. The black dotted line indicates the price ceiling as discussed by the EU parliament.

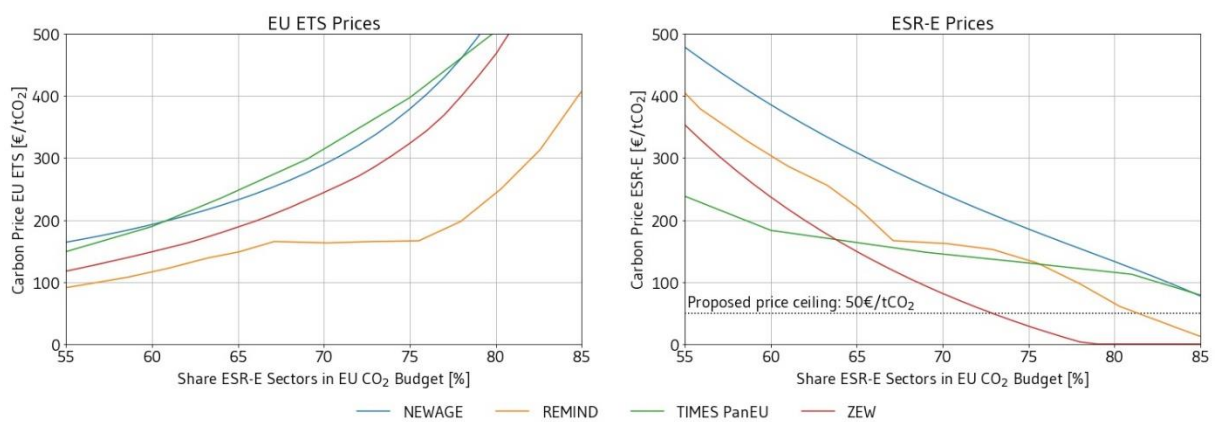


Figure 1: Carbon prices in 2030 in EU ETS and ESR-E sectors

Note: Own calculations. Graphs show implicit carbon price (y-axis measured in $\text{€}_{2021}/\text{tCO}_2$), i.e., marginal abatement cost, of EU ETS (left panel) and ESR-E (right panel) depending on the allocation of the 2030 EU carbon budget (x-axis). The budget allocation is expressed as the share of energy-related carbon allocated to the ESR-E sectors. Moving from the left to right therefore corresponds to a reallocation of the carbon budget from the EU ETS to the ESR-E and, therefore, increases (decreases) the EU ETS (ESR-E) abatement effort. The black dotted line indicates the price ceiling as discussed by the parliament.

Figure 2 shows the model results for the budget allocation proposed by the EU commission. The EU ETS prices range from 130 to 210 €/tCO₂, whereas ESR prices lie between 175 and 350 €/tCO₂. Given the large range of different model types, this range is surprisingly narrow.

