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Unilateral EU climate action, carbon leakage and CBAM – calculations with GINFORS-E

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Abstract

Two models with different model philosophies have been applied in the project "Climate Protection Scenarios until 2050 Considering CO_2 price Differences and Carbon Leakage" for the German Federal Environment Agency to quantify the socio-economic effects of unilateral EU climate action. The following paper describes the design of the main scenarios and the results with the GINFORS-E model.

In the case of the unilateral increase of the EU ambition level in climate protection, there is a partial shift of production out of the EU in carbon-intensive sectors such as chemicals, basic metals and non-metallic minerals because the costs in the EU increase. Leakage rates are highest in full auctioning and lowest in CBAM. However, as these sectors are of little economic importance for the EU, other macroeconomic effects predominate. For example, CO_2 reduction comes along with a decrease in energy imports, an increase in energy efficiency and structural change. Overall, the GDP effects for the EU are slightly positive. Some energy exporting countries are negatively affected. The effects on the long-term growth path are very small, and significantly smaller than the expected negative macroeconomic effects of climate change. Free allocation of emission allowances is better for the EU economy than auctioning, and full allocation of emission allowances with a CBAM mechanism also performs slightly worse than free allocation. Carbon leakage occurs especially in the carbon-intensive sectors of the EU ETS. Free allocation of emission allowances and a CBAM can reduce carbon leakage.

The assumption of higher Armington elasticities slightly worsens the macroeconomic effects for the EU, as carbon leakage effects get larger. The design of the CBAM plays only a minor role for the economic impacts. With stronger climate ambition of other countries, the effects on EU GDP worsen slightly.

Introduction

Two models with different model philosophies have been applied in the project "Climate Protection Scenarios until 2050 Considering CO_2 price Differences and Carbon Leakage" for the German Federal Environment Agency to quantify the socio-economic effects of unilateral EU climate action. One model, GEM-E3, is a general computable equilibrium model following neoclassical theory; the other model, GINFORS-E, is a macroeconometric model following a post-Keynesian approach. In the reference scenario the EU and the other countries do not take any additional climate protection measures. In contrast, the EU targets of 55% GHG reduction by 2030 and 95% by 2050 are met in three scenarios, while nothing changes in the rest of the world. In these three scenarios, the design of the EU ETS, i.e., the allocation of emission allowances, is differentiated. The first assumes free allocation of emission allowances in the EU, the second full auctioning of all ETS sectors, and the third is in line with the EU fitfor55 proposal. It includes full auctioning and a CBAM on direct emissions, both introduced between 2026 and 2035, while compensation for indirect emissions from electricity is phased out until 2040. In further sensitivities, various assumptions such as the Armington elasticities, the design of the CBAM and the stronger participation of other countries in climate mitigation are examined.

The following paper describes the design of the main scenarios and the results with the GINFORS model. Results of the GEM-E3 model as well as a short comparison of the results of both models can be found in the sister paper presented in the same session.

Scenario design

In addition to the reference scenario and global scenarios,[1] ten core policy scenarios and five sensitivities have been quantified with the two models. The scenario short description is provided below:

Table 1: Scenarios

No.	Abbreviation	Short description
6	NDCs_Ref	Until 2030 NDCs as specified in 2020 are reached for EU and non-EU; after 2030 carbon prices in non-EU increase with the rate of GDP growth, while the EU reduces emissions by 80% by 2050. Free allocation to ETS industry in EU (80%) and 100% free allocation in non-EU until 2030, decreasing to 0 in 2050. Compensation for indirect emissions in EU as today until 2030, decreasing to 0 by 2040. Sector split between ETS and non-ETS in EU until 2030. Single country-specific carbon prices in non-EU (no sector split).
7	EU_FA	EU targets in 2030 and 2050 reached; free allocation to ETS industry in EU (80% until 2030), gradually decreasing to 0 in 2050. Auctioning for all other sectors in EU. Non-EU and other assumptions for EU as in scenario 6
8	EU_AU	As 7, but full auctioning for all sectors in EU, and no compensation in any year for indirect emissions
9	EU_ff55	As 7, but EU fitfor55 as agreed including gradual shift from free allocation to auctioning and phase-in of CBAM on direct emissions from 2026 to 2034 according to the time path prescribed in the new CBAM regulation and the new ETS regulation. Compensation for direct emissions phased out until 2040 (basic metals, paper).
9a	EU_ff55_CBAM_dic	As 9, CBAM on direct and indirect emissions
9b	EU_ff55_CBAM_d	As 9, CBAM on direct emissions, no compensation in any year for indirect emissions
6D	NDCs_Ref_AD	Scenario 6 with doubled (GINFORS-E) elasticities
10	EU_FA_AH EU_FA_AD	Scenario 7 with doubled (GINFORS-E)/halved (GEM-E3) Armington elasticities
11	EU_AU_AH EU_AU_AD	Scenario 8 with doubled/halved Armington elasticities
12	EU_ff55_AH EU_ff55_AD	Scenario 9 with doubled/halved Armington elasticities
6a, 10a,	NDCs_Ref_AG	Scenarios 6 to 9 with elasticities from GEM-E3 (only GINFORS-E)

[1] That are described in the still unpublished technical project report.

No.	Abbreviation	Short description
11a, 12a	EU_FA_AG EU_AU_AG EU_ff55_AG	
13	EU_FA_RW	Scenario 7 with raising ambition in (some) RoW countries, China on path for carbon neutrality in 2060, advanced OECD countries introduce carbon prices of 50% of EU price
14	EU_AU_RW	Scenario 8 with raising ambition in (some) RoW countries as in scenario 13
15	EU_ff55_RW	Scenario 9 with raising ambition in (some) RoW countries as in scenario 13

Source: Own compilation

Most scenarios consider unilateral climate action by the EU achieving ambitious climate change targets for 2030 (55%) and 2050 (95%), while other countries only achieve their 2030 Nationally Determined Contributions (NDCs) submitted in 2020. In the reference, the EU pursues the targets set in 2020, i.e. 40% GHG reduction by 2030. The targets of the other countries, also as of 2020, are listed in Table 2. The differences among the scenarios mainly relate to the ambition of countries to reduce GHG emissions, the adoption or not of a CBAM mechanism and the rule of allowances provision. All emission reduction targets are achieved using carbon pricing and emissions trading (where applicable).

Table 2: NDC targets (as of 2020) for major emitting countries for 2030 in Mt CO_2

Entity	Type of Emissions	Amount in Mt in 2030	Unconditional Targets
EU-28	GHG		40% below 1990 level by 2030.
China	CO_2	12439	To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level.
USA	GHG	5181 (2025)	26-28% below 2005 levels by 2025.
Russia	GHG	2820	25-30% below 1990 levels by 2030.
India	GHG	9687	To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level.
Japan	GHG	1043	26% by 2030 (equivalent to 25.4% reduction compared to 2005).
Turkey	GHG	687	21% below BAU levels by 2030.
Brazil	GHG	1571	37% below 2005 by 2025, 43% by 2030 (indicative).

