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Final report

Climate Protection Scenarios until 2050 Considering CO2 Price Differences and Carbon Leakage

Central report on the modelling results within the project “Models for the analysis of international interrelations of the EU ETS and of a CBAM”

by:

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Abstract: Climate Protection Scenarios until 2050 Considering CO2 Price Differences and Carbon Leakage

Two models with different model philosophies are used to quantify the socio-economic effects of unilateral EU climate action, assuming free allocation as practiced in the EU ETS until 2025, and alternatively full auctioning and the gradual introduction of a CBAM. 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.

The results from both models suggest that an effective CBAM can play a significant role in countering the risk of carbon leakage in the case of unilateral EU climate action. Moreover, a CBAM also has a noticeable positive effect on sectoral production in industry and especially in the sectors covered by the EU ETS, as well as on GDP. In essence, both models show that the carbon leakage risk is no convincing argument against EU climate action, if EU ETS and CBAM are properly designed. The effects on the long-term growth path are also very small, and in both models significantly smaller than the expected negative macroeconomic effects of climate change.

In further sensitivities, various assumptions such as the Armington elasticities, the design of the CBAM (inclusion of indirect emissions, replacing compensation schemes in the EU) and the stronger participation of other countries in climate mitigation are examined. The assumption of higher substitution possibilities of domestic products by imported products slightly worsens the macroeconomic effects for the EU in both models. Different assumptions on Armington elasticities in both models explain at least part of the differences between the model results. The design of the CBAM plays only a minor role. With stronger climate ambition of other countries, the effects on EU GDP worsen slightly.

Kurzbeschreibung: Klimaschutzszenarien bis 2050 unter Berücksichtigung von CO_2-Preisunterschieden und Carbon Leakage

Zwei Modelle mit unterschiedlichen Modellphilosophien werden eingesetzt, um die sozioökonomischen Auswirkungen unilateraler EU-Klimamaßnahmen zu quantifizieren. Dabei wird von einer freien Zuteilung ausgegangen, wie sie im EU-Emissionshandelssystem bis 2025 praktiziert wird, und alternativ von einer vollständigen Versteigerung und der schrittweisen Einführung eines CBAM. Das eine Modell, GEM-E3, ist ein allgemeines berechenbares Gleichgewichtsmodell, das der neoklassischen Theorie folgt, das andere Modell, GINFORS-E, ist ein makroökonometrisches Modell, das einem postkeynesianischen Ansatz folgt.

Die Ergebnisse beider Modelle deuten darauf hin, dass ein wirksamer CBAM eine bedeutende Rolle bei der Bekämpfung des Carbon Leakage-Risikos im Falle eines klimapolitischen Vorangehens der EU spielen kann. Darüber hinaus hat ein CBAM auch einen spürbar positiven Effekt auf die sektorale Produktion in der Industrie, insbesondere in den Sektoren, die unter das EU ETS fallen, sowie auf das Bruttoinlandsprodukt (BIP). Im Wesentlichen zeigen beide Modelle, dass das Risiko der Verlagerung von CO_2-Emissionen kein überzeugendes Argument gegen Klimaschutzmaßnahmen der EU ist, wenn das EU ETS und der CBAM passend konzipiert sind. Die Wirkungen auf den langfristigen Wachstumspfad sind zudem sehr gering und in beiden Fällen deutlich kleiner als die erwarteten negativen gesamtwirtschaftlichen Wirkungen des Klimawandels.

In weiteren Sensitivitäten werden verschiedene Annahmen wie die Armington-Elastizitäten, die Ausgestaltung des CBAM und die stärkere Beteiligung anderer Länder am Klimaschutz variiert. Die Annahme höherer Substitutionsmöglichkeiten von heimischen Produkten durch importierte Produkte verschlechtert in beiden Fällen die gesamtwirtschaftlichen Effekte für die EU leicht. Unterschiedliche Annahmen zu den Armington-Elastizitäten in beiden Modellen erklären

zumindest einen Teil der Unterschiede zwischen den Modellergebnissen. Die Ausgestaltung des CBAM spielt nur eine geringe Rolle. Bei stärkerer Klimaambition anderer Staaten verschlechtern sich die Effekte auf das BIP der EU leicht.

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List of abbreviations

Abbreviation	Explanation
AAGR	Average annual growth rates
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CGE	Computable general equilibrium
CO_2	Carbon dioxide
DEHSt	Deutsche Emissionshandelsstelle (German Emissions Trading Authority)
EU	European Union
EU ETS	EU Emissions Trading Scheme
EU_ff55	EU-fit-for 55 package
GDP	Gross Domestic Product
GEM-E3	General Equilibrium Model – E3
GHG	Greenhouse gases
GINFORS-E	Global Interindustry Forecasting System - Energy
GWS	Institute of Economic Structures Research (Gesellschaft für Wirtschaftliche Strukturforschung)
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
KKP	Kaufkraftparitäten
Mtoe	Million tonnes of oil equivalent
NDCs	Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parities
RES	Renewable energy sources
RoW	Rest of world
$t.CO_2$	Tonnes of CO_2
UN	United Nations
WEO	World Energy Outlook

Summary

Motivation

The aim of this research project has been to improve the understanding of the suitability of two types of large-scale models differentiated by industries – macro-econometric models and computable general equilibrium (CGE) models – for analysing international emission effects and economic effects of scenarios in which the EU moves forward in climate policy and applies different design options in the already implemented emissions trading system in this context. In particular, we aim at extending and deepening the knowledge on how the two different models treat the design of the European Emissions Trading System (EU ETS) especially on allocation, and of a carbon border adjustment mechanism (CBAM) as implemented under the fit-for-55 reform package – both with a view especially to sector and overall economic activity as well as to changes in the EU's industry trade flows and to potential carbon leakage.

In this Central Report the carbon leakage risk for the EU industries under different policy assumptions is assessed, compared to the results of different modelling approaches, and we attempt to attribute the findings to model differences. By the last point, we also aim at providing insights for the interpretation of the results obtained from modelling the international effects of the EU moving forward in climate mitigation and the impacts of "how this is done" in terms of policy choice.

Besides these primarily methodical goals, our results also contribute to understanding the projected economic and carbon leakage effects of the revision of the "fit-for-55" measures, especially the increased abatement ambition until 2030 and 2050 in the EU and the gradual introduction of a CBAM.

We therefore contribute to the available research by a) providing **key results** for different scenario settings **regarding ambition and design in the EU ETS and of a CBAM introduction** and b) providing indications on **which results differ in particular between the two models.** As can be seen below, we suggest that there is a high likelihood for the choice of model to be relevant at least for indicators such as carbon leakage rates and economic quantity and price effects, both economy-wide and by affected industry. The idea is to get a better grasp on the "robustness" of the results depending on the choice of model and indicative insights on which political questions, related to "uneven pace" of climate ambition, can be feasibly addressed by these two types of model.

In this way, we aim at assisting practitioners as well as researchers in interpreting the results from model-based scenario analyses on ETS design and on the effects of a CBAM. Such scenarios are applied, for example, in policy impact assessments by the European Commission. In addition, ideally the report can assist practitioners or researchers when commissioning – or even conducting – own scenario research in the context mentioned.

Approach

Two models, one each of the types mentioned above, **macro-econometric (GINFORS-E**) and **CGE (GEM-E3**), have been applied to policy scenarios that represent plausible political options. The model GEM-E3 (General Equilibrium Model – E3) is a general computable equilibrium (CGE) model that follows neoclassical theory, the other model GINFORS-E (Global Interindustry Forecasting System - Energy) is a macro-econometric model that follows a post-Keynesian approach. Both models are briefly described in sections 3, 4 and 7.

The central policy related scenarios addressing the **details of the EU ETS** (i.e., primarily allocation) as well as the potential **introduction of a CBAM**, **have been analysed with both**

models, and the results contrasted to each other. This report treats the allocation and the CBAM as key elements for the main scenarios:

a) ETS ambition according to Fit for 55 (FF55); free allocation for industry and auctioning for energy sectors; no CBAM.

b) ETS ambition according to FF55; auctioning for all ETS sectors; no CBAM.

c) ETS ambition according to FF55; auctioning gradually replacing free allocation for certain industry sectors as in the FF55, parallel gradual introduction of CBAM.

We approximate the actual CBAM scope, as prescribed in the EU "CBAM Regulation" 2023/956/EU, by assuming that the CBAM gradually replaces free allocation for the following industry sectors as covered in our models: Iron and Steel/Ferrous metals, Non-ferrous metals (both grouped together as "Basic metals" in GINFORS-E); Non-metallic minerals; and Chemical industry (where both industry sectors in our case include the entire respective sector e.g. also lime, glass and ceramics as well as organic and non-organic chemicals, as a further differentiation would require further sectoral differentiation than what is currently feasible in underlying databases of these models.

The analysis then added additional scenarios or sensitivities for d) the assumed international trade elasticities ("Armington elasticities"), e) the inclusion of indirect emissions into the CBAM (replacing compensation mechanisms in the EU for indirect emissions), and finally, f) of increased climate policy ambition in major trading partners of the EU. For GEM-E3, in addition g) a modified use of the budget revenues has been addressed.

Scenario design

The core policy scenarios are mainly characterized by unilateral EU climate action so that the GHG reduction targets of -55% until 2030 and -95% until 2050 are achieved. The results of the policy scenarios are compared with a reference scenario representing EU climate policy before the Fit-for-55 policy package, which was adopted in 2023. More precisely, in the reference scenario the EU "only" reduces its GHG emissions by 40% by 2030 and by 80% by 2050 compared with 1990 levels. Mitigation ambition outside the EU, in contrast, is assumed to be only very modest, with all major trading partner countries adhering to their respective Nationally Determined Contributions (NDC) targets by 2030, which are countries' post-2020 climate actions according to the Paris Agreement, and afterwards raising the carbon price by the rate of real GDP.

By itself, raising the EU climate policy ambition by tightening the EU ETS cap likely leads to increased carbon prices which, in turn, could be a catalyst for carbon leakage via the relocation of production and associated emissions to third countries, especially in carbon-intensive industries. This could even be exacerbated by comparatively higher emission intensities there (although this is only plausible in certain countries and industries). Next to that, reduced demand for fossil fuels in the EU could exert a notable negative effect on the prices of these commodities incentivizing their consumption in other countries (fuel price-effect), which is not accounted for in the scenarios, as the same (fix) energy prices are assumed in both models. Among these effects, our models focus on the industry/trade carbon leakage channel (relocation of production - including via shifting investment). The effect of climate mitigation in the EU could thus be undermined. Moreover, production and thus value-added as well as jobs are relocated outside the EU. Measures to counteract leakage, such as the Carbon Border Adjustment Mechanism (CBAM) or free allocation, which was formerly the main instrument for this goal, are thus evaluated in different constellations across policy scenarios.

Quantitative results for a total of three core policy scenarios and various sensitivities have been obtained with the two models. All scenarios consider the EU "moving forward" in achieving ambitious climate change targets for 2030 and 2050, while other countries are assumed to (only) achieve their 2030 Nationally Determined Contributions (NDCs) submitted in 2020, with no significant further emission reduction efforts thereafter. The only exception being scenarios 13 to 15 which include also higher climate mitigation ambition outside Europe. The degree of this "moving forward" of the EU differs between the reference scenario (scenario 6, NDCs-Ref) and the other scenarios which, as indicated at the beginning, reflect increased ambition assuming a target of 55% reduction in the EU by 2030 and of 95% by 2050, in line with the Green Deal. The scenarios mainly differ in the allocation rule for the emissions: Free allocation in scenario 7 (EU_FA), full auctioning in scenario 8 (EU_AU), and finally scenario 9 (EU_ff55) that is oriented at the Fit-For-55-package including the gradual phase-in of a CBAM. While there is some chance for increased climate policy ambition (and implementation) by major EU trading partner countries, the present analyses show the maximum possible negative economic impacts, that is, when the EU is the only jurisdiction raising its ambitions.

In addition, for both models the sensitivity of results was determined with respect to a) changes in the design of CBAM, b) the values of the Armington elasticities, and c) changes in climate protection policy ambition in the rest of the OECD and China. The Armington elasticities describe the substitution possibilities between domestic and imported goods and between different supplier countries for imported goods.

Results of the GEM-E3 model are presented in section 3 and of the GINFORS-E model in section 4. A comparison of important results for both models is provided in Section 5. It can already be seen in the historical data for 2015 that there are partly significant differences in the data serving as input to the models. In the case of GDP in purchasing power parities this is mainly due to different base years with different exchange rates (2014 in GEM-E3 and 2010 in GINFORS-E). An attempt has been made to align the GDP growth rates in both models after 2020. However, there are also historical differences in energy consumption and energy-related emissions between the two models, which are discussed in more detail in the respective technical report (Lutz et al. 2024).

The two models share many common features but also have fundamental differences. Both models are using similar datasets comprising of input-output tables, bilateral trade matrices, and energy balances. GEM-E3 is calibrated on a single base year. The GEM-E3 production and consumption functions are dynamically calibrated over time starting from their base year values following normative assumptions. GINFORS-E is calibrated on a time series of historical data. The factor demand and final demand functions in GINFORS-E are empirically estimated on long time series data. The price elasticities in GINFORS-E are generally lower than those assumed in GEM-E3. Consistent with this, lower Armington elasticities for international trade are also applied in GINFORS-E. This is based on the model philosophy that adjustment processes take longer than in the CGE model, which reflects faster adjustment processes.

The key model differences explain some of the differences in results. Optimisation and full utilisation rate in GEM-E3 mean that the economy in the reference is at its optimum. Climate policy through higher CO_2 prices usually leads to slightly negative macroeconomic effects unless specific assumptions are made about additional financing. Investment is more constrained in GEM-E3 than in GINFORS-E.