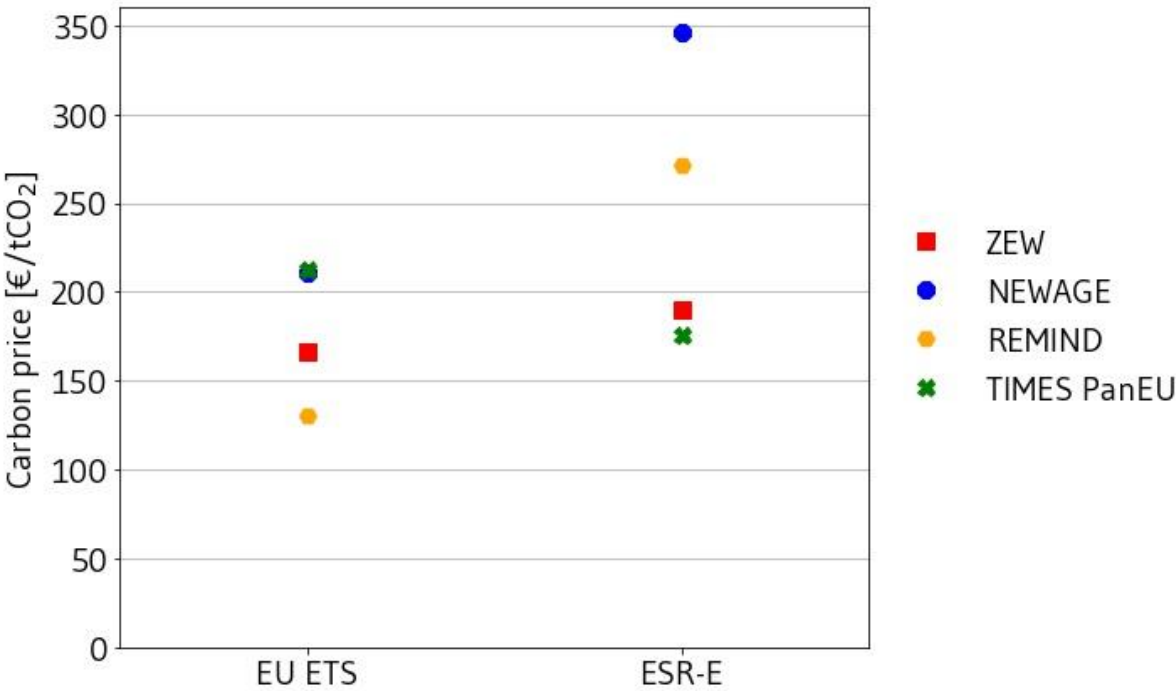


Figure 2: Carbon prices in 2030 in EU ETS and ESR sectors for the EC’s proposed budget split
 Note: Own calculations. The graph shows implicit carbon prices (left axis measured in €₂₀₂₁/tCO₂) of each model for the EU ETS (left) and the ESR-E (right panel) sectors under the budget allocation as proposed by EC, i.e., about 62-63% of energy related carbon emissions.

The results lead to three main insights: First, our EU ETS and ESR-E price estimates lie well above the 50 to 80€/tCO₂ that are reported by the EC’s impact assessment. This price difference can partly be explained by the fact that the impact assessment includes a broad range of additional policies whereas our models focus on carbon pricing. As the stringencies of complementarity policies essentially depend on the individual Member States, there is a chance, that – in the absence of a price cap - prices would be higher than currently reported by the Commission. However, if the ESR-E price is capped at 50€/tCO₂ as discussed by the EU parliament, substantial abatement has to come from

complementary policy measures such as technology standards or subsidies in order to sufficiently reduce emissions in the ESR-E sectors.

Second, the range of the ESR-E price is broader than the one of the ETS. This reflects much larger uncertainties about abatement cost and additional policies in ESR-E sectors compared to the EU ETS sectors. For example, in the electricity sector abatement cost are relatively well known. In contrast, in the buildings and transport sectors we have less information and certainty on abatement cost and demand elasticities as they depend on many uncertain factors including household behavior.

Third, the low price difference between EU ETS and ESR-E prices at the proposed budget split indicates that the gains of carbon trade between ESR-E and EU ETS sectors are limited. This implies that the proposed split of carbon budgets between sectors is relatively well chosen.

In the next section, we analyze the potential welfare gains of different budget allocations in detail.

4. Optimal allocation of the EU carbon budget

Figure 3 provides the EU ETS and ESR-E carbon price depending on the carbon budget allocation together with the welfare measure of the respective model. Whereas the CGE models (NEWAGE, ZEW CGE) directly provide economic welfare, REMIND reports the gross domestic product (GDP) and TIMES-PanEU reports energy system cost. Since demand in TIMES-PanEU is constant, changes in cost are equivalent to changes in economic welfare. Welfare changes are measured relative to the *Fulltrade* scenario which implements a uniform carbon price across the EU and, therefore, provides an indicator for the regulatory approach with lowest abatement cost.³ From these results we can derive the following three main insights:

First, CO₂ prices under *Fulltrade* range from 163€/tCO₂ to 266€/tCO₂. Again, they are significantly higher than the prices reported by the EC.

Second, under the *Fulltrade* scenario, the models allocate between 60% and 70% of the EU's carbon budget to the ESR-E sectors. Therefore, the proposed budget split of 62-63% is at the lower end of this range.

Third, the relatively flat cost curves indicate that a slight variation in the allocation of carbon budgets between EU ETS and ESR-E sectors has no major consequences on welfare. This implies that slight changes of the split of several per cent do not significantly affect welfare. However, when more than around 70% of the total budget is allocated to the ESR-E budget, EU ETS prices start to increase more steeply, reducing welfare substantially.

³ For models that implement commodity and/or income and/or final energy taxation (NEWAGE, ZEW CGE, REMIND), the optimal, i.e., least cost solution, might slightly deviate from the *Fulltrade* scenario due to tax interaction effects (e.g., Boeters, 2014; Goulder, 1995).