Source: Own compilation

In scenario 6 the NDC targets for GHG emissions from 2020 are reached in 2030 (NDCs_Ref). The EU wants to reduce GHG emissions 40% below their 1990 level until 2030. For 2050, in this scenario the EU targets a reduction of 80% compared to 1990. In the results, the EU always includes the EU-27 plus the United Kingdom. Sector separation into ETS and non-ETS is maintained in the EU until 2030. After that, a single carbon price applies. In all other countries, a uniform country-specific carbon price applies, growing with GDP after 2030.

Allocation of emission allowances in the EU ETS is based on the 4th phase of the EU ETS: free allocation in carbon-intensive sectors of 80% of sector emissions until 2030. Afterwards, this share decreases linearly to zero by 2050. There is also compensation for increased electricity costs due to the ETS for the basic metals and paper industries, which will be phased-out until 2040. In the electricity sector, emission allowances are fully auctioned. For the rest of the world, emission allowances are fully auctioned in the electricity sector and in the non-ETS sector. In other ETS industries there is free allocation until 2030. Afterwards auctioning is linearly phased in until 2050.

Scenario 7 (EU_FA) differs from Scenario 6 in that the EU (and the UK and other countries that apply the EU-ETS as Switzerland and Norway) tighten their reduction targets. The EU meets the new NDC targets (55% in 2030/95% in 2050). In this, CCS is excluded from potential mitigation portfolio in industry and power generation alike, as there is currently no visible scope for it. For nuclear energy, also restrictions have been assumed. No new installations are considered beyond those already under construction. All other countries do not pursue more advanced mitigation targets compared to scenario 6 (NDCs_Ref), as an approximated representation of international commitments' status in 2020. In the EU, the sector split ends after 2030 and a uniform CO_2 price is established. Allocation in the EU and the rest of the world is the same as in scenario 6.

In scenario 8 (EU-AU), the reduction targets remain unchanged compared to scenario 7. However, the allocation of emission allowances changes, which are now auctioned in full and in all sectors in the EU. Compensation for increased electricity costs due to the ETS is also eliminated.

Scenario 9 (EU_ff55) is strongly oriented towards the expected EU policy under the fitfor55 package. The emission targets (EU and non-EU) are as in scenarios 7 and 8. In the EU, the sector allocation remains until 2030. From 2026, a carbon border adjustment mechanism (CBAM) is gradually introduced until 2034, and at the same time the free allocation is reduced and phased-out in 2034. The choice of sectors for the CBAM is based on the European Commission' s proposal (EU 2021a) and the final CBAM regulation (EU 2023). This implies that CBAM is only exerted for direct emissions associated with the imported products. There is still compensation for increased electricity costs due to the ETS as in scenario 6. The assumptions for the rest of world remain as in scenarios 7 and 8.

Scenario 9a is a sensitivity to scenario 9. The difference compared to scenario 9 is that the CBAM is implemented on direct and indirect emissions and that compensation for indirect costs is phased out between 2025 and 2034 (CBAM_dic). Scenario 9b is another sensitivity to scenario 9. The only difference compared to scenario 9 is that there is no compensation for indirect emissions until 2040. (CBAM_d).

Scenarios 10 to 12 examine the role of Armington elasticities for EU unilateral climate action impacts. Armington elasticities are used in two places in the models. They explain on a sector level a) the price dependence of import quotas on the ratio of domestic price and import price (sigma x) and b) the price dependence of a country's import share in the total imports of the country under consideration (sigma m). An additional scenario 6a repeats the Ref_NDCs scenario with the adjusted Armington elasticities for GINFORS-E, in order to serve as a new reference for these sensitivities.

Table 3: Assumptions for Armington elasticities in the different scenarios

Model	Scenarios	Industry	sigma m default value	sigma x default value
GINFORS-E	6-9, 9a, 9b, 13-15	All CBAM sectors	4	1
	6a, 10-12	All CBAM sectors	8	2
	6G, 10a, 11a, 12 a	Basic metals, paper and paper products	5.94	2.91
		Chemical Products, rubber and plastic products	6.64	3.31
		Non-metallic minerals	3.84	1.91

Source: GINFORS-E.

Table 3 contains the assumptions in GINFORS-E in scenarios 6 to 9 and the adjusted Armington elasticities in the sensitivities 10 to 12 and 6a (EU_FA_AH, EU_AU_AH, and EUff55_AH for GEM-E3, EU_FA_AD, EU_AU_AD, and EUff55_AD for GINFORS-E). They are halved in GEM_E3 and doubled in GINFORS-E compared to scenarios 6 to 9. Three additional sensitivities are only run with the GINFORS-E model apply the original Armington elasticities from GEM-E3 in GINFORS-E (10a, 11a, 12 a).

A final set of sensitivities (13-15, EU_FA_RW, EU_AU_RW, EU_ff55_RW) builds on scenarios 7 to 9. A higher level of ambition in climate protection is assumed for important countries outside the EU in the Rest of the world. For China, it is assumed that a pathway is followed that will make the country climate neutral by 2060. For other advanced OECD countries, a carbon price of 50% of the EU price is assumed in each case.

Results for unilateral action (scenario 7 to 9 against 6)