Table S-1: Scenarios

No.	Abbreviation	Short description
Reference scenario		
6	NDCs_Ref	The EU reduces its GHG emissions by 40% by 2030 and by 80% by 2050 compared with 1990 levels
Main scenarios		
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 indirect emissions phased out until 2040 (basic metals, paper).
Scenarios serving sensitivity analysis		
9a	EU_ff55_CBAM_dic	As 9, CBAM on direct and indirect emissions. Compensation for indirect emissions phased out until 2034.
9b	EU_ff55_CBAM_d	As 9, CBAM on direct emissions, no compensation in any year for indirect emissions
9r	REC	As 9, revenue recycling via energy efficiency investment in CBAM sectors
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, 11a, 12a	NDCs_Ref_AG EU_FA_AG EU_AU_AG EU_ff55_AG	Scenarios 6 to 9 with Armington elasticities from GEM-E3 (only GINFORS-E)
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

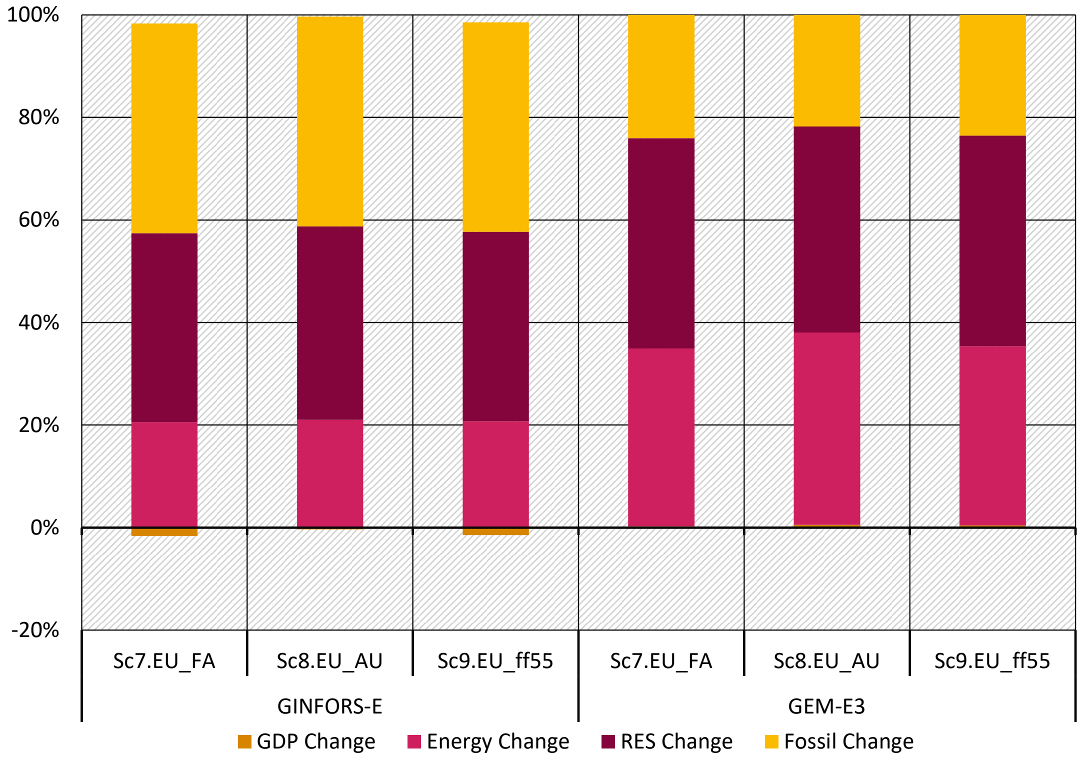
In contrast, the empirically estimated behavioural equations, together with the assumption that capacity is not fully utilized, allow for additional climate change investments in GINFORS-E, which can have a positive effect in the more demand-driven approach. Elasticities of substitution tend to be lower in GINFORS-E, which, together with assumptions about mark-up pricing, investment and financing, make the GINFORS-E model more responsive to climate policy in economic terms. Impacts in terms of GDP or production changes in non-carbon intensive sectors and not directly affected countries tend to be higher than in GEM-E3.

CO_2 emissions are modelled endogenously in both models. Carbon prices are a key factor influencing the development of energy-related emissions. They are adjusted in the models based on the previous year's price until the maximum annual CO_2 emissions per country. i.e. the annual emission target, are reached. In the reference scenario (NDCs_Ref), the carbon prices in both models are similar. In 2030, quite low prices of around or less than 50 USD are sufficient to achieve the target of a 40% GHG reduction compared to 1990. In the following years, prices rise sharply in both models and reach a level of about 300 USD to achieve a GHG reduction of 80% compared to 1990. In the target scenarios 7 to 9, the differences in CO_2 prices are significantly larger, as higher price levels are necessary for reaching the more ambitious GHG reduction targets. While GINFORS-E requires a price of 226 USD2010/t in 2030, GEM-E3 requires a much lower price of around 76 USD2014. By 2050, the prices then converge again strongly and are at 524 USD2014 in GEM-E3 and 577 USD2010 in GINFORS-E. These carbon prices indicate the following: In the short term the GEM-E3 is more flexible regarding the representation of abatement options (hence the lower carbon price). In the long-term remaining GHG emissions are harder to abate and both models have a similar and steeper “implied” marginal abatement cost curve. The scenario comparison only measures the delta between a 95% to an 80% GHG reduction in 2050. The following results do not describe the overall effects of climate protection in Germany and the EU, but only the effects of this difference.

Energy Transition. The two models show different adoption of the technological choices in decomposition analyses to reduce GHG emissions. GINFORS-E decarbonises the energy system mainly by substituting between fossil fuels and by renewable energy deployment. In GEM-E3, renewable energy deployment and energy efficiency improvements are ranked first. Changes in economic activities are marginal in both models, see Figure S-1.

Carbon Leakage. In the short term the EU escalating carbon prices increase production costs for EU located firms deteriorating competitiveness in the domestic market, due to competition with imports, and in the international markets. However, changes in costs are relatively low and both models report relatively modest carbon leakage rates below 34% for 2030 (see Table S-2, with the exception of full auctioning for Chemicals and pharmaceutical products and Basic Metals in GEM-E3), with GEM-E3 having significantly larger rates in the case of free allocation and full auctioning (despite the lower 2030 carbon prices that the CGE model produces).). A leakage rate of 10% means that if greenhouse gas emissions in the EU are reduced, 10% of this will be offset by higher emissions in the rest of the world. This result is partly driven by higher elasticities of substitution in GEM-E3 which increases substitution processes away from the carbon-intensive sectors and also increases carbon leakage. Higher assumed trade (Armington) elasticities in GEM-E3, allowing for easier substitution between domestic and imported products, also have an influence, but the above-mentioned general picture still holds even when applying identical trade elasticity assumptions between both models.

Figure S-1: EU emission reduction Kaya decomposition for 2030 – compared to Sc6.NDCs_Ref in 2030 (left – GINFORS-E, right – GEM-E3)



Source: GEM-E3 and GINFORS-E.

Table S-2: Carbon leakage rates by sector for 2030 - each in comparison to Sc6.NDCs_Ref

	GINFORS-E			GEM-E3		
	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55
Paper products and printing	1.10%	2.09%	1.35%	0.9%	9.2%	-2.2%
Chemicals and pharmaceutical products	5.87%	10.40%	5.63%	37.2%	88.7%	6.6%
Other non-metallic minerals	10.07%	19.52%	9.26%	1.8%	33.9%	-23.7%
Basic metals	18.34%	26.97%	17.99%	10.5%	95.8%	-124.8%

Source: GEM-E3 and GINFORS-E.

In scenario 9 (EU fit for 55 package including the gradual introduction of a CBAM), in GEM-E3 the introduction of CBAM is quite effective hence the carbon leakage rate - compared to the above-mentioned reference scenario - is actually nominally negative, i.e., leakage is lower. A reason for negative carbon leakage rates is that carbon prices for imports from non-EU countries to the EU increase by more than the carbon prices for products made in the EU due to scenario design, i.e. because of the existence of a carbon price in EU in the reference scenario: The increase for imports amounts to the full (high) carbon price observed in the CBAM scenario from zero in the reference scenario (Sc.6), while for domestic production it is merely the increase between the carbon prices of the reference scenario and the CBAM-scenario (Sc. 9). In GINFORS-E, the leakage rate is also lower than under the scenarios without a CBAM for most ETS sectors, with the exception of paper.

Leakage rates of over (-)100% may come as a surprise, but they are possible in a global model because, unlike in a partial model with a fixed global production volume, e.g. for the steel industry, equilibrium or induced effects can lead to further effects in the total model, which in principle can lead to higher positive or negative effects globally on production and related emissions than in the EU itself. More detailed information is presented in the textbox before Table 15.

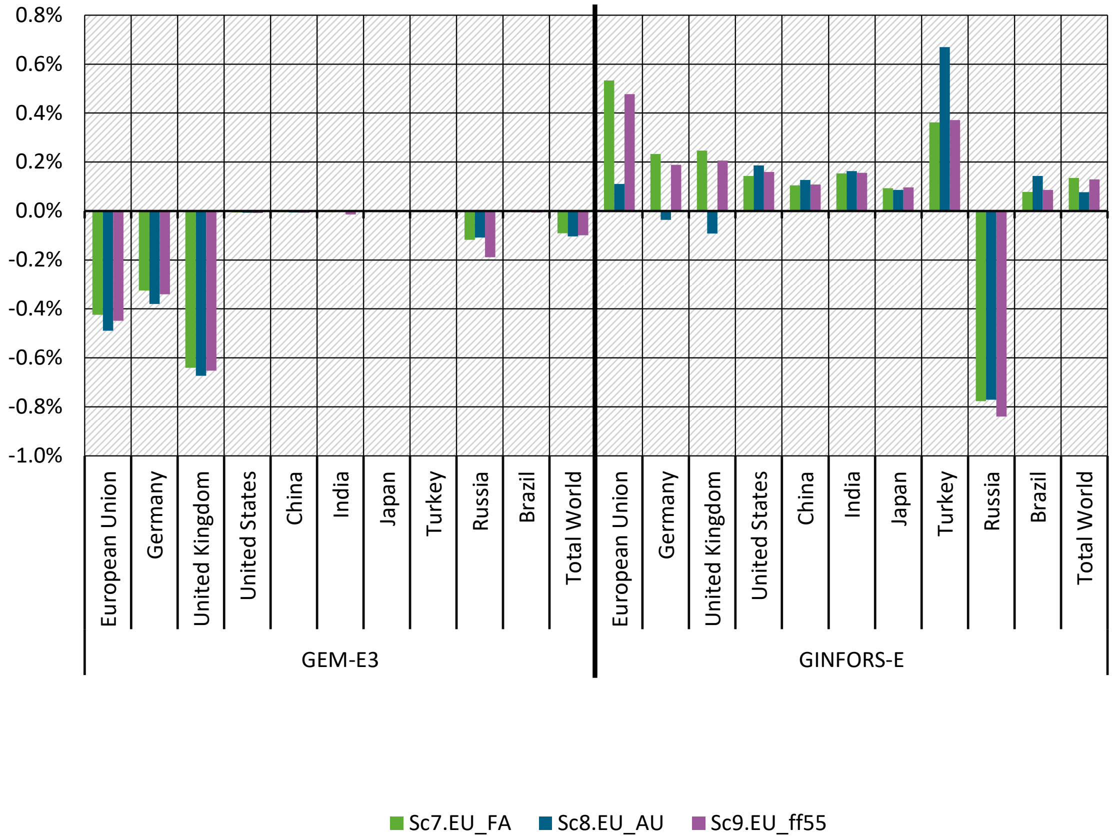
At a sectoral level, the leakage takes place in the carbon intensive and trade exposed sectors. According to both models, basic metals is the most vulnerable sector regarding carbon leakage. GEM-E3 also considers chemicals together with non-metallic minerals as sectors quite exposed. Both models present the highest carbon leakage rates in Scenario 8. Full auctioning increases the risk of carbon leakage considerably according to both models. At the same time, the differences for scenarios 7 and 8 *between* the two models are high. In GEM-E3, the leakage effects in the designated ETS sectors are between two- to ten-times higher than in GINFORS-E. In scenario 9 with the CBAM, GEM-E3 reports negative leakage rates for three of the four sectors listed in Table S-2, i.e. an additional emission reduction in non-EU countries takes place. A reason is that carbon prices for imports from non-EU countries to the EU increase by more than the carbon prices for products made in the EU: The increase for imports amounts to the full (high) carbon price observed in the CBAM scenario, while for domestic production it is merely the increase between the carbon prices of the reference scenario (Sc.6) and the CBAM-scenario (Sc. 9). In GINFORS-E, leakage rates are lower in scenario 9 than in the auction scenario 8 and even in the case of free allocation in scenario 7, with the exception of paper products and printing.

Aggregate Economic Effects. In the scenarios covering free allocation, full auctioning, and CBAM (scenarios 7 to 9), the country GDP effects are predominantly slightly negative in GEM-E3, and positive in GINFORS-E. Only in the case of Russia it is the other way around: the negative effects are much more pronounced in GINFORS-E than in GEM-E3. It is also interesting to note that the more positive GDP results in GINFORS-E apply both for EU countries with ambitious climate goals in scenarios 7-9 while also holding for (non-EU) countries without such goals. The difference in GDP in both models is driven by the crowding out effect and lower constraints in GINFORS-E as briefly described above. In GEM-E3 additional investments in clean energy have to be financed by cancelling investments of equal value elsewhere in the economy whereas in GINFORS-E the additional investments are financed from idle financial deposits. Additional investment has positive short-term demand effects but will increase capital costs in the long-term. So GINFORS-E allows for some temporal bringing forward of investments, which allows induces positive macroeconomic effects. In addition, the GEM-E3 model assumes full operation of equipment (factories), hence additional demand for goods may create inflationary effects (which lessen in the long term once investments increase the production capacity of the economy). On the other hand, GINFORS-E assumes utilization rates of below 1, i.e. availability of idle production capital, and it is possible for factories to meet the additional demand without the (full) inflationary effects.

As noted above, for the EU, the two models show different signs for the effects in 2030. In GEM-E3, the negative effects on GDP for the EU-28, Germany and the United Kingdom are between 0.3 and 0.6% compared to the reference. In the CGE model, higher CO_2 prices without any type of carbon revenues recycling leads to a deceleration of the growth rate in GDP. The effects are in a small range between 0.4 and 0.5 percentage points for the EU, strongest with full auctioning and smallest with free allocation of emission allowances. Other countries are hardly affected in GEM-E3. One exception is Russia, which can export less fossil fuels to the EU.

In GINFORS-E, on the other hand, the GDP effects in 2030 are positive for scenarios 7 to 9 compared to the reference for the EU, with the design of the EU ETS playing a significantly larger role. Here, the direction of the macroeconomic effects is open due to the structural changes induced by the carbon price increase, as the economy has unused resources in the reference. The increased CO_2 reduction in the core scenarios (7, 8 and 9) is associated with certain changes in production and consumption structures towards sectors with low carbon emissions and lower fossil fuel imports. Energy efficiency increases and clean energy technology costs are lower. While industrial production is slightly lower than in the reference, as prices increase, production in the construction and service sectors increases a bit. As these sectors account for most of the European production and value added, this change is sufficient for the slightly positive GDP effect in the EU.