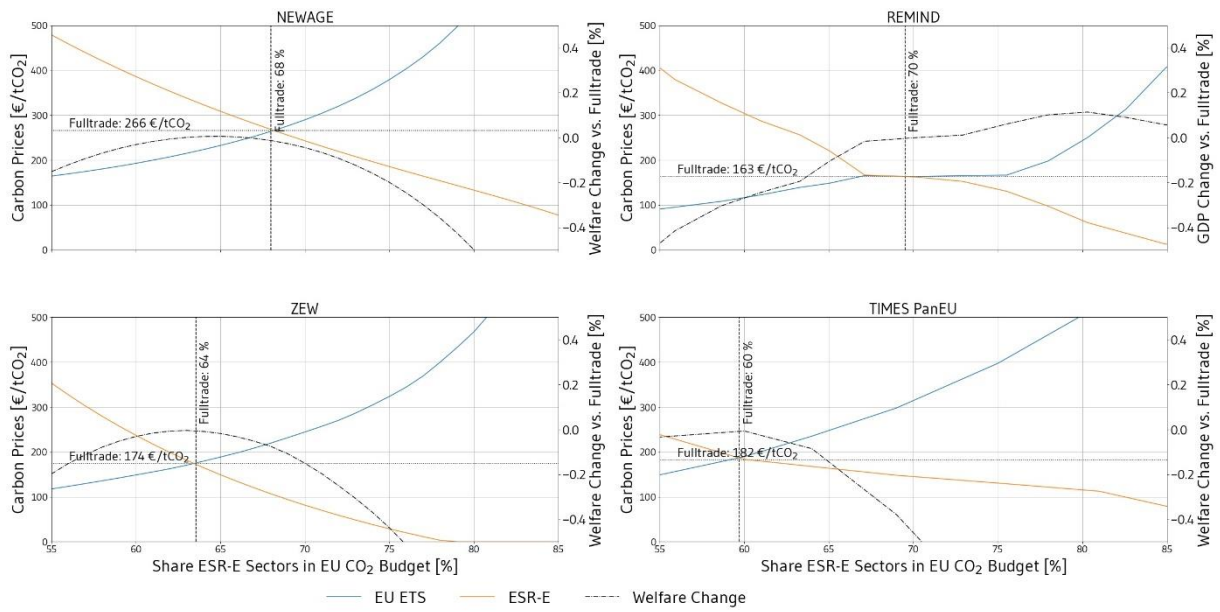


Figure 3: Optimal split between ESR and ETS sectors

Note: Own calculations. The graphs show implicit carbon prices (left axis measured in $\text{€}_{2021}/\text{tCO}_2$) for the EU ETS (blue line) and the ESR-E (orange line) depending on the allocation of the EU energy-related carbon budget (x-axis) for each model. The right axis measures the welfare cost of deviating from a single EU carbon price uniform across all sectors (black dash-dotted line). The horizontal dotted line shows the respective EU-wide uniform carbon price (fulltrade). The vertical dotted line depicts the carbon budget allocation under this uniform price.

5. Conclusion

We provide a multi-model assessment of the allocation of the carbon budget to EU ETS and ESR-E sectors based on four models. We find that the emission share allocated to the ESR-E sectors of around 62-63% (64% based on total GHG emissions) proposed by the Commission is at the lower end of the optimal range determined by the models. Yet, none of the models shows a major welfare loss for the budget split proposed by the EC compared to the optimal split. More explicitly, in our modelling framework, the welfare cost of a separated EU climate policy relative to a uniform carbon price are surprisingly invariant to the allocation of the EU carbon budget.

For the budget allocation as proposed by the EC, our models show an EU ETS price range from 130 to 210€/tCO₂ and an ESR-E price range of 175-350€/tCO₂. These ranges are well above prices reported by the EC.

This has several implications for the current policy debate: First, if the ETS2 price were capped at 50 €/tCO₂ as discussed by the European Parliament, more stringent complementary policies will be needed to reach the target. While in this case the observed carbon prices will be relatively low, the total abatement costs for consumers will be even higher due to inefficiencies that arise from the lack of flexibility to mitigate emissions where it is cheapest. Second, a slightly more ambitious reduction target in the EU ETS sectors as discussed by the EU parliament could be favorable from an economic efficiency perspective if the ESR targets would be reduced accordingly. Finally, welfare effects are relatively invariant to smaller shifts in the budget split. Thus, if further adjustments are needed in the course of the ongoing negotiations, the effect on overall welfare would be small.