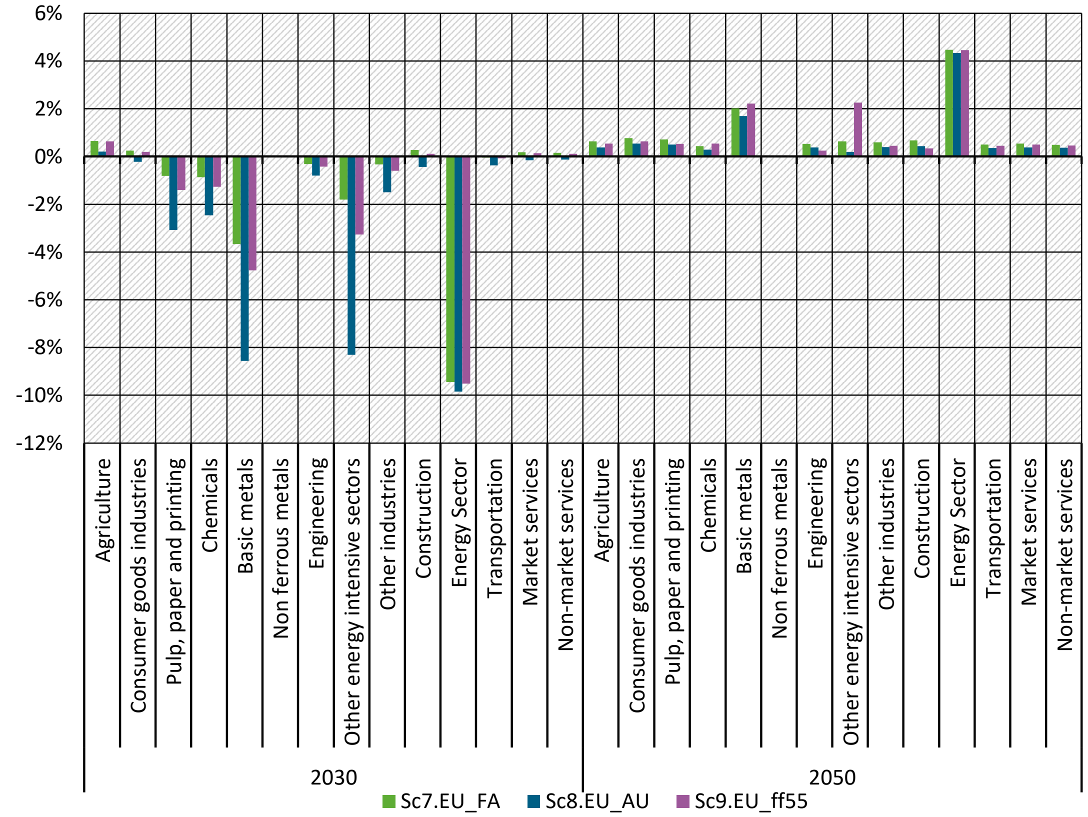
Because the emission pathways between scenarios 7, 8 and 9 hardly differ, some figures are shown below only for scenario 9 in comparison to scenario 6. Only the EU plus the UK have to reduce their emissions in scenarios 7 to 9 compared to scenario 6 (Figure 1). This indicates that the scenarios are not very well-balanced regarding climate mitigation action and that a unilateral European effort is in no way sufficient to achieve the Paris climate targets. Analytically, the analysis of unilateral action makes sense to show the maximum conceivable difference in the ambition level between Europe and the other competing countries, because there are fears that unilateral action will lead to carbon leakage, i.e. the shifting of emissions and related production abroad.

Figure 1: Deviations in CO_2 emissions per capita against scenario 6.NDCs_Ref

Source: GINFORS-E.

According to Figure 2 production by industries is influenced by the allocation design in the EU ETS. In the case of free allocation in Scenario 7 only the energy sector, basic metals and other energy-intensive sectors, which include non-metallic minerals, suffer significant reductions against the reference scenario 6 in 2030. In the case of full auctioning in scenario 8 the effects are more negative for carbon intensive industries. If the EU introduces a CBAM, impacts will be less negative (scenario 9) compared to full auctioning. But also the CBAM will not prevent some negative impacts for these industries, which will be worse off than under free allocation in 2030. To better understand the mechanisms behind, external trade effects need to be reviewed.

Figure 2: EU sectoral production – deviations from Sc6.NDCs_Ref

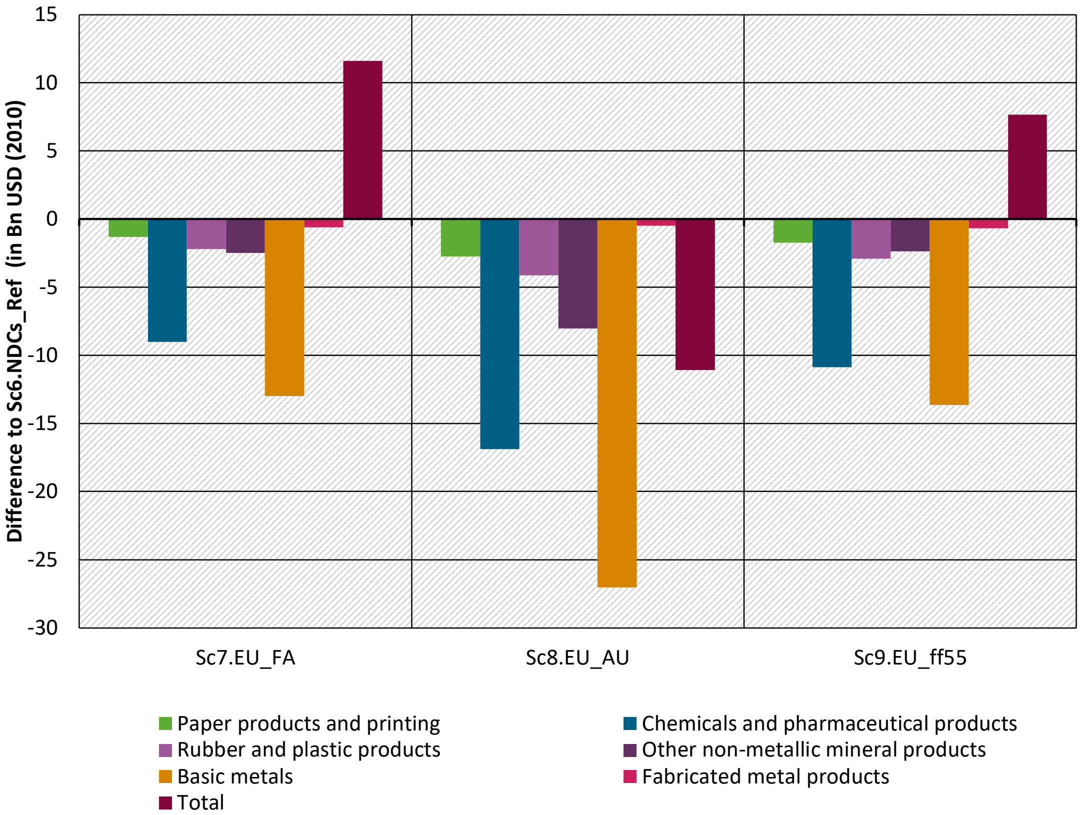


Source: GINFORS-E.

The effects of a border adjustment mechanism (CBAM) in scenario 9 become visible when comparing external trade effects for CO_2-intensive sectors in 2030 (Figure 3). EU imports of non-metallic minerals and particularly for basic metals decrease significantly in scenario 9 in 2030. On the other hand, total imports are at a similar level as in scenarios 7 and 8. On the export side, the decline in exports in the case of full auctioning of emission rights in 2030 in scenario 8 can be significantly reduced in scenario 9. They remain somewhat higher than in the case of free allocation in scenario 7. The slight decline in total exports in scenario 9 , despite the introduction of the CBAM, is remarkable. The protection of the CBAM industries leads to higher prices in the EU also for other downstream industries and thus to declining international competitiveness. In 2050, most effects are only small compared to the reference and in some industries as basic metals even positive. After the energy transition, the EU will then produce largely carbon free at internationally competitive costs.

In terms of EU net exports, scenarios 7, 8 and 9 differ somewhat for the industries particularly affected: Free allocation and CBAM will have similar effects, while full auctioning will be more negative for carbon-intensive industries but also for the EU economy as a whole (Figure 3). In other words, total imports decline more than total exports. Overall, the effect on net exports is slightly positive, with total effects being more positive in the CBAM scenario 9 compared to full auctioning in scenario 8.