Figure S-2: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030

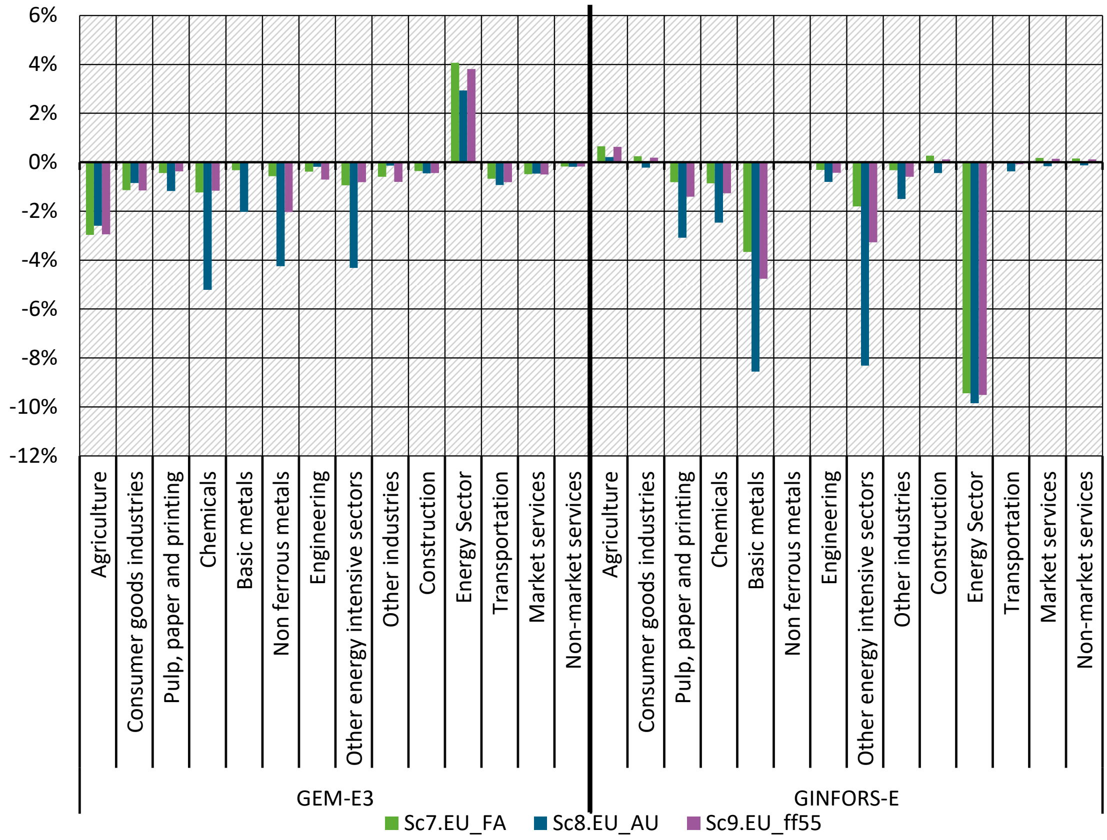


Source: GEM-E3 and GINFORS-E.

For the average annual growth rates, however, this means only very small differences between the results of the two models. When considering the differences in the sign of the GDP effects, it should always be considered that the long-term growth dynamics in both models are hardly changed by the climate protection measures.

Sectoral economic effects: The sectoral production effects in the carbon-intensive sectors are, by and large, negative in both models apart from the energy sector in GEM-E3. The degree of the production drop in the "Basic metals sector" and the "Other energy intensive sectors" (mainly non-metallic minerals such as cement) is somewhat larger in GINFORS-E. For "Chemicals" the drop for the auctioning scenario is larger in GEM-E3, while the effects for the other two scenarios are similar. In the other sectors, the overall effects also diverge, specifically for the Energy Sector.

Figure S-3: EU sectoral production – deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030



Source: GEM-E3 and GINFORS-E.

In GEM-E3 and in GINFORS-E, the CBAM leads to less negative production effects than auctioning in all three energy-intensive sectors where it is applied – chemicals, basic metals, and other energy intensive sectors. Remarkably, in GEM-E3, CBAM even leads to positive production effects in 2050 for these three sectors compared to the reference scenario with less ambitious climate policy, whereas free allocation, and even more the auctioning case, have negative production impacts in these sectors. This might explain a part of the more positive effect in the CBAM scenario versus free-allocation scenario. In contrast, in GINFORS-E, the CBAM scenario leads to slightly larger drops in production than free allocation.

The effects on the energy sector go in opposite directions. In GINFORS-E, until 2030 reductions in gas consumption are not compensated by higher electricity production so that total energy production decreases. In GEM-E3, however, energy production increases due to electrification in the economy and deployment of biofuels until 2030 and the deployment of hydrogen and clean gas until 2050. In GEM-E3 and in GINFORS-E the CBAM protects the energy intensive industries in the domestic market, which leads to the reduction in imports. However, CBAM increases the production costs of downstream sectors (that are now purchasing more expensive imported materials). These downstream sectors include e.g. engineering, construction and agriculture, but also sectors covered by ETS, as they use their own products as inputs due to the broader sector coverage as well. This increase is having a negative impact on competitiveness and production. In non-energy-intensive sectors like services, the effects in GINFORS-E are slightly more positive.

Sensitivity analysis: The main leakage channel in both models is relocation of production and resulting changes in trade patterns, where the assumed values of Armington elasticities play a central role. The analysis shows that higher elasticities lead to stronger effects in the carbon-intensive sectors. Moreover, GINFORS-E reacts more strongly to changes in the Armington elasticities than GEM-E3. A probable key factor here is the lower substitution elasticity, e.g, for the labour demand, in accordance with elasticities estimated by means of econometric analyses. With respect to CBAM design, the analysis shows that an extension of the scope towards indirect emissions of imports has a minor impact on results in both models while the question of revenue recycling can notably improve the sectoral and aggregate impacts of unilateral EU climate action. Therefore, it is important to recall that we assume a parallel phase-out of the current compensation payments for indirect costs by EU Member states. In this sense, recycling via e.g. the EU's Innovation Fund and Modernisation Fund, should be seen as essential elements of a successful climate mitigation policy. Detailed results are presented in sections 3 and 4.

Increasing non-EU ambition in climate mitigation in scenarios 13, 14 and 15 shows small negative impacts in the EU in GEM-E3 and in GINFORS-E. In 2050, unilateral action is slightly less economically beneficial in terms of GDP for the EU (due to lower demand of non-EU countries) than the participation of advanced OECD countries and China in climate mitigation in both models. But at least in GINFORS-E, climate mitigation with participation of other countries is still more beneficial than no additional climate action, at least in the cases of free allocation and full auctioning and close to zero in the CBAM case. These results partly contradict the expectation that global climate mitigation will be more economically advantageous for the EU than unilateral climate protection. This applies in any case to the carbon intensive industries in the EU. However, in other countries, increased climate protection sometimes results in slightly negative macroeconomic effects, which then more than offset the benefits for energy-intensive industries, which play only a minor role in the overall economy, for the EU as well.

Key insights: There is a risk of carbon leakage in the case of unilateral EU climate action. Carbon-intensive sectors lose international competitiveness and reduce production compared to a scenario without additional climate mitigation in both models. The macroeconomic costs in the form of GDP losses are limited in the GEM-E3 model. GINFORS-E even reports small GDP increases for the EU in the case of unilateral action. Negative macroeconomic and sectoral effects can be further reduced by appropriate design of the EU ETS including a CBAM. Both models show that the carbon leakage risk is no convincing argument against EU climate action, if EU ETS and CBAM are properly designed.

In general, the macroeconomic effects of additional international climate mitigation efforts are small, while the carbon emissions are reduced strongly. It is important to note that the economic benefits of global climate protection in the form of lower losses and damages are not included in the scenarios. They are expected to be several times higher than the reported macroeconomic effects of ambitious climate mitigation. The message of the study is positive: far-reaching climate protection worldwide is possible and leads only to marginal macroeconomic effects. CBAM is the most suitable of the analysed design options of the EU ETS with regard to carbon leakage. The economic effects (GDP and sectoral industry production), in contrast, for the year 2030 are slightly more positive with free allocation. The results for full auctioning without a CBAM are clearly the worst.

Outlook: Future modelling 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 modelling. 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. Furthermore, for policies such as the CBAM, current sector differentiation in the models is not adequate, as it (at its start at any rate) covers only parts of the sectors aggregated in the models (e.g. only fertilizers and ammonia, but not the chemical industry as a whole). In this regard, specific datasets such as EXIOBASE, GLORIA or GTAP could be explored to what extent more differentiated data is available and respective modelling is possible. This might follow the approach taken in the European Commission's Impact Assessment from July 2021 on the introduction of a CBAM which integrated data from EXIOBASE and included serval checks for consistency (EU 2021b).

Distinguishing between parts of an industry that have already been transformed to climate neutrality and those that are still carbon-intensive would also be valuable for modelling. Model coupling with sector-specific models or energy system models could likewise be an approach for future improvements. Energy system or industry sector models have higher subsector differentiation and may also include technology differentiation, e.g. the separation between primary and secondary steel.

With regard to the industry sectors, it could also be considered and analysed in more detail how different behaviours and time horizons concerning low-carbon investment, which are also be influenced by the political framework, can be depicted.

In addition, there is a need to further refine the modelling of climate policy design with a view to the sectors particularly affected and to better understand the impact channels. At the same time, a focus should also be on the newly emerging industries, which have played only a minor role in previous statistics and model data sets. They are at least as decisive for the socio-economic success of climate policy as the carbon-intensive industries. In political practice, policy measures often go beyond pure price instruments. These realities must also be included in climate policy modelling. In any case, it is important to understand what drives economic agents and how their behaviour can be targeted cost-effectively towards climate neutrality. To this end, data availability and computing capacities for modelling socio-economic impacts of climate mitigation policies are improving. At the same time, models will remain limited to relevant sub-areas of reality. To this end, they should be deepened in the future on the one hand and focused on central policy issues and product differentiations on the other.

Zusammenfassung

Motivation

Ziel dieses Forschungsprojekts war es, das Verständnis für die Eignung von zwei Arten von großen Modellen, die sich nach Branchen unterscheiden – makroökonometrische Modelle und berechenbare allgemeine Gleichgewichtsmodelle (CGE) – für die Analyse internationaler Emissionseffekte und wirtschaftlicher Auswirkungen von Szenarien zu verbessern, in denen die EU in der Klimapolitik voranschreitet und in diesem Zusammenhang verschiedene Gestaltungsoptionen im bereits implementierten Emissionshandelssystem anwendet. Insbesondere wollen wir das Wissen darüber erweitern und vertiefen, wie die beiden verschiedenen Modelle die Gestaltung des Europäischen Emissionshandelssystems (EU ETS) behandeln, insbesondere im Hinblick auf die Zuteilung, und wie ein CO_2-Grenzausgleichssystem (CBAM) im Rahmen des Reformpakets „Fit for 55“ umgesetzt wird – beides mit Blick auf die sektorale und gesamtwirtschaftliche Aktivität sowie auf Veränderungen in den Handelsströmen der EU-Industrie und auf mögliches Carbon Leakage.

In diesem Teilbericht „Central report“ wird das Risiko der Verlagerung von CO_2-Emissionen (Carbon Leakage) für die EU-Industrien unter verschiedenen politischen Annahmen bewertet und mit den Ergebnissen verschiedener Modellierungsansätze verglichen. Wir versuchen, die Ergebnisse auf Modellunterschiede zurückzuführen. Mit dem letzten Punkt wollen wir auch Erkenntnisse für die Interpretation der Ergebnisse liefern, die aus der Modellierung der internationalen Auswirkungen der Fortschritte der EU beim Klimaschutz und der Auswirkungen der Art und Weise, wie dies im Hinblick auf politische Entscheidungen geschieht, gewonnen wurden.

Neben diesen in erster Linie methodischen Zielen tragen unsere Ergebnisse auch zum Verständnis der prognostizierten wirtschaftlichen und Carbon Leakage-Effekte der Überarbeitung der „Fit-for-55“-Maßnahmen bei, insbesondere der erhöhten Reduktionsziele bis 2030 und 2050 in der EU und der schrittweisen Einführung eines CBAM.

Wir tragen daher zu den verfügbaren Forschungsergebnissen bei, indem wir a) **wichtige Ergebnisse** für verschiedene Szenarien **in Bezug auf Ambitionen und Ausgestaltung im EU ETS und der Einführung eines CBAM** liefern und b) Hinweise darauf geben, **welche Ergebnisse sich insbesondere zwischen den beiden Modellen unterscheiden.** Wie unten zu sehen ist, gehen wir davon aus, dass die Wahl des Modells mit hoher Wahrscheinlichkeit zumindest für Indikatoren wie die Verlagerungsraten von CO_2-Emissionen und die wirtschaftlichen Mengen- und Preiseffekte relevant ist, und zwar sowohl für die gesamte Wirtschaft als auch für die betroffene Branchen. Die Idee ist es, die „Robustheit“ der Ergebnisse in Abhängigkeit von der Wahl des Modells besser zu verstehen und aufschlussreiche Erkenntnisse darüber zu gewinnen, welche politischen Fragen im Zusammenhang mit dem „ungleichmäßigen Tempo“ der Klimaschutzambitionen durch diese beiden Modelltypen sinnvollerweise angegangen werden können.

Auf diese Weise wollen wir sowohl Praktiker:innen als auch Forscher:innen bei der Interpretation der Ergebnisse modellbasierter Szenarioanalysen zur ETS-Gestaltung und zu den Auswirkungen eines CBAM helfen. Solche Szenarien werden beispielsweise bei der Folgenabschätzung von Maßnahmen durch die Europäische Kommission angewendet. Darüber hinaus kann der Bericht im Idealfall Praktikern oder Forschern bei der Beauftragung – oder sogar Durchführung – eigener Szenarioforschung in dem genannten Kontext helfen.

Ansatz

Zwei Modelle, jeweils eines der oben genannten Typen, **makroökonometrisch (GINFORS-E)** und **CGE (GEM-E3)**, wurden auf politische Szenarien angewendet, die plausible politische Optionen darstellen. Das Modell GEM-E3 (General Equilibrium Model – E3) ist ein allgemeines berechenbares Gleichgewichtsmodell (CGE), das der neoklassischen Theorie folgt, das andere Modell GINFORS-E (Global Interindustry Forecasting System - Energy) ist ein makroökonometrisches Modell, das einem postkeynesianischen Ansatz folgt. Beide Modelle werden in den Abschnitten 3, 4 und 7 kurz beschrieben.

Die zentralen politikbezogenen Szenarien zu den **Einzelheiten des EU ETS** (d. h. in erster Linie zur Zuteilung) sowie zur möglichen **Einführung einer CBAM wurden mit beiden Modellen analysiert und die Ergebnisse einander gegenübergestellt.** In diesem Bericht werden die Zuteilung und die CBAM als Schlüsselelemente für die Hauptszenarien behandelt:

a) ETS-Ziele gemäß Fit for 55 (FF55); kostenlose Zuteilung für die Industrie und Versteigerung für den Energiesektor; kein CBAM.

b) ETS-Ziele gemäß FF55; Versteigerung für alle ETS-Sektoren; kein CBAM.

c) ETS-Ziele gemäß FF55; Versteigerung ersetzt schrittweise die kostenlose Zuteilung für bestimmte Industriesektoren wie in FF55, parallele schrittweise Einführung von CBAM.