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Appendix

Model characteristics

Model	Base year	Dynamics	Regional coverage	GHG coverage	Sectoral coverage
NEWAGE	2011	Recursive Dynamic	18 regions: Germany, France, Italy, Poland, Spain+Portugal, Benelux, Northern EU (Sweden, Finland, Denmark, Latvia, Estonia, Lithuania, Ireland), South-Eastern EU (Austria, Czechia, Slovenia, Slovakia, Hungary, Croatia, Greece, Cyprus, Malta, Bulgaria, Romania), UK, USA, China, India, Russia, Brazil, South Africa, OPEC and Arabic World, Rest of OECD, Rest of World	Energy related CO2 Emissions	23 sectors: (Transportation, Refined oil, Crude Oil, Coal, Natural Gas, Electricity, Paper and pulp and print, Glass, Cement, Rest of non-metallic minerals, Aluminum, Copper, Rest of non-ferrous metals, Vehicles, Chemistry, Iron and Steel, Machinery, Food and tobacco, Buildings, Agriculture, Services, Dwellings, Rest of industry)
REMIND	2010	Perfect foresight, 2005-2150	EU split into 9 subregions, 12 further regions to cover the world	Kyoto Gases; all energy-related emissions from transport/buildings/industry, industry process emissions; CH4/N2O/CO2 from agriculture, land use, land use change;	Transport, Buildings, Industry, Energy supply
TIMES PanEU	2005	Perfect foresight, 2010-2050	All EU member states, UK, Switzerland, Norway	Energy and process related emissions of CO2, CH4 and N2O, + Agriculture; Waste not considered.	Industry, Residential, Commercial, Transport, Agriculture, Electricity
ZEW CGE	2014	No	All EU member states with Luxemburg, Malta and Cyprus aggregated to one region. Rest of OECD, Brazil, China, OPEC, Russia, South Africa, India, USA, Rest of World	Energy related CO2 Emissions	Agriculture, energy intensive industries, Manufacturing, transport, services, coal/gas/oil extraction, refined oils, electricity generation (using discrete generation technologies)

Table 1: Model characteristics

Model	Energy efficiency	Policies baseline / base year	Inertia of transformation	Technology assumptions	EU reduction 2030 vs 2005 [%]	EU GHG budget 2030 [MtCO ₂ eq]	Reduction targets other Countries
NEWAGE	Exogenous AEEI, Energy Productivity improvements	Nuclear power phase out in Germany after 2020, other non-price-based measures	Region-specific capital with depreciation rate 4% p.a., technology-specific capital with explicit capital depreciation curves for electricity generation technologies	Several electricity generation limits	52.2%	1577	vs. 2011: UKI 54%, OEC 41%, USA 47%, BRZ 23%, RUS 20%, IND -28%, CHI 20%, RSA 26%, OPA -15%, ROW 1% (based on IEA, 2020)
REMIND	represented via CES substitution of capital against energy at the top level (capital, labor, energy)	subsidies on BEV in line with historic subsidies (roughly achieving the observed 2020 sales shares)	All energy supply technologies, grid, cars and trucks modeled with explicit vintages; for buildings and industry substitution is governed by CES function with substitution elasticities between 1 and 3	no hard bounds on expansion, but upscaling costs that increase with the square of the relative increase to the last time step	50.0%	2330	global CO ₂ budget from 2020 to peaking year of 900 Gt CO ₂ ("well below 2 °C" scenario, reaching median peaking warming of ~1.6-1.7°C)
TIMES PanEU	Energy Saving law for buildings (EnEV as part of the GEG); parts of the energy service law (industry); reduction quotas for the fleet consumption in transport	Current state of regulatory measures: coal phase out of EU member states, biofuel quotas (until 2030), renewable energy act in residential, oil phase out in building sector after 2026	Taking into account the stocks and the lifetime, maximum of new installed capacities of renewables, security of supply and required balancing energy, building times for huge investments	economic progress for emission free technologies (e.g. electrolysis, fuel cells, batteries)	46.7%	2140	Switzerland and Norway GHG neutrality in 2045, UK in 2050
ZEW CGE	No additional energy efficiency improvements assumed	No additional policies assumed	Capital malleability for electricity generation technologies governed by CET function with transformation elasticity equal to one.	Electricity: no expansion of nuclear and hydro power, "Other" technologies allowed to expand by 50%	47.7%	1523	OEC 40%, USA 44%, BRZ 33%, RUS 16%, IND -4%, CHI 25%, RSA 28%, OPA 0%, ROW 3%

Table 2: Base year and scenario assumptions



Ariadne's thread through the energy transition: The Kopernikus project Ariadne leads the way in a joint learning process with representatives from politics, business and society, exploring options for shaping the energy transition and providing scientific guidance to policy makers along the pathway towards a climate-neutral Germany.

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Who is Ariadne? In Greek mythology, Ariadne's thread enabled the legendary hero Theseus to safely navigate the labyrinth of the Minotaur. This is the guiding principle of the Ariadne energy transition project, in which a consortium of over 25 partners is providing guidance and orientation for shaping the energy transition through excellent research as a joint learning process between science, politics, business and society.

We are Ariadne:

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