Figure 3: EU sectoral net-exports 2030 - deviations from Sc6.NDCs_Ref

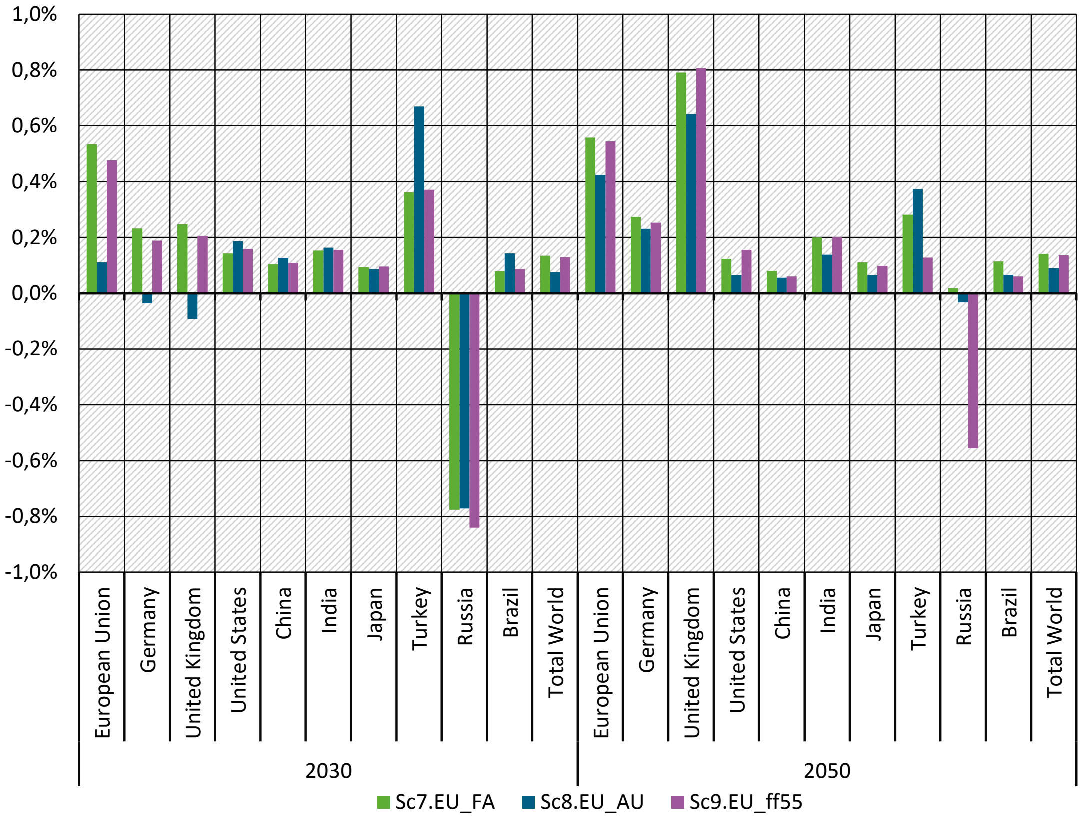


Source: GINFORS-E.

Increasing the EU GHG mitigation targets has a small but positive impact on the EU GDP. The following factors impact the EU economy in scenarios 7 to 9 compared to the reference due to the higher carbon prices in 2030:

1. International competitiveness: Change in production costs affect EU exports and imports. Trade effects in carbon-intensive industries are negative. Fossil fuel imports are lower compared to the reference. Impacts on total net exports are slightly positive in scenarios 7 and 9, and slightly negative in scenario 8 in 2030. Compared to GDP, the overall international trade effect is low.
2. There is no assumption about additional investment (crowding-out), but low-carbon investment replaces other investment and reduces energy use.
3. Structural change: As carbon prices increase sectoral costs and prices in carbon-intensive industries, a shift towards low- and zero-carbon sectors takes place.
4. Technology dynamics: In the longer term and as the deployment of clean energy technologies scales up, their capital costs are reduced making their adoption less costly in Europe and other parts of the world.
5. Lower energy use, structural change and technological change lead to a slightly positive effect on GDP.
6. Allocation of allowances: Free allocation is more favorable than auctioning. A CBAM can reduce negative impacts on carbon-intensive industries but will increase prices in downstream industries in the EU and in carbon-intensive industries in other parts of the world. Full auctioning will be less positive for EU-28, and even slightly negative for members like Germany and the UK.

Figure 4: GDP by country – deviations from Sc6.NDCs_Ref



Source: GINFORS-E.

Other scenarios and sensitivities

An overview of the additional scenarios and sensitivities can be found above. They refer to the design of the CBAM, the Armington elasticities and the participation of other countries in climate protection.