Wir approximieren den tatsächlichen CBAM-Umfang, wie er in der EU-„CBAM-Verordnung" 2023/956/EU vorgeschrieben ist, indem wir davon ausgehen, dass CBAM die kostenlose Zuteilung für die folgenden Industriesektoren, die in unseren Modellen abgedeckt sind, schrittweise ersetzt: Eisen und Stahl/Eisenmetalle, Nichteisenmetalle (beide in GINFORS-E als „Basismetalle" zusammengefasst); nichtmetallische Mineralien; und chemische Industrie (wobei beide Industriesektoren in unserem Fall den gesamten jeweiligen Sektor umfassen, z. B. auch Kalk, Glas und Keramik sowie organische und anorganische Chemikalien, da eine weitere Differenzierung eine stärkere sektorale Differenzierung erfordern würde, als sie derzeit in den zugrunde liegenden Datenbanken dieser Modelle möglich ist).

Die Analyse fügte dann zusätzliche Szenarien oder Sensitivitäten für d) die angenommenen internationalen Handelselastizitäten („Armington-Elastizitäten"), e) die Einbeziehung indirekter Emissionen in den CBAM (Ersatz der Ausgleichsmechanismen in der EU für indirekte Emissionen) und schließlich f) für eine ambitioniertere Klimapolitik bei den wichtigsten Handelspartnern der EU hinzu. Für GEM-E3 wurde zusätzlich g) eine modifizierte Verwendung der Einnahmen der öffentlichen Haushalte behandelt.

Szenario-Design

Die zentralen Politikszenarien sind hauptsächlich durch einseitige EU-Klimaschutzmaßnahmen gekennzeichnet, damit die Ziele zur Reduzierung der Treibhausgase von -55% bis 2030 und -95% bis 2050 erreicht werden. Die Ergebnisse der Politikszenarien werden mit einem Referenzszenario verglichen, das die EU-Klimapolitik vor dem 2023 verabschiedeten Maßnahmenpaket „Fit for 55" darstellt. Genauer gesagt reduziert die EU im Referenzszenario ihre Treibhausgasemissionen „nur" um 40% bis 2030 und um 80% bis 2050 im Vergleich zu den Werten von 1990. Im Gegensatz dazu wird davon ausgegangen, dass die Klimaschutzambitionen außerhalb der EU nur sehr bescheiden sind, wobei alle wichtigen Handelspartnerländer bis 2030 ihre jeweiligen national festgelegten Beiträge (NDC) einhalten, bei denen es sich um die Klimaschutzmaßnahmen der Länder nach 2020 gemäß dem Pariser Abkommen handelt, und danach den Kohlenstoffpreis um die Rate des realen BIP erhöhen.

Die Erhöhung der klimapolitischen Ambitionen der EU durch eine Verschärfung der Obergrenze für das EU-Emissionshandelssystem führt wahrscheinlich zu höheren CO_2-Preisen, die wiederum ein Katalysator für die Verlagerung von Produktion und damit verbundenen Emissionen in Drittländer sein könnten, insbesondere in CO_2-intensiven Industrien. Dies könnte durch vergleichsweise höhere Emissionsintensitäten in diesen Ländern noch verschärft werden (obwohl dies nur in bestimmten Ländern und Branchen plausibel ist). Darüber hinaus könnte sich eine geringere Nachfrage nach fossilen Brennstoffen in der EU spürbar negativ auf die Preise dieser Rohstoffe auswirken und Anreize für ihren Verbrauch in anderen Ländern schaffen (Energiepreiseffekt), was in den Szenarien nicht berücksichtigt wird, da in beiden Modellen von denselben (festen) Energiepreisen ausgegangen wird. Unter diesen Effekten konzentrieren sich unsere Modelle auf den Carbon-Leakage-Kanal der Industrie/des Handels (Verlagerung der Produktion – auch durch Verlagerung von Investitionen). Die Wirkung des Klimaschutzes in der EU könnte dadurch untergraben werden. Außerdem werden die Produktion und damit die Wertschöpfung sowie die Arbeitsplätze in Länder außerhalb der EU verlagert. Maßnahmen gegen Carbon Leakage, wie der Carbon Border Adjustment Mechanism (CBAM) oder die kostenlose Zuteilung, die bisher das Hauptinstrument für dieses Ziel war, werden daher in unterschiedlichen Konstellationen in den verschiedenen Politikszenarien bewertet.

Mit den beiden Modellen wurden quantitative Ergebnisse für insgesamt drei politische Kernszenarien und verschiedene Sensitivitäten ermittelt. In allen Szenarien wird davon ausgegangen, dass die EU bei der Erreichung ehrgeiziger Klimaschutzziele für 2030 und 2050 "vorankommt", während andere Länder (nur) ihre im Jahr 2020 eingereichten nationalen Klimaschutzbeiträge (NDCs) für 2030 erreichen und danach keine nennenswerten weiteren Emissionsminderungsanstrengungen unternehmen. Die einzige Ausnahme bilden die Szenarien 13 bis 15, die auch höhere Klimaschutzziele außerhalb Europas vorsehen. Das Ausmaß dieses "Voranschreitens" der EU unterscheidet sich zwischen dem Referenzszenario (Szenario 6, NDCs-Ref) und den anderen Szenarien, die, wie eingangs erwähnt, einen höheren Ehrgeiz widerspiegeln, indem sie von einem Reduktionsziel von 55 % in der EU bis 2030 und von 95 % bis 2050 ausgehen, in Übereinstimmung mit dem Green Deal. Die Szenarien unterscheiden sich hauptsächlich in der Zuteilungsregel für die Emissionen: Freie Zuteilung in Szenario 7 (EU_FA), vollständige Versteigerung in Szenario 8 (EU_AU) und schließlich Szenario 9 (EU_ff55), das sich am Fit-For-55-Paket orientiert und die schrittweise Einführung einer CBAM vorsieht. Auch wenn es eine gewisse Chance für höhere klimapolitische Ambitionen (und deren Umsetzung) seitens der wichtigsten EU-Handelspartnerländer gibt, zeigen die vorliegenden Analysen die maximal möglichen negativen wirtschaftlichen Auswirkungen, wenn die EU die einzige Region ist, die ihre Ambitionen erhöht.

Darüber hinaus wurde für beide Modelle die Sensitivität der Ergebnisse in Bezug auf a) Änderungen in der Ausgestaltung von CBAM, b) die Werte der Armington-Elastizitäten und c) Änderungen in den klimapolitischen Ambitionen der übrigen OECD-Länder und Chinas ermittelt. Die Armington-Elastizitäten beschreiben die Substitutionsmöglichkeiten zwischen inländischen und importierten Gütern sowie zwischen verschiedenen Lieferländern für importierte Güter.

Table Z-3: Szenarien

Nr.	Abkürzung	Kurzbeschreibung
Referenzszenario		
6	NDCs_Ref	Die EU reduziert ihre Treibhausgasemissionen bis 2030 um 40 % und bis 2050 um 80 % gegenüber dem Niveau von 1990 (siehe oben).
Hauptszenarien		
7	EU_FA	EU-Ziele für 2030 und 2050 erreicht; kostenlose Zuteilung an die ETS-Industrie in der EU (80 % bis 2030), schrittweise Verringerung auf 0 im Jahr 2050. Versteigerung für alle anderen Sektoren in der EU. Nicht-EU und andere Annahmen für die EU wie in Szenario 6.
8	EU_AU	Wie 7, aber vollständige Versteigerung für alle Sektoren in der EU und keine Kompensation für indirekte Emissionen in irgendeinem Jahr.
9	EU_ff55	Wie 7, aber EU fitfor55 wie vereinbart, einschließlich des schrittweisen Übergangs von der kostenlosen Zuteilung zur Versteigerung und der schrittweisen Einführung von CBAM für direkte Emissionen von 2026 bis 2034 gemäß dem in der neuen CBAM-Verordnung und der neuen ETS-Verordnung festgelegten Zeitplan. Ausgleich für indirekte Emissionen schrittweise abgeschafft bis 2040 (Metalle, Papier).
Szenarien für Sensitivitätsanalysen		
9a	EU_ff55_CBAM_dic	Wie 9, CBAM auf direkte und indirekte Emissionen. Kompensation für indirekte Emissionen schrittweise bis 2034.
9b	EU_ff55_CBAM_d	Wie 9, CBAM auf direkte Emissionen, keine Kompensation in irgendeinem Jahr für indirekte Emissionen
9r	REC	Wie 9, Recycling von Einnahmen durch Investitionen in die Energieeffizienz in CBAM-Sektoren
6D	NDCs_Ref_AD	Szenario 6 mit verdoppelten (GINFORS-E) Armington-Elastizitäten
10	EU_FA_AH EU_FA_AD	Szenario 7 mit verdoppelten (GINFORS-E)/halbierten (GEM-E3) Armington-Elastizitäten
11	EU_AU_AH EU_AU_AD	Szenario 8 mit verdoppelten/halbierten Armington-Elastizitäten
12	EU_ff55_AH EU_ff55_AD	Szenario 9 mit verdoppelten/halbierten Armington-Elastizitäten
6a, 10a, 11a, 12a	NDCs_Ref_AG EU_FA_AG EU_AU_AG EU_ff55_AG	Szenarien 6 bis 9 mit Armington-Elastizitäten aus GEM-E3 (nur GINFORS-E)
13	EU_FA_RW	Szenario 7 mit höheren Ambitionen in (einigen) RoW-Ländern, China auf dem Weg zur CO_2-Neutralität im Jahr 2060, fortgeschrittene OECD-Länder führen CO_2-Preise von 50% des EU-Preises ein
14	EU_AU_RW	Szenario 8 mit höheren Ambitionen in RoW-Ländern wie in Szenario 13
15	EU_ff55_RW	Szenario 9 mit höheren Ambitionen in RoW-Ländern wie in Szenario 13

Quelle: Eigene Zusammenstellung

Die Ergebnisse des Modells GEM-E3 werden in Abschnitt 3 und die des Modells GINFORS-E in Abschnitt 4 ausführlich vorgestellt. Ein Vergleich wichtiger Ergebnisse beider Modelle findet sich in Abschnitt 5, wo zunächst die beiden Referenzszenarien NDCs_Ref für beide Modelle gegenübergestellt werden. Bereits bei den historischen Daten für das Jahr 2015 zeigt sich, dass es zum Teil erhebliche Unterschiede in ihren Ausgangsdaten gibt, die den Modellen als Input dienen. Im Falle des BIP in Kaufkraftparitäten (KKP) ist dies vor allem auf unterschiedliche Basisjahre mit unterschiedlichen Wechselkursen zurückzuführen (2014 in GEM-E3 und 2010 in GINFORS-E). Es wurde versucht, die zukünftigen Wachstumsraten anzugleichen. Es gibt jedoch auch historische Unterschiede im Energieverbrauch und bei den energiebezogenen Emissionen zwischen den beiden Modellen, die in dem entsprechenden technischen Bericht (Lutz et al. 2024) ausführlicher behandelt werden.

Die beiden Modelle weisen viele Gemeinsamkeiten, aber auch grundlegende Unterschiede auf. Beide Modelle verwenden ähnliche Datensätze, die aus Input-Output-Tabellen, bilateralen Handelsmatrizen und Energiebilanzen bestehen. GEM-E3 ist auf ein einziges Basisjahr kalibriert. Die Produktions- und Konsumfunktionen von GEM-E3 werden im Laufe der Zeit dynamisch kalibriert[1], ausgehend von den Werten des Basisjahres und unter Berücksichtigung normativer Annahmen. GINFORS-E wird anhand einer Zeitreihe historischer Daten kalibriert. Die Faktornachfrage- und Konsumfunktionen in GINFORS-E werden empirisch anhand langer Zeitreihen geschätzt. Die Preiselastizitäten in GINFORS-E sind im Allgemeinen niedriger als die in GEM-E3 angenommenen. Dementsprechend werden in GINFORS-E auch niedrigere Armington-Elastizitäten für den internationalen Handel angewendet. Dies basiert auf der Modellphilosophie, dass Anpassungsprozesse länger dauern als im CGE-Modell, das schnellere Anpassungsprozesse widerspiegelt.

Die wichtigsten Modellunterschiede erklären einige der Unterschiede in den Ergebnissen. Optimierung und Vollauslastung in GEM-E3 bedeuten, dass sich die Wirtschaft in der Referenz in einem Optimum befindet. Klimapolitik durch höhere CO_2-Preise führt in der Regel zu leicht negativen makroökonomischen Effekten, es sei denn, es werden spezifische Annahmen über zusätzliche Finanzierung getroffen. Die Investitionen sind in GEM-E3 stärker eingeschränkt als in GINFORS-E. Im Gegensatz dazu ermöglichen die empirisch geschätzten Verhaltensgleichungen zusammen mit der Annahme, dass die Kapazitäten nicht voll ausgelastet sind, in GINFORS-E zusätzliche Klimaschutzinvestitionen, die sich in der eher nachfrageorientierten Modellierung positiv auswirken können. Die Substitutionselastizitäten sind in GINFORS-E tendenziell geringer, was zusammen mit den Annahmen über Aufschlagskalkulation, Investitionen und Finanzierung dazu führt, dass das GINFORS-E-Modell generell stärker auf die Klimapolitik reagiert. Die Auswirkungen in Form von BIP- oder Produktionsänderungen in nicht kohlenstoffintensiven Sektoren und nicht direkt betroffenen Ländern sind tendenziell höher als in GEM-E3.

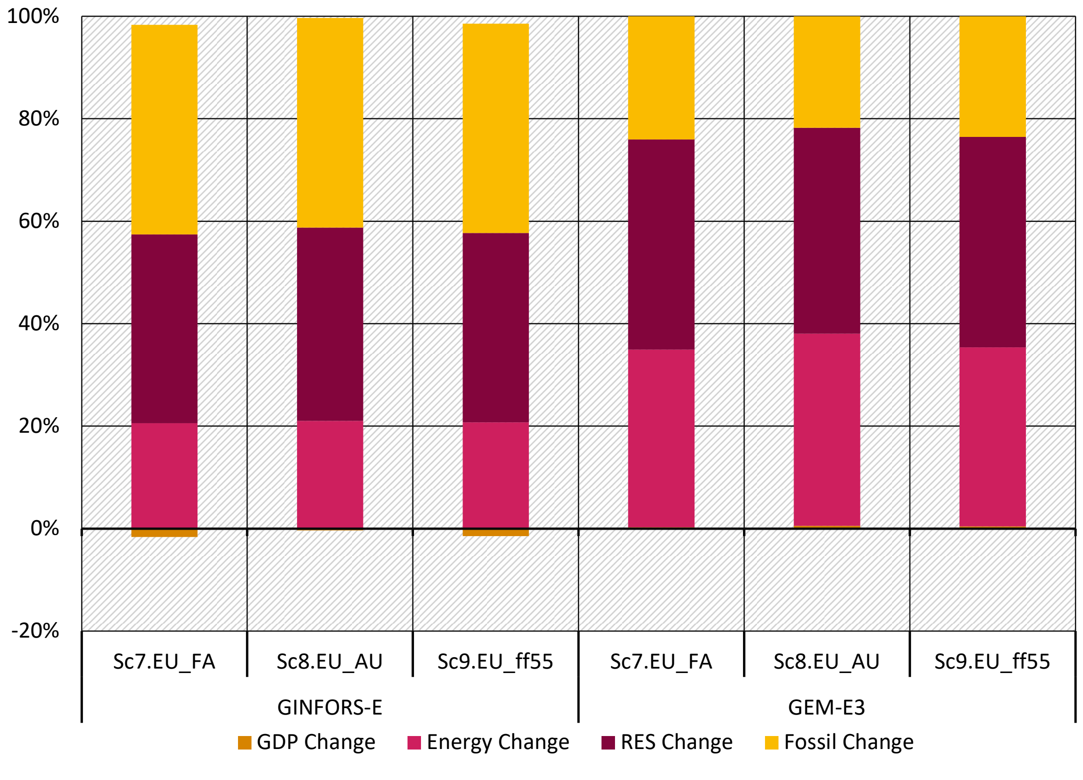
Die **CO_2-Emissionen** werden in beiden Modellen endogen modelliert. Die Kohlenstoffpreise sind ein Schlüsselfaktor, der die Entwicklung der energiebezogenen Emissionen beeinflusst. Sie werden in den Modellen auf der Grundlage des Vorjahrespreises angepasst, bis die maximalen jährlichen CO_2-Emissionen pro Land, also das jährliche Emissionsziel, erreicht sind. Im Referenzszenario 6 (NDCs_Ref) sind die CO_2-Preise in beiden Modellen ähnlich. Im Jahr 2030 reichen recht niedrige Preise von etwa oder weniger als 50 USD aus, um das Ziel einer 40 %igen

[1] Die dynamische Kalibrierung bezieht sich auf die Anpassung von Produktivitätsparametern, Konsum- und Handelsmustern und Investitionserwartungen an externe Informationen mit Hilfe einer automatisierten Methodik, die im GEM-E3-Benutzerhandbuch, Kapitel 9, unter https://e3modelling.com/modelling-tools/gem-e3/ ausführlich beschrieben wird.

THG-Reduktion gegenüber 1990 zu erreichen. In den Folgejahren steigen die Preise in beiden Modellen stark an und erreichen ein Niveau von 300 USD, um eine THG-Reduktion von 80 % gegenüber 1990 zu erreichen. In den Zielszenarien 7 bis 9 sind die Unterschiede bei den CO_2-Preisen deutlich größer, weil höhere Preisniveaus notwendig sind, um die ambitionierteren THG-Minderungsziele zu erreichen. Während GINFORS-E einen Preis von 226 USD2010/t im Jahr 2030 ermittelt, liegt der Preis für GEM-E3 mit rund 76 USD2014 deutlich niedriger. Bis 2050 nähern sich die Preise dann wieder stark an und liegen bei 524 USD2014 in GEM-E3 und 577 USD2010 in GINFORS-E. Diese CO_2-Preise zeigen Folgendes: Kurzfristig ist GEM-E3 flexibler, was die Darstellung von Vermeidungsoptionen angeht (daher der niedrigere Kohlenstoffpreis). Langfristig sind die verbleibenden THG-Emissionen schwieriger zu reduzieren und beide Modelle haben eine ähnliche und steilere Kurve der "impliziten" Grenzvermeidungskosten. Der Szenarienvergleich misst nur das Delta zwischen einer 95 %igen und einer 80 %igen THG-Reduzierung im Jahr 2050. Die folgenden Ergebnisse beschreiben also nicht die Gesamtwirkungen des Klimaschutzes in Deutschland und der EU, sondern nur die Auswirkungen des zusätzlichen Klimaschutzes.

Energiewende. Die beiden Modelle weisen unterschiedliche Annahmen der technologischen Entscheidungen in den Dekompositionsanalysen zur Reduzierung der THG-Emissionen aus. GINFORS-E dekarbonisiert das Energiesystem hauptsächlich durch die Substitution zwischen fossilen Energieträgern und durch den Einsatz erneuerbarer Energien. Bei GEM-E3 stehen der Einsatz erneuerbarer Energien und die Verbesserung der Energieeffizienz an erster Stelle. Die Veränderungen der wirtschaftlichen Aktivitäten sind in beiden Modellen marginal, siehe Abbildung Z-4.

Figure Z-4: Komponentenzerlegung der EU-Emissionsreduktion für 2030 – verglichen mit Szenario Sc6.NDCs_Ref in 2030 (links – GINFORS-E, rechts – GEM-E3)



Quelle: GEM-E3 and GINFORS-E.

Carbon Leakage. Kurzfristig erhöhen die steigenden CO_2-Preise in der EU die Produktionskosten für in der EU ansässige Unternehmen und verschlechtern die Wettbewerbsfähigkeit auf dem Binnenmarkt und den internationalen Märkten. Die Kostenänderungen sind jedoch relativ gering, und beide Modelle weisen im Jahr 2030 relativ niedrige Verlagerungsraten (Carbon Leakage) von unter 34% auf (siehe Tabelle S-2, mit Ausnahme der vollständigen Versteigerung für Chemikalien und pharmazeutische Produkte und Basismetalle in GEM-E3), wobei GEM-E3 im Fall der kostenlosen Zuteilung und der vollständigen Versteigerung deutlich höhere Raten aufweist (trotz der niedrigeren CO_2-Preise für 2030, die das CGE-Modell produziert). Eine Verlagerungsrate von 10 % bedeutet, dass bei einer Reduzierung der Treibhausgasemissionen in der EU 10 % davon durch höhere Emissionen im Rest der Welt ausgeglichen werden. Dieses Ergebnis ist zum Teil auf höhere Substitutionselastizitäten in GEM-E3 zurückzuführen, die Substitutionsprozesse weg von den kohlenstoffintensiven Sektoren verstärken und auch die Verlagerung von CO_2-Emissionen erhöhen. Auch die in GEM-E3 angenommenen höheren Handelselastizitäten (Armington-Elastizitäten), die eine einfachere Substitution zwischen inländischen und importierten Produkten ermöglichen , haben einen Einfluss, aber das oben erwähnte allgemeine Bild bleibt auch dann bestehen, wenn in beiden Modellen identische Annahmen zur Handelselastizität getroffen werden.

Table Z-4: Carbon Leakage-Raten nach Sektor für 2030 - jeweils im Vergleich zu Sc6.NDCs_Ref

	GINFORS-E			GEM-E3		
	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55
Papier- und Druckerzeugnisse	1.10%	2.09%	1.35%	0.9%	9.2%	-2.2%
Chemische und pharmazeutische Erzeugnisse	5.87%	10.40%	5.63%	37.2%	88.7%	6.6%
Sonstige nicht-metallische Mineralien	10.07%	19.52%	9.26%	1.8%	33.9%	-23.7%
Metalle	18.34%	26.97%	17.99%	10.5%	95.8%	-124.8%

Quelle: GEM-E3 und GINFORS-E.

In Szenario 9 (EU-Paket für 55, einschließlich der schrittweisen Einführung eines CBAM) ist die Einführung des CBAM in GEM-E3 recht effektiv, sodass die Carbon Leakage-Rate – im Vergleich zum oben genannten Referenzszenario – tatsächlich nominal negativ ist, d. h. die Verlagerung ist geringer. Ein Grund für negative Carbon Leakage-Raten ist, dass die CO_2-Preise für Importe aus Nicht-EU-Ländern in die EU aufgrund der Szenariogestaltung, d. h. aufgrund der Existenz eines CO_2-Preises in der EU im Referenzszenario, stärker steigen als die CO_2-Preise für in der EU hergestellte Produkte: Der Anstieg für Importe beläuft sich auf den vollen (hohen) CO_2-Preis, der im CBAM-Szenario gegenüber Null im Referenzszenario (Sc.6) liegt, während er für die inländische Produktion lediglich dem Anstieg zwischen den CO_2-Preisen des Referenzszenarios und des CBAM-Szenarios (Sc. 9) entspricht. In GINFORS-E ist die Leakage-Rate für die meisten ETS-Sektoren ebenfalls niedriger als in den Szenarien ohne CBAM, mit Ausnahme von Papier.

Carbon Leakage-Raten von über (-)100 % mögen überraschen, sind aber in einem globalen Modell möglich, da im Gegensatz zu einem Teilmodell mit einem festen globalen Produktionsvolumen, z. B. für die Stahlindustrie, Gleichgewichts- oder induzierte Effekte im Gesamtmodell zu weiteren Effekten führen können, die im Prinzip weltweit zu höheren positiven oder negativen Auswirkungen auf die Produktion und die damit verbundenen

Emissionen führen können als in der EU selbst. Detailliertere Informationen sind in der Textbox vor Tabelle 15 zu finden.

Auf sektoraler Ebene finden das Carbon Leakage in den CO_2-intensiven und handelsexponierten Sektoren statt. Nach beiden Modellen ist die Metallerzeugung der anfälligste Sektor für die Verlagerung von Emissionen. GEM-E3 betrachtet auch die chemische Industrie zusammen mit den nichtmetallischen Mineralien als besonders gefährdete Sektoren. Beide Modelle zeigen die höchsten Verlagerungsraten in Szenario 8. Die vollständige Versteigerung erhöht nach beiden Modellen das Risiko der Verlagerung von CO_2-Emissionen erheblich. Gleichzeitig sind die Unterschiede für die Szenarien 7 und 8 zwischen den beiden Modellen groß. In GEM-E3 sind die Verlagerungseffekte in den ausgewiesenen ETS-Sektoren drei- bis zehnmal höher als in GINFORS-E. In Szenario 9 mit der CBAM weist GEM-E3 negative Leakage-Raten für drei der vier in Table Z-4 aufgeführten Sektoren auf, d.h. es findet eine zusätzliche Emissionsreduktion in Nicht-EU-Ländern statt. Ein Grund dafür ist, dass die CO_2-Preise für Importe aus Nicht-EU-Ländern in die EU aufgrund des CBAM in Szenario 9 stärker steigen als die CO_2-Preise für in der EU hergestellte Produkte zwischen Szenario 6 und Szenario 9. Der Anstieg für Importe entspricht dem vollen (hohen) CO_2-Preise, der im CBAM-Szenario beobachtet wird, während es sich bei der inländischen Produktion lediglich um den Anstieg zwischen den CO_2-Preisen des Referenzszenarios (Szenario 6) und des CBAM-Szenarios (Szenario 9) handelt, weil im Referenzszenario 6 in der EU bereits ein erheblicher CO_2-Preis besteht. In GINFORS-E sind die Carbon Leakage-Raten in Szenario 9 niedriger als im Auktionsszenario 8 und sogar als im Fall der kostenlosen Zuteilung in Szenario 7, mit Ausnahme von Papierprodukten und Druckerzeugnissen.

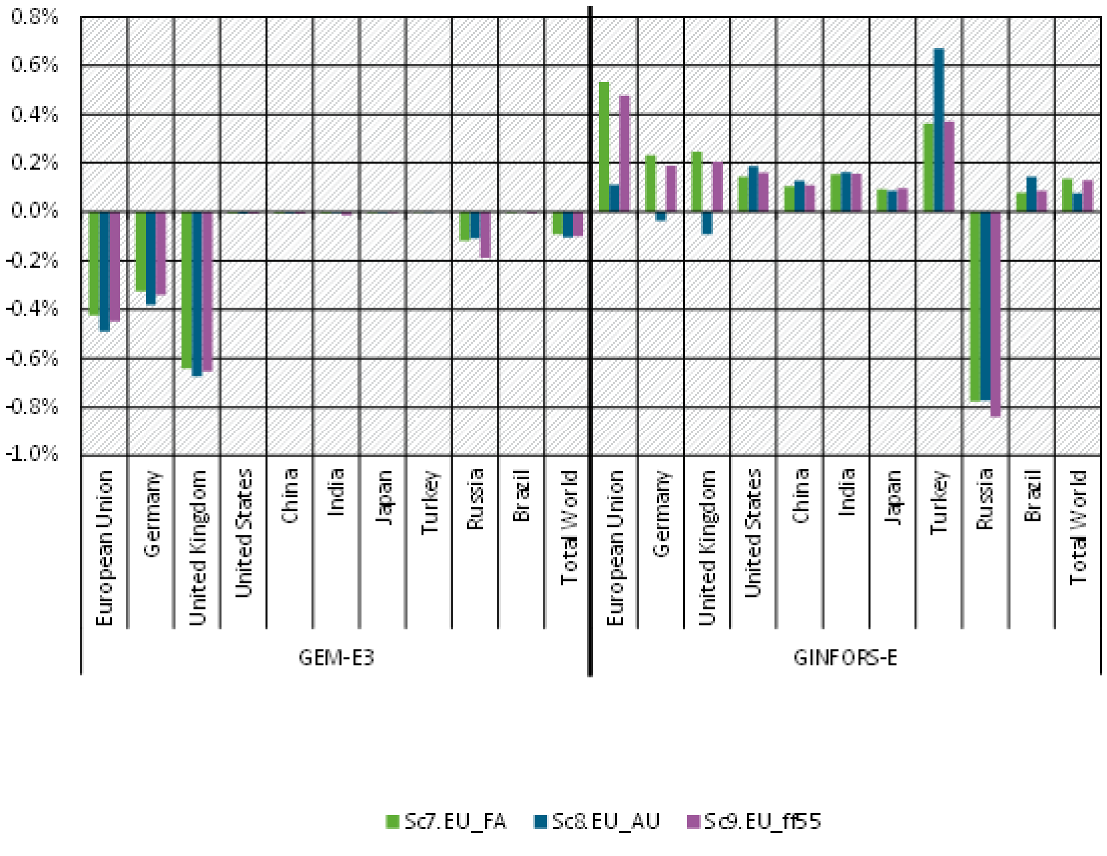
Gesamtwirtschaftliche Auswirkungen. In den Szenarien mit kostenloser Zuteilung, vollständiger Versteigerung und CBAM (Szenarien 7 bis 9) sind die Auswirkungen auf das BIP der Länder in GEM-E3 überwiegend leicht negativ und in GINFORS-E positiv. Nur im Falle Russlands ist es umgekehrt: Die negativen Auswirkungen sind in GINFORS-E viel stärker ausgeprägt als in GEM-E3. Interessant ist auch, dass die positiveren BIP-Ergebnisse in GINFORS-E sowohl für EU-Länder mit ehrgeizigen Klimazielen in den Szenarien 7-9 gelten als auch für (Nicht-EU-)Länder ohne solche Ziele. Der Unterschied im BIP in beiden Modellen ist auf den Crowding-Out Effekt und die geringeren Beschränkungen in GINFORS-E zurückzuführen, wie oben kurz beschrieben. In GEM-E3 müssen zusätzliche Investitionen in saubere Energie durch die Streichung gleichwertiger Investitionen an anderer Stelle in der Wirtschaft finanziert werden, während in GINFORS-E die zusätzlichen Investitionen aus ungenutzten Finanzeinlagen finanziert werden. Zusätzliche Investitionen haben kurzfristig positive Nachfrageeffekte, erhöhen aber langfristig die Kapitalkosten. GINFORS-E lässt also ein gewisses zeitliches Vorziehen von Investitionen zu, was positive makroökonomische Effekte nach sich ziehen kann. Darüber hinaus geht das Modell GEM-E3 von einer vollständigen Auslastung der Anlagen (Fabriken) aus, so dass eine zusätzliche Nachfrage nach Gütern inflationäre Auswirkungen haben kann (die sich langfristig abschwächen, sobald die Investitionen die Produktionskapazität der Wirtschaft erhöhen). Auf der anderen Seite geht GINFORS-E von Auslastungsraten von unter 1 aus, d.h. von der Verfügbarkeit von ungenutztem Produktionskapital, und es ist möglich, dass Fabriken die zusätzliche Nachfrage ohne (volle) inflationäre Auswirkungen befriedigen.