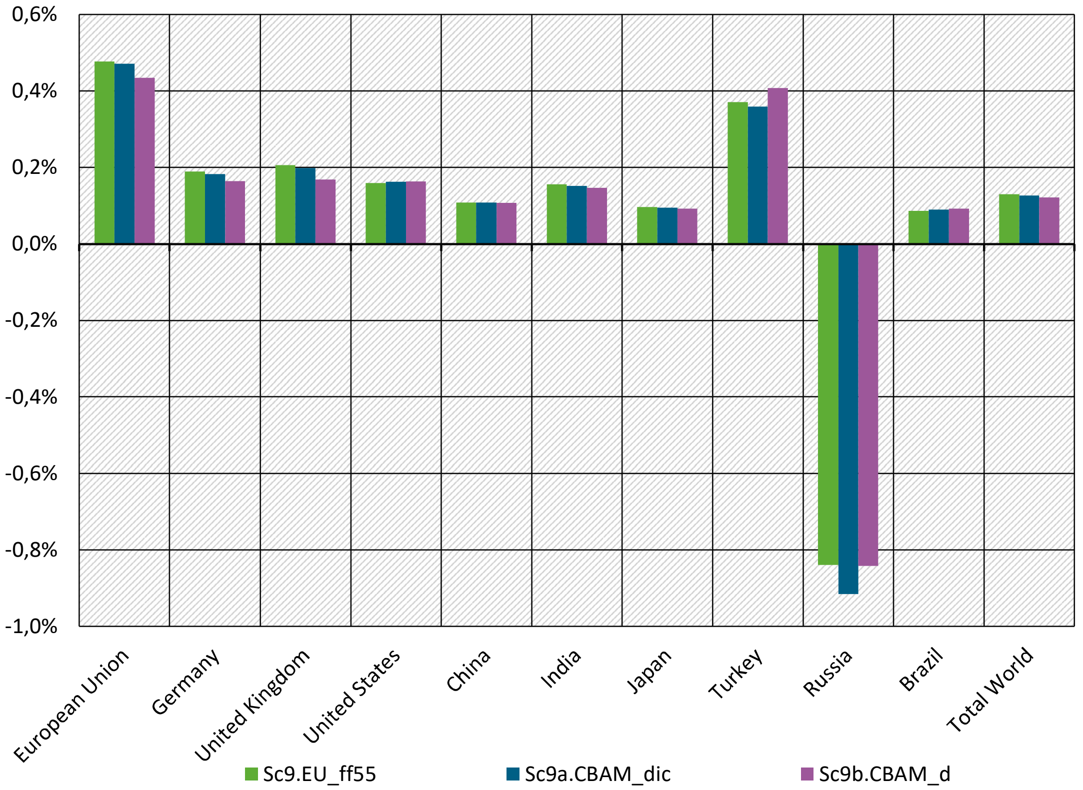
CBAM

Scenario Sc9.EU_ff55 incorporates a CBAM mechanism that is limited to direct emissions while European industries affected by the carbon price are initially compensated for indirect emissions – the latter is phased out until 2040. Based on this scenario two sensitivities are run: Sc9a.CBAM_dic extends the CBAM to also capture indirect emissions; compensation for indirect emissions is already phased out until 2034. Sc9b.CBAM_d only applies the CBAM to direct emissions with no compensation for indirect emissions.

If the CBAM is also extended to indirect emissions, but compensation for indirect emissions is phased out earlier (Sc9a.CBAM), the overall economic effects for the EU are almost unchanged. The inclusion of indirect emissions in the CBAM will be positive for protected industries, but the quicker phase-out of indirect cost compensation is negative for basic metals and the paper industry, which are compensated in scenario 9.

As can be expected, the positive economic effects compared to the reference scenario (for which again Sc6. NDCs_Ref is used) are not as pronounced for the countries applying the CBAM when compensation for indirect emissions is not considered in Sc9b.CBAM_d (see Figure 5).

Figure 5: Deviation in GDP in 2030, compared to Sc6.NDCs_Ref



Source: GINFORS-E.

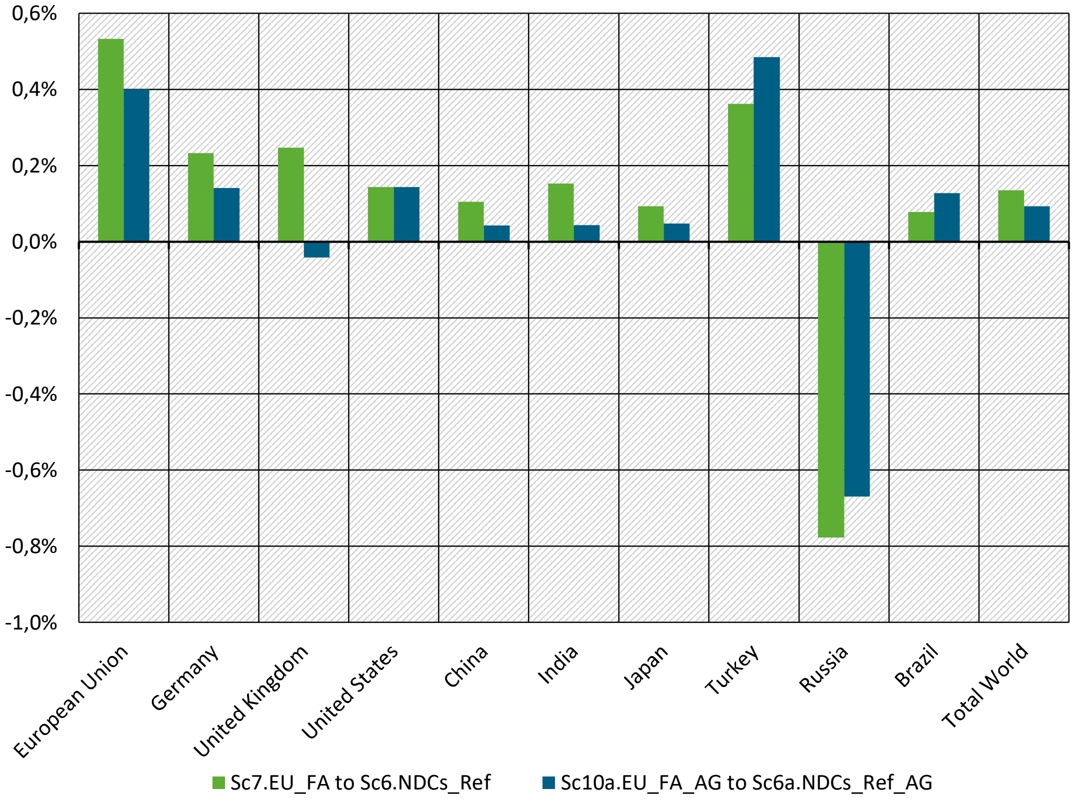
The effects of the sensitivities are limited compared to scenario 9 in relation to the reference. The choice of whether to introduce a CBAM is clearly more important for the results than its concrete design regarding indirect emissions and compensation for indirect emissions. Also, impacts of the different CBAM options on EU sectoral production are small, although the elimination of compensation for higher electricity costs would reduce exports by more than 1% in the basic metals sector in 2030. Ultimately, the openness, i.e. the relation of exports and imports to domestic production of this sector is limited.

Trade Elasticities

In scenarios 10a to 12a, the Armington elasticities from GEM-E3 are used for scenarios 7 to 9 in GINFORS-E (see Table 3). Armington elasticities are important assumptions of substitutability between domestic and foreign products. They explain on a sector level a) the price dependence of import quotas on the ratio of domestic price and import price (sigma x), and b) the price dependence of a country's import share in the total imports of the country under consideration (sigma m). An additional scenario 6G repeats the Ref-NDCs scenario with the adjusted Armington elasticities.

The following comparison first shows for the case of free allocation how the effects of a unilateral approach differ depending on the chosen Armington elasticities. As expected, higher substitution elasticities lead to less positive macroeconomic effects of climate protection for the EU. They decrease from around 0.5% to 0.4% in 2030. In other countries, such as the USA and China, the effects are also slightly worse, probably because economic activity in the EU is lower. Neighboring countries such as Turkey and Russia, on the other hand, can benefit a bit from higher substitution elasticities (Figure 6). This effect mainly stems from foreign trade with carbon intensive products. The effect on net exports is significantly stronger for most industries due to the higher substitution possibilities. The effect on basic metal exports is particularly high in 2030.