Wie bereits erwähnt, weisen die beiden Modelle für die EU unterschiedliche Vorzeichen für die Auswirkungen im Jahr 2030 auf. In GEM-E3 liegen die negativen Auswirkungen auf das BIP für die EU-28, Deutschland und das Vereinigte Königreich zwischen 0,3 und 0,6 % im Vergleich zur

Referenz. Im CGE-Modell führen höhere CO_2-Preise ohne jegliche Art von Verwendung der CO_2-Preiseinnahmen zu einer Verlangsamung der Wachstumsrate des BIP. Die Auswirkungen liegen in einem kleinen Bereich zwischen 0,4 und 0,5 Prozentpunkten für die EU, am stärksten bei vollständiger Versteigerung und am geringsten bei kostenloser Zuteilung von Emissionszertifikaten. Andere Länder sind in GEM-E3 kaum betroffen. Eine Ausnahme ist Russland, das weniger fossile Brennstoffe in die EU exportieren kann.

In GINFORS-E hingegen sind die BIP-Effekte im Jahr 2030 für die Szenarien 7 bis 9 im Vergleich zur Referenz für die EU positiv, wobei die Ausgestaltung des EU ETS eine deutlich größere Rolle spielt. Hier ist die Richtung der makroökonomischen Effekte aufgrund der durch die CO_2-Preiserhöhung induzierten strukturellen Veränderungen offen, da die Wirtschaft in der Referenz über ungenutzte Ressourcen verfügt. Die verstärkte CO_2-Reduktion in den Kernszenarien (7, 8 und 9) ist mit bestimmten Veränderungen der Produktions- und Verbrauchsstrukturen hin zu Sektoren mit geringen CO_2-Emissionen und geringeren Importen fossiler Brennstoffe verbunden. Die Energieeffizienz steigt und die Kosten für saubere Energietechnologien sind niedriger. Die Industrieproduktion ist zwar etwas niedriger als im Referenzszenario, aber da die Preise steigen, nimmt die Produktion im Bau- und Dienstleistungssektor etwas zu. Da auf diese Sektoren der größte Teil der europäischen Produktion und Wertschöpfung entfällt, ist diese Veränderung ausreichend für den leicht positiven BIP-Effekt in der EU.

Figure Z-5: BIP Abweichungen von Sc6.NDCs_Ref für GEM-E3 und GINFORS-E in 2030



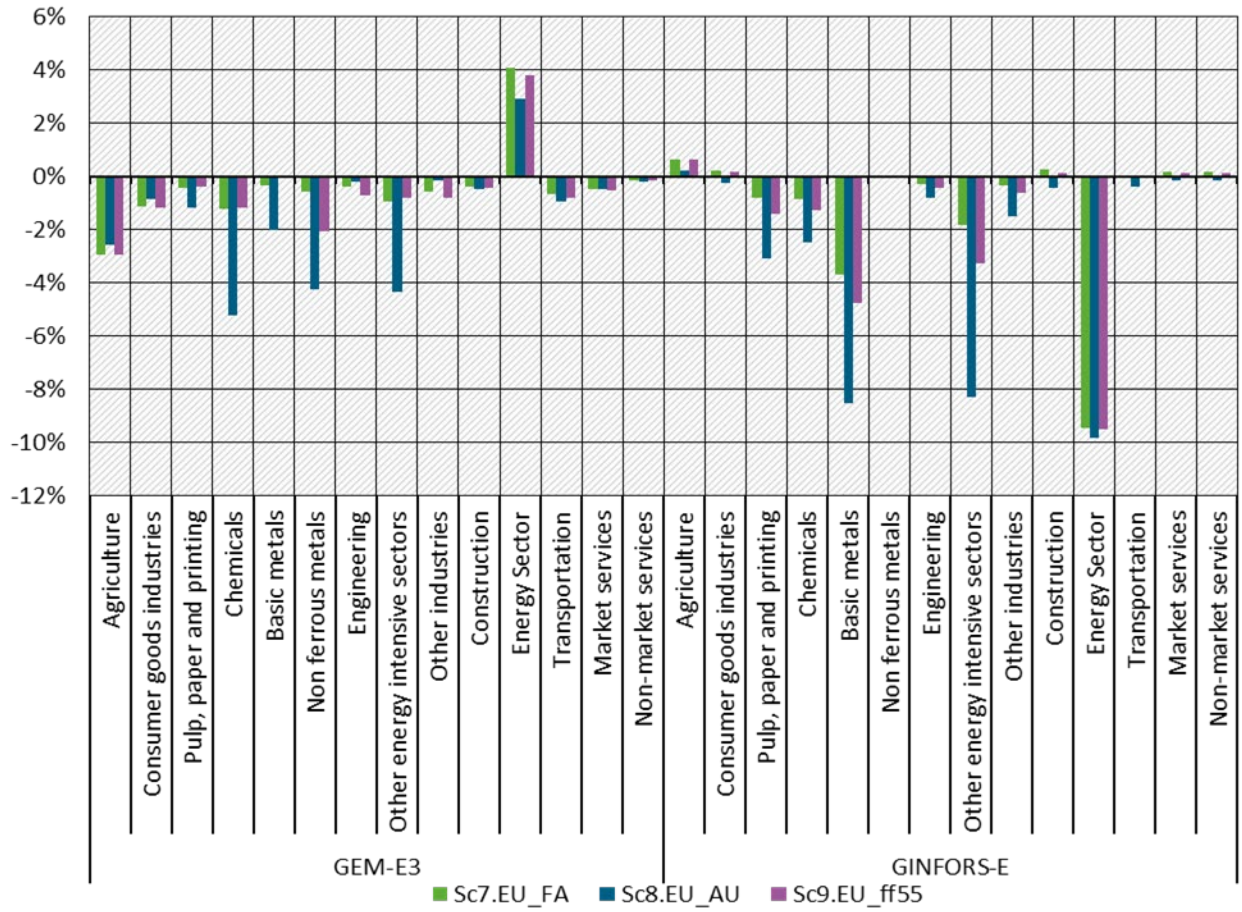
Quelle: GEM-E3 und GINFORS-E.

Für die durchschnittlichen jährlichen Wachstumsraten bedeutet dies jedoch nur sehr geringe Unterschiede zwischen den Ergebnissen der beiden Modelle. Bei der Betrachtung der

Unterschiede im Vorzeichen der BIP-Effekte sollte immer berücksichtigt werden, dass die langfristige Wachstumsdynamik in beiden Modellen durch die Klimaschutzmaßnahmen kaum verändert wird.

Sektorale Produktionseffekte: Die sektoralen Produktionseffekte in den CO_2-intensiven Sektoren sind im Großen und Ganzen in beiden Modellen negativ. Das Ausmaß des Produktionsrückgangs in den Basismetallen und den "anderen energieintensiven Sektoren" (hauptsächlich nichtmetallische Mineralien wie Zement) ist in GINFORS-E etwas größer, während für die Chemie die modellübergreifenden Unterschiede divergieren; in GEM-E3 ist der Rückgang für das Versteigerungsszenario größer, während der Effekt für CBAM positiver ausfällt als in GINFORS-E. In den anderen Sektoren weichen die Gesamteffekte ebenfalls voneinander ab, insbesondere für den Energiesektor.

Figure Z-6: Sektorale Produktion der EU – Abweichungen von Sc6.NDCs_Ref für GEM-E3 und GINFORS-E in 2030



Quelle: GEM-E3 und GINFORS-E.

In GEM-E3 und in GINFORS-E führt der CBAM in allen drei energieintensiven Sektoren, in denen er angewandt wird - Chemie, Grundmetalle und andere energieintensive Sektoren - zu weniger negativen Produktionsauswirkungen als die Versteigerung. Bemerkenswerterweise führt die CBAM in GEM-E3 für diese drei Sektoren im Jahr 2050 sogar zu positiven Produktionsauswirkungen im Vergleich zum Referenzszenario mit weniger ehrgeiziger Klimapolitik, während die kostenlose Zuteilung und noch mehr die Versteigerung negative Produktionsauswirkungen in diesen Sektoren haben. Dies könnte einen Teil der positiveren

Auswirkungen des CBAM-Szenarios gegenüber dem Szenario mit freier Zuteilung erklären. In GINFORS-E hingegen führt das CBAM-Szenario zu etwas stärkeren Produktionsrückgängen als die freie Zuteilung.

Die Auswirkungen auf den Energiesektor gehen in entgegengesetzte Richtungen. In GINFORS-E wird der Rückgang des Gasverbrauchs bis 2030 nicht durch eine höhere Stromerzeugung kompensiert, so dass die Gesamtenergieerzeugung zurückgeht. In GEM-E3 hingegen steigt die Energieerzeugung aufgrund der Elektrifizierung der Wirtschaft und des Einsatzes von Biokraftstoffen bis 2030 sowie des Einsatzes von Wasserstoff und sauberem Gas bis 2050. In GEM-E3 und in GINFORS-E schützt der CBAM die energieintensiven Industrien auf dem heimischen Markt, was zu einem Rückgang der Importe führt. Allerdings erhöht der CBAM die Produktionskosten der nachgelagerten Sektoren (die nun teurere importierte Materialien kaufen). Zu diesen nachgelagerten Sektoren gehören z. B. der Maschinenbau, das Baugewerbe und die Landwirtschaft, aber auch Sektoren, die unter das EU ETS fallen, da sie aufgrund der breiteren sektoralen Abdeckung auch ihre eigenen Produkte als Inputs verwenden. Dieser Anstieg wirkt sich negativ auf die Wettbewerbsfähigkeit und die Produktion aus. In nicht-energieintensiven Sektoren wie den Dienstleistungen sind die Auswirkungen in GINFORS-E etwas positiver.

Sensitivitätsanalyse: Der wichtigste Leakage-Kanal ist in beiden Modellen die Verlagerung der Produktion und die daraus resultierenden Veränderungen der Handelsstrukturen, wobei die angenommenen Werte der Armington-Elastizitäten eine zentrale Rolle spielen. Die Analyse zeigt, dass höhere Elastizitäten zu stärkeren Effekten in den CO_2-intensiven Sektoren führen. Außerdem reagiert GINFORS-E stärker auf Änderungen der Armington-Elastizitäten als GEM-E3. Ein Schlüsselfaktor ist hier wahrscheinlich die geringere Substitutionselastizität, z.B. für die Arbeitsnachfrage, in Übereinstimmung mit den mittels ökonometrischer Analysen geschätzten Elastizitäten. In Bezug auf die Ausgestaltung der CBAM zeigt die vorliegende Analyse, dass eine Ausweitung des Anwendungsbereichs auf indirekte Emissionen von Importen in beiden Modellen einen geringen Einfluss auf die Ergebnisse hat, während die Frage der Rückführung von Einnahmen die sektoralen und aggregierten Auswirkungen von unilateralen EU-Klimamaßnahmen deutlich verbessern kann. In diesem Zusammenhang ist es wichtig, daran zu erinnern, dass wir von einem parallelen Auslaufen der derzeitigen Ausgleichszahlungen für indirekte Kosten durch die EU-Mitgliedstaaten ausgehen. In diesem Sinne sollte die Einnahmenverwendung, z. B. über den Innovations- und den Modernisierungsfonds der EU, als wesentliches Element einer erfolgreichen Klimaschutzpolitik angesehen werden. Detaillierte Ergebnisse werden in den Abschnitten 3 und 4 vorgestellt.

Eine Erhöhung der Klimaschutzambitionen außerhalb der EU in den Szenarien 13, 14 und 15 hat in GEM-E3 und in GINFORS-E nur geringe negative Auswirkungen auf die EU. Im Jahr 2050 sind unilaterale Maßnahmen für die EU in Bezug auf das BIP etwas weniger vorteilhaft (aufgrund der geringeren Nachfrage von Nicht-EU-Ländern) als die Beteiligung fortgeschrittener OECD-Länder und Chinas am Klimaschutz in beiden Modellen. Aber zumindest in GINFORS-E ist der Klimaschutz mit Beteiligung anderer Länder immer noch vorteilhafter als keine zusätzlichen Klimaschutzmaßnahmen, zumindest in den Fällen der kostenlosen Zuteilung und der vollständigen Versteigerung und nahe Null im CBAM-Fall. Diese Ergebnisse widersprechen teilweise der Erwartung, dass globaler Klimaschutz für die EU wirtschaftlich vorteilhafter ist als einseitiger Klimaschutz. Dies gilt auf jeden Fall für die kohlenstoffintensiven Industrien in der EU. In anderen Ländern führt ein verstärkter Klimaschutz jedoch mitunter zu leicht negativen gesamtwirtschaftlichen Effekten, die dann auch für die EU die Vorteile für energieintensive Industrien, die in der Gesamtwirtschaft nur eine untergeordnete Rolle spielen, mehr als ausgleichen.

Zentrale Erkenntnisse: Im Falle einseitiger EU-Klimamaßnahmen besteht die Gefahr der Verlagerung von CO_2-Emissionen. CO_2-intensive Sektoren verlieren ihre internationale Wettbewerbsfähigkeit und verringern ihre Produktion im Vergleich zu einem Szenario ohne zusätzliche Klimaschutzmaßnahmen in beiden Modellen. Die makroökonomischen Kosten in Form von BIP-Verlusten sind im GEM-E3-Modell begrenzt. GINFORS-E berichtet sogar von geringen BIP-Zuwächsen für die EU im Falle von einseitigen Maßnahmen. Negative makroökonomische und sektorale Auswirkungen können durch eine geeignete Ausgestaltung des EU ETS einschließlich eines CBAM weiter reduziert werden. Beide Modelle zeigen, dass das Carbon Leakage-Risiko kein überzeugendes Argument gegen EU-Klimamaßnahmen ist, wenn EU ETS, CBAM und die Rückführung der Einnahmen aus beiden Instrumenten passend konzipiert sind.