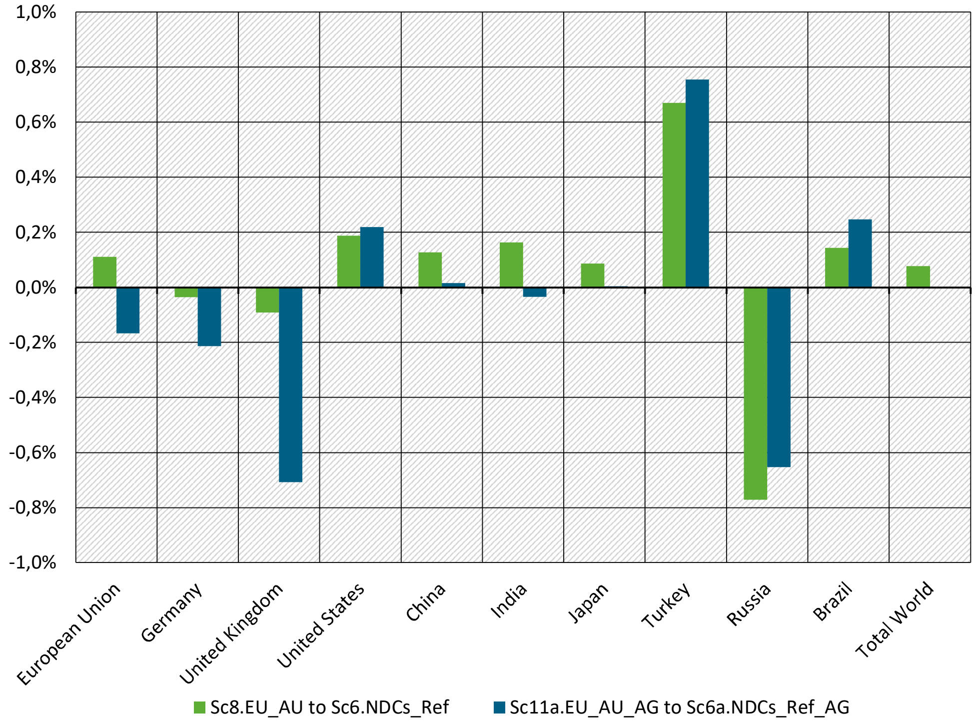
Figure 6: GDP deviations – Sc 7.EU_FA compared to Sc 6.NDCs_Ref and Sc10a.EU_FA_AG compared to 6a.NDCs_Ref_AG in 2030



Source: GINFORS-E.

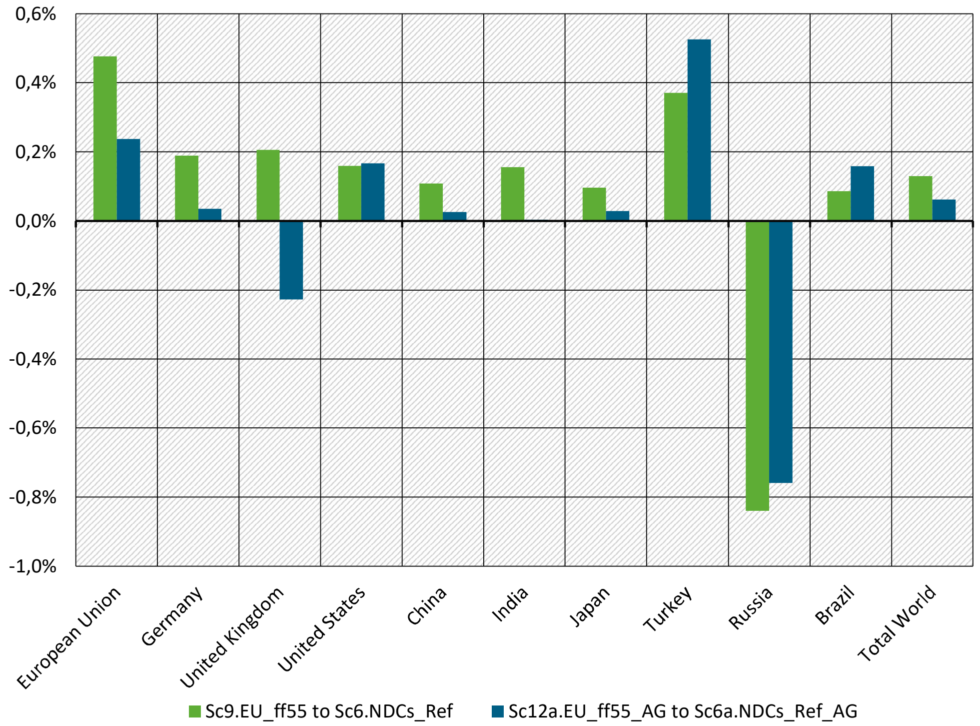
A similar picture emerges for the scenario comparison if the emission allowances are fully auctioned (Scenario 8 vs. 11, Figure 7) or the policy is oriented towards the fitfor55 package (Scenario 9 vs. 12, Figure 8). It is interesting that in the first case the sign of the GDP effect changes in the EU and also in Germany and the UK and the effect becomes negative. In the CBAM case, GDP impacts on EU, Germany and the UK also get more negative. Assumptions about the Armington elasticities have a quite strong impact on the macroeconomic effects in GINFORS-E, as higher elasticities reduce EU exports especially from carbon-intensive products, and also facilitate substitution of domestic products with imported products. This particularly favors neighboring countries with strong trade relations with the EU, such as Turkey.

Figure 7: GDP deviations – Sc8.EU_AU compared to Sc6.NDCs_Ref and Sc11a.EU_AU_AG compared to Sc6a.NDCs_Ref_AG in 2030



Source: GINFORS-E.

Figure 8: GDP deviations – Sc9.EU_ff55 compared to Sc6.NDCs_Ref and Sc12a.EU_ff55_AG compared to Sc6a.NDCs_Ref_AG in 2030



Source: GINFORS-E.

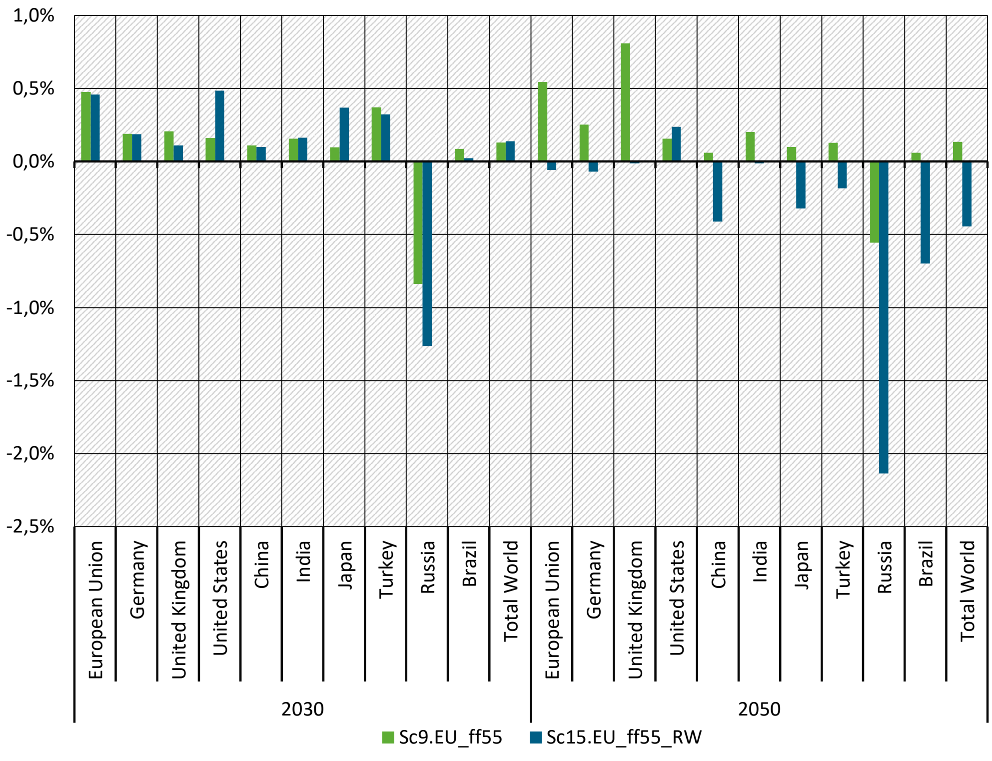
Non-EU Ambition in GHG emission reduction