Im Allgemeinen sind die makroökonomischen Auswirkungen zusätzlicher internationaler Klimaschutzbemühungen gering, während die CO_2-Emissionen stark reduziert werden. Es ist wichtig zu beachten, dass der wirtschaftliche Nutzen des globalen Klimaschutzes in Form von geringeren Verlusten und Schäden in den Szenarien nicht enthalten ist. Sie dürften um ein Vielfaches höher sein als die ausgewiesenen gesamtwirtschaftlichen Effekte eines ambitionierten Klimaschutzes. Die Botschaft der Studie ist positiv: Weitreichender Klimaschutz weltweit ist möglich und führt nur zu marginalen gesamtwirtschaftlichen Effekten. CBAM ist von den untersuchten Ausgestaltungsoptionen des EU ETS die am besten geeignete in Bezug auf Carbon Leakage. Die wirtschaftlichen Effekte (BIP und sektorale Industrieproduktion) sind dagegen für das Jahr 2030 bei einer kostenlosen Zuteilung etwas positiver. Die Ergebnisse für eine Vollversteigerung ohne CBAM sind eindeutig die schlechtesten.

Ausblick. Zukünftige Modellierungen könnten in verschiedene Richtungen verbessert werden, insbesondere um die Politik besser zu informieren: Die Klimapolitik in der EU behandelt Anlagen innerhalb der einzelnen Industriesektoren unterschiedlich, was auch in der Modellierung besser berücksichtigt werden sollte. Insbesondere für die CO_2-intensiven Sektoren ist eine detailliertere Beschreibung der Sektoren erforderlich, da sich die verwendeten Technologien und Energiequellen und damit die CO_2-Emissionen erheblich unterscheiden. Darüber hinaus ist für politische Maßnahmen wie den CBAM die derzeitige sektorale Differenzierung in den Modellen nicht angemessen, da sie (jedenfalls zu Beginn) nur Teile der in den Modellen aggregierten Sektoren abdeckt (z. B. nur Düngemittel und Ammoniak, nicht aber die chemische Industrie insgesamt). Diesbezüglich könnte mit spezifischen Datensätzen wie EXIOBASE, GLORIA oder GTAP untersucht werden, inwieweit differenziertere Daten verfügbar sind und eine entsprechende Modellierung möglich ist. Dies könnte dem Ansatz folgen, der in der Folgenabschätzung der EU-Kommission vom Juli 2021 zur Einführung einer CBAM verfolgt wurde, die Daten aus EXIOBASE integrierte und mehrere Konsistenzprüfungen beinhaltete (EU 2021b).

Für die Modellierung wäre auch eine Unterscheidung zwischen Teilen einer Branche, die bereits auf Klimaneutralität umgestellt wurden, und solchen, die noch CO_2-intensiv sind, wertvoll. Eine Modellkopplung mit sektorspezifischen Modellen oder Energiesystemmodellen könnte ebenfalls ein Ansatz für zukünftige Verbesserungen sein. Energiesystem- oder Branchenmodelle weisen eine höhere Differenzierung der Teilsektoren auf und können auch eine technologische Differenzierung enthalten, z. B. die Trennung zwischen Primär- und Sekundärstahl. In Bezug auf die Industriesektoren könnte auch genauer betrachtet und analysiert werden, wie unterschiedliche Verhaltensweisen und Zeithorizonte bezüglich kohlenstoffarmer Investitionen, die auch durch die politischen Rahmenbedingungen beeinflusst werden, abgebildet werden können.

Zusätzlich besteht die Notwendigkeit, die Modellierung der Ausgestaltung der Klimapolitik mit Blick auf die besonders betroffenen Sektoren weiter zu verfeinern und die Wirkungskanäle besser zu verstehen. Dabei sollten auch neu entstehende THG-neutrale Industrien in den Blick genommen werden, die in den bisherigen Statistiken und Modelldatensätzen nur eine untergeordnete Rolle gespielt haben. Sie sind für den sozioökonomischen Erfolg der Klimapolitik mindestens ebenso entscheidend wie die CO_2-intensiven Industrien. In der politischen Praxis gehen politische Maßnahmen oft über reine Preisinstrumente hinaus. Diese Realitäten müssen auch in der klimapolitischen Modellierung berücksichtigt werden. In jedem Fall ist es wichtig zu verstehen, was die Wirtschaftsakteure antreibt und wie ihr Verhalten kosteneffizient in Richtung Klimaneutralität verändert werden kann. Dazu verbessern sich die Datenverfügbarkeit und die Rechnerkapazitäten für die Modellierung der sozioökonomischen Auswirkungen von Klimaschutzmaßnahmen. Gleichzeitig werden die Modelle auf relevante Teilbereiche der Realität beschränkt bleiben. Daher sollten sie in Zukunft einerseits vertieft und andererseits auf zentrale Politikfragen und Produktdifferenzierungen fokussiert werden.

1 Introduction

The aim of this research project has been to improve the understanding of the suitability of two types of large-scale models differentiated by industries – macro-econometric models and computable general equilibrium (CGE) models – for analysing international emission effects and economic effects of scenarios in which the EU moves forward in climate policy and applies an emissions trading system in this context. In particular, we aim at extending and deepening the knowledge on how the two different models treat the design of the European Emissions Trading System (EU ETS) especially on allocation, and of a carbon border adjustment mechanism (CBAM) as implemented under the fit-for-55 reform package – both with a view especially to sector and overall economic activity as well as to changes in the EU's industry trade flows and to potential carbon leakage.

Work package 2 has been split into a "Technical Report" and this Central Report to assess the carbon leakage risk for the EU industries under different policy assumptions and compare the results of different modelling approaches and attempt to attribute the findings to model differences. By the last point, we also aim at providing insights for the interpretation of the results obtained from modelling the international effects of the EU moving forward in climate mitigation and the impacts of "how this is done" in terms of policy choice.

Besides these primarily methodical goals, our results also contribute to understanding the projected economic and carbon leakage effects of the revision of the "fit-for-55" measures, especially the increased abatement ambition until 2030 and 2050 in the EU and the gradual introduction of a CBAM.

We therefore contribute to the available research by a) providing **key results** for different scenario settings **regarding ambition and design in the EU ETS and of a CBAM introduction** and b) providing indications on **which results differ in particular between the two models.** As can be seen below, we suggest that there is a high likelihood for the choice of model to be relevant at least for indicators such as carbon leakage rates and economic quantity and price effects, both economy-wide and (to a lesser extent) by industry. The idea is to get a better grasp on the "robustness" of the results depending on the choice of model and indicative insights on which political questions, related to "uneven pace" of climate ambition, can be feasibly addressed by these two types of model.

In this way, we aim at assisting practitioners (governmental, nongovernmental and likely also commercial) as well as researchers in interpreting the results from model-based scenario analyses on ETS design and on the effects of a CBAM. Such scenarios are applied, for example, in policy impact assessments by the European Commission. In addition, ideally the report can assist practitioners or researchers when commissioning – or even conducting – own scenario research in the context mentioned.

Two models, one each of the types mentioned above, **macro-econometric (GINFORS-E**) and **CGE (GEM-E3**), have been applied to policy scenarios that represent plausible political options. The model GEM-E3 (General Equilibrium Model – E3) is a general computable equilibrium (CGE) model that follows neoclassical theory, the other model GINFORS-E (Global Interindustry Forecasting System - Energy) is a macro-econometric model that follows a post-Keynesian approach. Both models are briefly described in sections 3, 4 and 7. Details on model harmonization can be found in the Technical report (Lutz et al. 2024).

This study considers the socio-economic effects of EU climate change mitigation scenarios up to 2050 using two macroeconomic models with different model philosophies. The core scenarios are mainly characterized by unilateral EU climate protection so that the climate mitigation targets of -55% until 2030 and -95% until 2050 are achieved. They are compared with a reference scenario in which the EU "only" reduces its GHG emissions by 40% by 2030 and by 80% by 2050 compared with 1990 levels.

Unilateral EU climate action via carbon pricing can induce the problem of carbon leakage. Higher carbon prices in the EU lead to higher costs for carbon-intensive industries, which then relocate part of their production to other parts of the world and possibly even produce there with higher emissions per output unit. The effect of climate protection in the EU is thus reduced because global emissions, which are decisive for the climate effect, are reduced less than in the EU alone. At the same time, production and jobs are relocated outside the EU.

The central policy related scenarios addressing the **details of the EU ETS** (i.e., primarily allocation) as well as the potential **introduction of a CBAM**, **have been analysed with both models, and the results contrasted to each other, This is presented in the "Central Report" of this project (see section 1.2 below).** This report treats the allocation and the CBAM as key elements for the main scenarios:

- ETS ambition according to Fit-for-55 (FF55); free allocation for industry and auctioning for energy sectors; no CBAM.
- ETS ambition according to FF55; auctioning for all ETS sectors; no CBAM.
- ETS ambition according to FF55; auctioning gradually replacing free allocation for certain industry sectors as in the FF55, parallel gradual introduction of CBAM.

We approximate the actual CBAM scope, as prescribed in the EU "CBAM Regulation" 2023/956/EU, **by assuming that the CBAM gradually replaces free allocation for the following industry sectors as covered in our models: Iron and Steel/Ferrous metals, Non-ferrous metals** (both grouped together as "Basic metals" in GINFORS-E)**; Non-metallic minerals; and Chemical industry** (where both industry sectors in our case include the entire respective sector e.g. also lime, glass and ceramics as well as organic and non-organic chemicals, as a further differentiation would require further sectoral differentiation than what is currently feasible in underlying databases of these models.

The analysis then added additional scenarios or sensitivities for d) the assumed international trade elasticities ("Armington elasticities"), e) the inclusion of indirect emissions into the CBAM (replacing compensation mechanisms in the EU for indirect emissions), and finally, f) of increased climate policy ambition in major trading partners of the EU. For GEM-E3, in addition g) a modified use of the budget revenues has been addressed.

During the time that this project was performed, major changes in the economic and political environment took place. Especially the level of ambition in international climate protection, at EU level – including in Germany – and in several major global economies has increased significantly over the past two years. Many countries responsible for about 75% of global emissions have committed to the target of climate neutrality by 2050 or, like China and Russia, by 2060 at the latest. India committed to climate neutrality until 2070 during COP 26. The EU has also increased its level of ambition, aiming to reduce GHG emissions by 55% from 1990 levels by 2030 through the Green Deal, the "fit for 55" legislative package from July 2021. This package also includes the gradual inclusion of a carbon border adjustment mechanism (CBAM) for certain carbon-intensive goods. The corresponding design of the EU ETS – especially in terms of the allocation mechanism applied – is central to the project. At the EU level, the latest framework assumptions available for the long-term development of population, economic growth, energy prices and emissions have been applied in this context. The current energy price crisis and the fear of supply shortages due to the war in Ukraine and the sanction measures of the West against Russia are currently high on the political agenda. What this means for the energy transition and climate protection in Germany and Europe is only beginning to become visible.

Against this background, it has been most feasible to apply a modelling period to 2050 GEM-E3 data build on a new GTAP10 database. The model has been applied in different impact assessments also for the EU fit for 55 package (EU 2018, EU 2020). GINFORS-E also covers all years up to 2050. It has been applied in impact assessments for the EU adaptation strategy (EU 2021c) and for the adaptation of the EU energy directive (Neiva et al. 2021). During these applications, various parts of the models have been updated and adjusted. Both models have been applied to measure impacts of climate change on European islands (Vrontisi et al. 2022).

Section 2 describes the individual scenarios. The results of the GEM-E3 model are presented in detail in section 3 and of the GINFORS-E model in section 4. A comparison of important results for both models is provided in Section 5: there, at first the results for the reference scenario NDCs_Ref are compared, followed by contrasting the results for scenarios 7 to 9. Conclusions for climate policy design and future modelling are drawn in section 6. Finally, the two models used, GEM-E3 and GINFORS-E, are briefly described in section 7.

2 Scenario design

A reference scenario, three core policy scenarios and various other scenarios and sensitivities have been quantified with the two models. The reference scenario can be described as follows: 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 are maintained until 2030, decreasing linearly afterwards to 0 in 2050. Some energy intensive industries (basic metals, paper) in the EU receive compensation for indirect emissions as today until 2030, decreasing to 0 by 2040. The sector split between ETS and non-ETS remains in the EU until 2030. For the rest of the world, single country-specific carbon prices without sector split are assumed, so that countries reach their NDC targets This means low carbon prices for other industrialized countries and China. For other countries, no carbon prices are set. A brief description of the other scenarios is provided below (Table 5).

Table 5: Scenarios

No.	Abbreviation	Short description
6	NDCs_Ref	Reference scenario as described above
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 indirect emissions phased out until 2040 (basic metals, paper).
9a	EU_ff55_CBAM_dic	As 9, CBAM on direct and indirect emissions. Compensation for indirect emissions phased out until 2034.
9b	EU_ff55_CBAM_d	As 9, CBAM on direct emissions, no compensation in any year for indirect emissions
9r	REC	As 9, revenue recycling via energy efficiency investment in CBAM sectors
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, 11a, 12a	NDCs_Ref_AG EU_FA_AG EU_AU_AG EU_ff55_AG	Scenarios 6 to 9 with elasticities from GEM-E3 (only GINFORS-E)

No.	Abbreviation	Short description
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.

All scenarios in this report consider the EU "moving forward" in achieving ambitious climate change targets for 2030 and 2050, while other countries only achieve their 2030 Nationally Determined Contributions (NDCs) submitted in 2020, and afterwards apply no significant further emission reduction efforts (in modelling terms, this means that the carbon prices resulting from NDC targets in 2030 afterwards increase only at the rate of real GDP). The only exception are scenarios 13 to 15 with also higher climate mitigation ambition outside Europe. The degree of this "moving forward" of the EU is different between scenario 6 (**NDCs-Ref**), in which the EU reaches its NDC for 2030 of -40% compared to 1990 – and -80% until 2050 -, and the other scenarios in this report, in which the EU's targets are still more ambitious (see below for the details). The NDC targets of the other countries, also as of 2020, are listed in Table 6.

Table 6: NDC targets for 2030 major emitting countries 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

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 to the sectors basic metals (in GEM-E3, meaning for both ferrous metals and non-ferrous metals; GINFORS-E in general does not differentiate these sectors) and for paper products and printing.[2] This compensation is phased out linearly already until 2040 to reflect the decarbonization of the electricity supply. 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.

The differences among the scenarios 7 to 15 thus mainly relate to the rule of allowance allocation, the adoption or not of a CBAM (either with or without inclusion of indirect emissions), and finally the ambition assumed for the non-EU countries between 2030 and 2050. All emission reduction targets are assumed to be achieved using carbon pricing.

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, because the technology is still in the demonstration phase and the scope is very limited at least until 2030. [3] 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. Allocation in the EU and the rest of the world is the same as in scenario 6.[4]

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. This scenario primarily serves to illustrate the impact of a CBAM (as included in the following scenario 9) when free allocation is not granted.

Scenario 9 (**EU_ff55**) is strongly oriented towards the EU policy under the fitfor55 package, especially the revised ETS directive and the new CBAM directive. 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 reason is that because the CBAM covers only direct emissions in this scenario, the compensation is still important for the carbon leakage protection. The assumptions for the rest of the world (Non-EU) remain as in scenarios 7 and 8.