This final set of simulations (13-15, EU_FA_RW, EU_AU_RW, EU_ff55_RW) builds on scenarios 7 to 9. A higher level of ambition in climate protection is assumed for important countries outside the EU. For China, it is assumed that a pathway is followed that will make the country climate neutral by 2060. For the other highly industrialized OECD countries like the USA, Canada and Japan, a carbon price of 50% of the EU price is assumed in each case. For a few less advanced OECD countries such as Turkey, Mexico, or Chile no carbon price is assumed. The scenarios with higher climate mitigation ambition in other countries are again compared to the reference scenario 6 (NDCs_Ref).

Figure 9 shows the effects of increased climate protection measures once only in the EU (Scenario 9, EU_ff55) and in the EU as well as in China and in advanced OECD countries (Scenario 15 EU_ff55_RW) for the case of a CBAM in the EU. In 2030, the overall economic effects in the EU, China, Turkey and India are very similar in both scenarios. In the case of China, this is mainly due to the quite low carbon price in 2030, even if they meet the path to carbon neutrality. Only afterwards are significantly higher carbon prices necessary. The USA and Japan, on the other hand, benefit from their additional climate mitigation efforts in 2030. In Russia, the negative GDP effect intensifies somewhat because global demand for oil and gas is lower in scenario 15 (EU_ff55_RW) than in scenario 9 (EU_ff55). The effect on global growth is similar and slightly positive in both scenarios compared to the reference (NDCs_Ref).

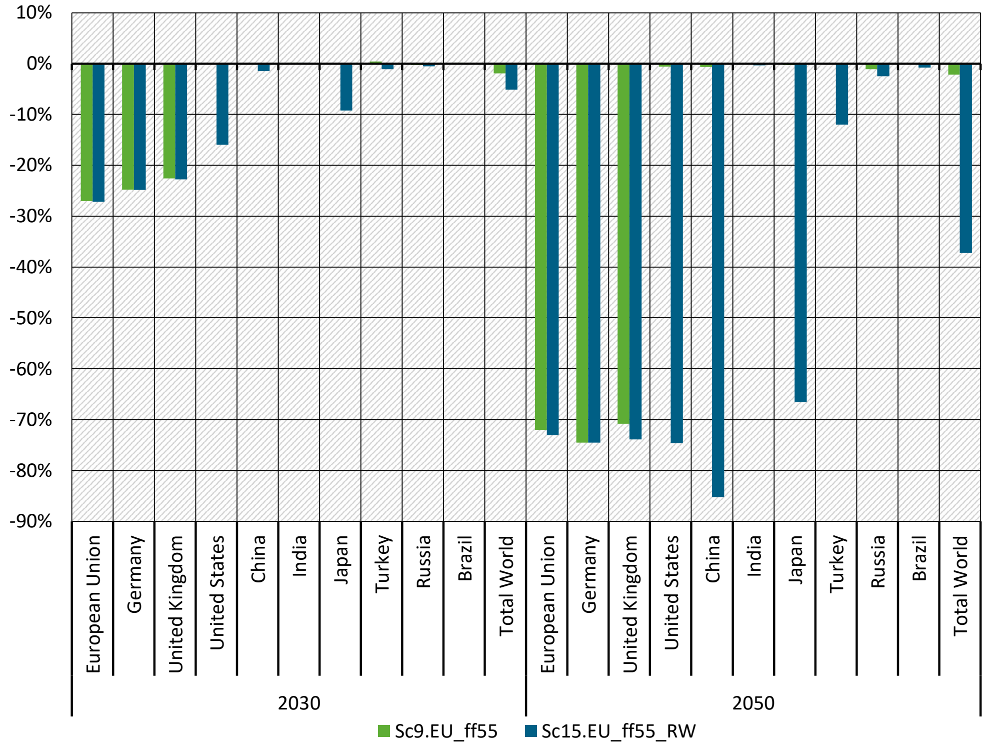
In 2050, on the other hand, scenario 15 shows slightly positive GDP effects only in the USA and Turkey, while they are negative especially in China and Japan as well as Brazil. Globally, the effects are also slightly negative, whereby in addition to China, particularly the exporters of fossil fuels are worse off than in the reference. The effects in the EU due to higher mitigation efforts in other parts of the world are very close to zero in 2030.

Figure 9: Deviations in GDP – Sc15.EU_ff55_RW and Sc9.EU_ff55 compared to Sc6.NDCs_Ref in 2030 and 2050



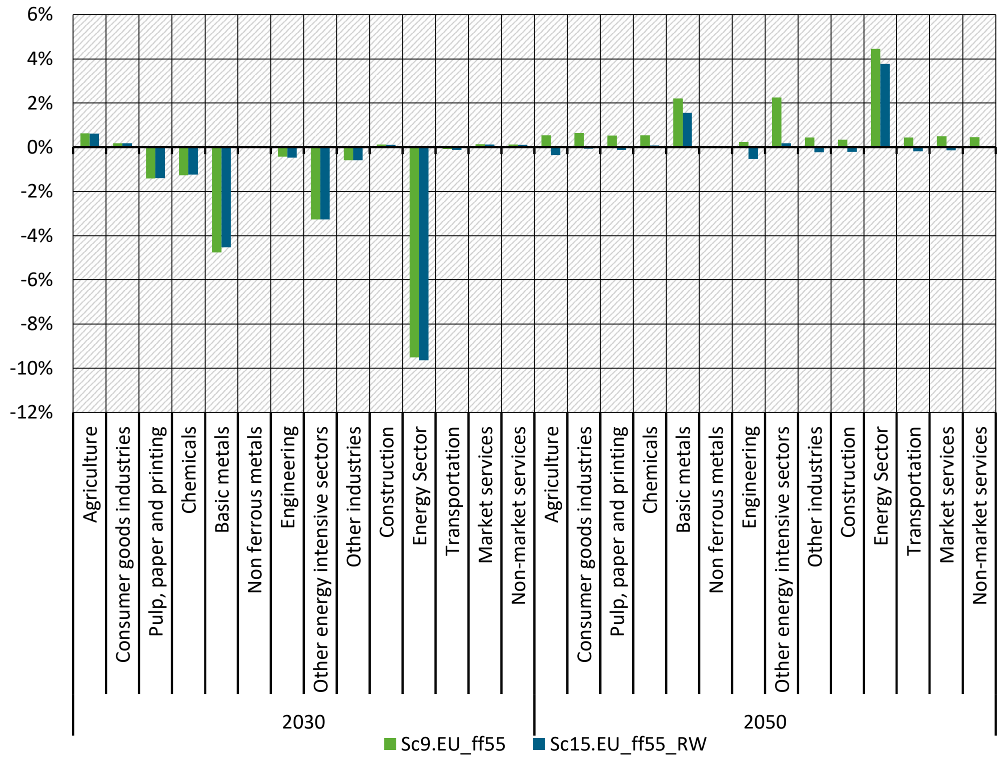
Source: GINFORS-E.

Figure 10: Deviations in carbon emissions per capita – Sc15.EU_ff55_RW and Sc9.EU_ff55 compared to Sc6.NDCs_Ref in 2030 and 2050



Source: GINFORS-E.

Figure 11: Deviations in EU sectoral production – Sc15.EU_ff55_RW and Sc9.EU_ff55 compared to Sc6.NDCs_Ref in 2030 and 2050



Source: GINFORS-E.

The sectoral production effects in the EU due to the participation of other countries in climate protection are very small in 2030. They are a bit larger in 2050, but there is no structural change in the EU economy visible due to more ambition in climate mitigation in other parts of the world (Figure 11).

Conclusions and outlook

There is a risk of carbon leakage if the EU acts unilaterally. However, the effects are limited and can be further reduced by appropriate design of the EU ETS. They are not an argument against achieving the climate targets in the EU.

A CBAM is economically better than full auctioning but cannot completely avoid carbon leakage because prices in the EU rise and thus international competitiveness decreases on the export side. For the future, it makes sense to examine further design options for the CBAM and the EU ETS as a whole. This includes other policy instruments than carbon prices. The EU and member states rely heavily on support measures for carbon-intensive industries including the innovation and modernization funds of the EU or the German industry price concept for electricity, which has so far only been reflected to a limited extent in models.

Assumptions on Armington elasticities are important for the macroeconomic effects of unilateral climate mitigation of the EU. Empirically robust results would be important in this regard, and the time aspect also plays an important role, which should be investigated in more detail. Other model parameters could also be tested more thoroughly for their potential impact. Finally, the question of international participation in climate mitigation measures is important. As countries such as the USA with the Inflation Reduction Act do not implement pure carbon price solutions, the informative value of the modeled high carbon prices is limited. Further research is also needed in this direction to model implemented and planned policies more realistically.

Future modeling could be improved in different directions in particular to better inform policy: Climate policy in the EU treats plants differently within individual industry sectors, which should also be better reflected in modeling. More sector detail is needed, especially for these CO_2-intensive sectors, because technologies and energy sources used, and thus CO_2 emissions, differ significantly. In this regard, specific datasets such as EXIOBASE or GLORIA could be explored to what extent more differentiated data is available and respective modeling is possible. Distinguishing between parts of an industry that have already been transformed and those that are still carbon-intensive would also be valuable for modeling. Coupling with sector-specific models or energy system models could also be an approach for future improvements. With regard to the industry sectors, it could also be considered and analyzed in more detail how different behaviors and time horizons concerning low-carbon investment, which are also be influenced by the political framework, can be depicted.

Appendix: The model GINFORS-E

GINFORS-E[2] is a global model that it is designed for assessments of economic, energy, climate and environmental policies up to the year 2050. It is a bilateral world trade model based on OECD data, which consistently and coherently models exports and imports of 25 goods groups for 64 countries and one 'rest of the world' region. All EU-27 countries, additional European economies and international major trade partners are explicitly modeled. It incorporates a macro-model, consisting of exports and imports, other core components of final demand (private and public sector consumption and investment), markets for goods and the labour market, for each country. The country models are also divided into 36 goods categories in accordance with the OECD internationally harmonised input-output (IO) tables. For every country OECD bilateral trade data on industry level is linked to the IO tables. Each national model is linked to an energy model, which determines energy conversion, energy generation and final demand for energy for 19 energy sources disaggregated by economic sector based on IEA energy balances. Energy-related CO_2 emissions are linked to energy use. The model considers technological trends and price dependencies.

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[2] https://web.jrc.ec.europa.eu/modinv/discovery/midas/explore/models/model-ginfors-e/

GINFORS-E is designed for the assessment of economic, energy, climate, and environmental policies up to the year 2050. The model can be used to ana-lyse the socioeconomic impacts of a variety of price changes and policies in individual countries in a global context. Explicitly covered are all EU countries, all OECD countries, and their major trading partners. GINFORS-E is a macroeconometric model built on post-Keynesian theory. The parameters used in the model equations are estimated econometrically based on time series data from OECD, UN, IMF, and IEA from 1990 to 2019. Actors have myopic expectations and follow past behavioural routines. Markets are not assumed to be cleared. The model resolves annually.

In Lutz et al. (2010) the model is clearly described in detail, although some of the relations have changed (e.g., OECD has adjusted the sector classification several times). In recent years, the way the model deals with the energy sector has been further refined to take account of global developments in renewable energy technologies. The model has also started to be used to examine future changes in consumption-based greenhouse gas emissions, which is why the name has been extended to GINFORS-E. Simulations of macroeconomic impacts of different electricity price scenarios have been calculated for the German Ministry of Economic Affairs and Energy (Lutz et al. 2015). Earlier work includes economic impacts of international different climate regimes (Lutz, Meyer 2009a, Lutz, Wiebe 2012), high oil and gas prices (Lutz, Meyer 2009b) and peak oil (Lutz et al. 2012), explicit modelling of learning curves for renewable energy technologies (Rogge et al. 2015; Wiebe, Lutz 2016). For DG CLIMA the model has been used to project consumption-based emissions and evaluate specific technology scenarios taking global supply chains into account (Wiebe et al. 2016). It also shows how electric cars can be captured in an input-output framework. For DG GROW (2017) the model has been used to explore macroeconomic impacts of different scenarios for powertrains and the competitiveness of the European automobile industry. In 2020 and 2021, the model has informed the EU impact assessments for the EU 2021 adaptation strategy and the study on the taxation of the air transport sector as part of the green taxation information on the Fit for 55 package (Neiva et al. 2021, EU 2021). It has also been used to determine socioeconomic impacts of climate change on European islands (Vrontisi et al. 2022). Since 2020, the model has also been extended by a submodule for agriculture and applied to project future global land-use impact of bioeconomy (Toebben et al. 2022).

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