[2] In contrast, no compensation is assumed for the other industry sectors covered by the EU ETS: thus, also not for non-metallic minerals and for the chemical industry. This assumption reflects the actual policy design as practiced, e.g., in Germany: here, the ferrous metals, the non-ferrous metals industry and the paper and pulp industry are granted compensation for most of their respective electricity consumption. In contrast, in the sectors non-metallic minerals and the chemical industry only a share of much less than 50% of sector electricity consumption receives compensation.

[3] Under the "NER 300" promotion program, only one demonstration project was finally implemented, while all other initial plans throughout the EU have been abandoned or at least put on hold.

[4] We follow the principle that in general, changes from one scenario to the next shall address one major adjustment only, in order for these changes to remain visible in the results. Here, the key difference is the raised EU target ambition for 2030 and for 2050. We therefore do not make changes also in terms of free allocation and/or compensation for indirect cost from the ETS.

Scenario 9a is a sensitivity to scenario 9. The only two differences compared to scenario 9 are that the CBAM is implemented on direct **and indirect** emissions (**CBAM_dic**) and that the compensation payments for indirect emissions are gradually phased out simultaneously with the phase-in of the CBAM until 2034. Scenario 9b is another sensitivity to scenario 9. The only difference compared to scenario 9 is that there is no compensation for indirect emissions throughout (**CBAM_d**).

Scenario 9r (**REC)** has only been implemented in GEM-E3. It builds on scenario 9 but uses the CBAM revenues for energy efficiency investments in the CBAM sectors. **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 shares 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 NDCs_Ref scenario with the adjusted Armington elasticities for GINFORS-E, in order to serve as a new reference for these sensitivities[5]. In GEM-E3, the parameters of the Armington function are re-calibrated to produce the same results as in the scenario 6 by using the half elasticity and re-calibrating the other calibrated parameters (beta and delta) of the Armington function.

The following Table 7 gives an overview of the Armington elasticities in the two models and the different scenarios. In the centrals scenarios 6-9, 9a, 9b and 13-15, sector specific elasticities are used in GEM-E3, while no sector differentiation is made in GINFORS-E. With the exception of non-metallic minerals, elasticities are higher in GEM-E3 than in GINFORS-E. in scenarios 10-12 – and also 6D for GINFORS-E – these parameters are halved for GEM-E3 and doubled for GINFORS-E. In scenarios 6a, 10a, 11a, and 12 a, the original elasticities from GEM-E3 are used for GINFORS-E, to allow for a model comparison with identical Armington elasticities.

Table 7: Assumptions for Armington elasticities in the two models and different scenarios

Model	Scenarios	Industry	sigma m value	sigma x value
GEM-E3	6-9, 9a, 9b, 9r, 13-15	Ferrous metals, paper products, publishing	5.9	2.95
		Chemical Products, rubber and plastic products	6.6	3.3
		Non-metallic minerals	3.8	1.9
	10-12	Ferrous metals, paper products, publishing	2.95	1.475
		Chemical Products, rubber and plastic products	3.3	1.65
		Non-metallic minerals	1.9	0.95
GINFORS-E	6-9, 9a, 9b, 13-15	All CBAM sectors	4.0	1.0
	6D, 10-12	All CBAM sectors	8.0	2.0

[5] Because of the different model philosophy GINFORS-E does not include the original Armington function as does GEM-E3. In GINFORS-E, the decision between domestic production and imports as well as between the different supplier countries of the imports is represented at two different points in the model as separate functions.

Model	Scenarios	Industry	sigma m value	sigma x value
	6a, 10a, 11a, 12a	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: GEM-E3 and GINFORS-E.

Different assumptions for the CBAM factor, shares of auctioning in industry, and compensation of indirect emissions in the two models are detailed in Table 8.

Table 8: CBAM factor, share of auctioning in industry and compensation of indirect emissions in the two models and different scenarios

			2025	2030	2035	2040	2045	2050
GEM-E3 and GINFORS-E	CBAM-Factor		0	0.485	1	1	1	1
	Share of auctioning in industry	Sc6.NDCs_Ref	0.2	0.2	0.4	0.6	0.8	1
		Sc7.EU_FA	0.2	0.2	0.4	0.6	0.8	1
		Sc8.EU-AU	1	1	1	1	1	1
		SC9.EU_ff55	0.2	0.588	1	1	1	1
		9a.EU_ff55_CBAM_dic	0.2	0.588	1	1	1	1
		9b.EU_ff55_CBAM_d	0.2	0.588	1	1	1	1
	Compensation of indirect emissions	Sc6.NDCs_Ref	0.75	0.75	0.375	0	0	0
		Sc7.EU_FA	0.75	0.75	0.375	0	0	0
		Sc8.EU-AU	0	0	0	0	0	0
		SC9.EU_ff55	0.75	0.75	0.375	0	0	0
		9a.EU_ff55_CBAM_dic	0.75	0.386	0	0	0	0
		9b.EU_ff55_CBAM_d	0	0	0	0	0	0

Source: Own compilation.

In scenarios with a CBAM, the factor is increased from 0 to 1 in 2034. Free allocation is phased out until different years according to the allocation mechanism in the EU ETS. Compensation for indirect emissions is phased out until 2040 in the central scenarios.

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 (Table 9). For other advanced OECD countries, a carbon price of 50% of the EU price is assumed in each case.

Table 9: Chinese emission pathway with climate neutrality in 2060 - GHG in Mt

Sector	2030	2035	2040	2045	2050	2055	2060
CO_2 emissions according to new NDC	10884	9070	7256	5442	3628	1814	0

Source: The emission pathway is a linear interpolation from 2030 emissions to carbon neutrality in 2050.

3 GEM-E3 – Scenario results

3.1 Introduction

The clean energy transition is a capital-intensive process through which low value-added products (fuels) are substituted by investments in high value-added products (wind turbines, PV panels, Energy efficient appliances and machines). As a result, the fossil fuel related sectors are expected to decline and fuel import bills to shrink, but at the same time domestic investment expenditures increase. This process takes place in a dynamic energy system where prices, technology costs, production structures, consumer preferences and habits are all constantly evolving and where different and new types of labour skills, infrastructure and materials are needed. At the early stages of the transition, financing requirements are high while the technologies and skills required to make the transition may not have yet reached full learning potential – these are important potential bottlenecks. During this phase, it is possible that energy costs increase compared to business as usual. Policies and measures may create conditions which enable positive externalities, which bring cost reductions and cost-efficient uptake of technologies. Competitiveness impacts are not static, whilst needing to contend with potentially higher energy prices and costs, industry will also transform to produce the novel value-added products and materials (new clean energy technologies may require scarce raw materials that are located in few suppliers globally posing value chain risks). As for all technology-driven growth, first-mover advantages may drive competitiveness gains and export-driven growth. Timely coordination of all changes in the system is essential, including the mobilization of adequate financing to support the large-scale deployment of new technologies. All these elements show that the quantification and assessment of the economic and employment implications of energy and climate policies is a quite complex task as the uncertainties and the inter-dependencies and dynamics of multiple systems must be taken into account.

The GEM-E3 model[6] has been used to quantify a series of climate policy scenarios with different GHG emission reduction targets and configurations regarding the participation of countries, sectors, supply rule of emission allowances, mechanisms for allocating EUAs and revenue recycling and trade elasticities. In all cases the key mechanism driving the results of the model is the introduction of a carbon price. The carbon price is internalized in economic agents' choices (firms and households) and drives investments, fuel substitution, adoption of new production processes and consumption patterns. Carbon prices operate through the following main channels:

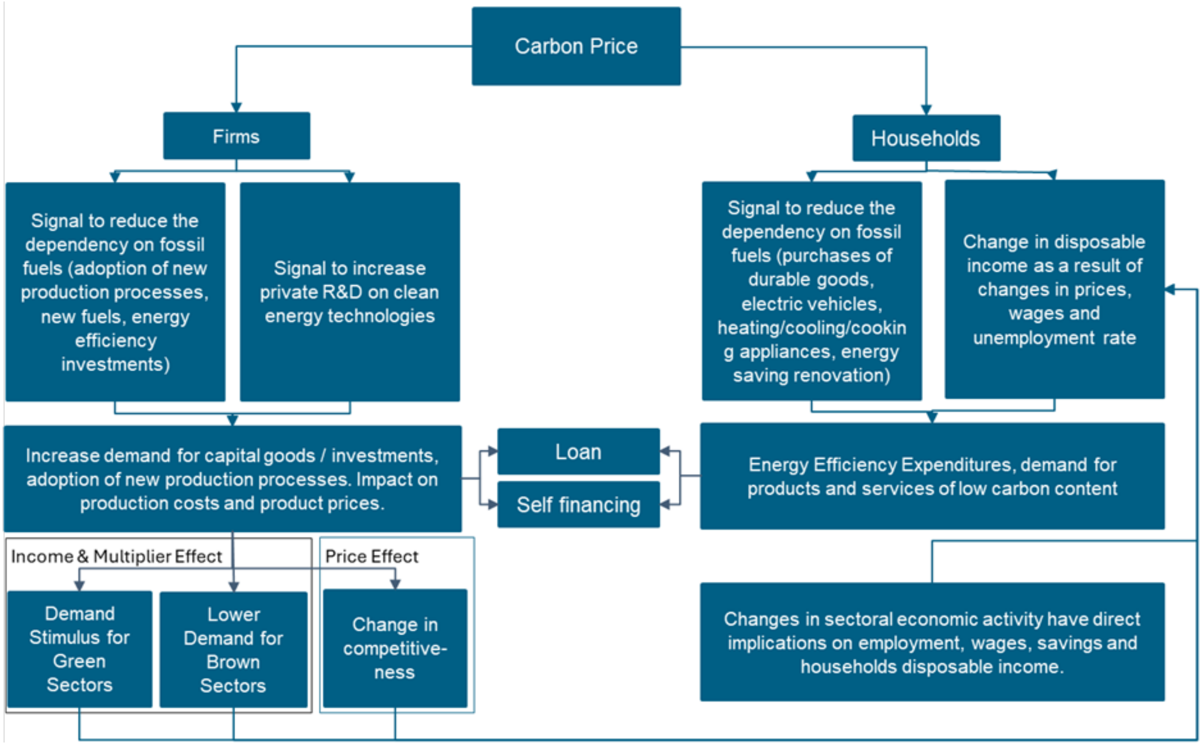
1. Increase production costs of firms (as they need to engage in more expensive but less carbon intensive production processes) and reduce households disposable income (as firms price higher their products).
2. Create a demand stimulus effect as the transition is capital intensive (the business model changes from low capital expenses (CAPEX) and high operational expenses (OPEX) to high CAPEX and low OPEX).
3. Drive firms and consumers to economic activities with high output and employment multiplier effects such as manufacturing and construction.
4. Accelerates R&D to clean energy technologies – lowering eventually their production costs.

The net economic and employment result of this adjustment is uncertain and depends on the country, sector and time. The figure below depicts the key mechanisms through which the

[6] Capros P, Van Regemorter D, Paroussos L, Karkatsoulis P, Fragkiadakis C, Tsani S, Charalampidis I, "GEM-E3 Model Documentation". 2017, available from https://e3modelling.com/wp-content/uploads/2018/10/GEM-E3_manual_2017.pdf

adjustment process of the economic system takes place in the GEM-E3 model once a carbon price is introduced.

Figure 7: Key mechanisms in GEM-E3 regarding carbon pricing



Source: E3-Modelling

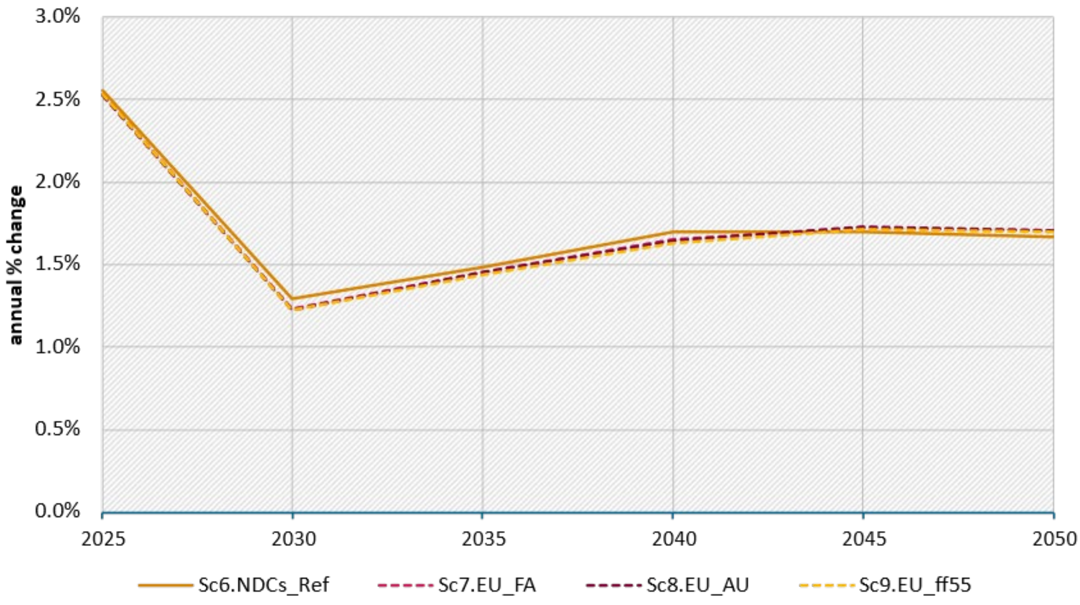
3.2 Scenario Comparison: Unilateral EU Action (7, 8, 9 vs 6)

(Scenarios 7, 8 and 9 are used to examine the economic impact of the EU's current GHG emission reduction targets (55% in 2030 and 95% in 2050 for the EU). The performance of these scenarios is compared to scenario 6 where EU implements the 40%/80% targets in 2030/2050, respectively, which formed the EU's previous mitigation goals. Apart from the level of the GHG targets these scenarios differ on the way that emissions allowances are supplied. Scenarios 6,7 represent an 80% free allocation in EU industries in 2030 and 100% free allocation in RoW. In all countries the free allocations decrease to zero by 2050. In scenario 8 full auctioning in all sectors in EU is assumed instead (no changes for the RoW). In Scenario 9 the CBAM mechanism is introduced linearly from 2026 to 2034 and at the same time the free allocation is reduced to zero in a complementary manner.

All scenarios simulated with the GEM-E3 model show that GHG emissions reductions are achieved with a net cost that ranges from -0.5% of GDP in scenario 7 to -0.64% of GDP (compared to Scenario 6 and for the period 2020-2050) in scenario 9. In terms of annual growth rates, the impact is virtually zero (from 2.61% annual growth rate in scenario 6 over the 2020-2050 period to 2.57% in Scenario 9).

In 2030, Scenario 9 performs "better" than Scenario 8 as free allowances still exist in Sc9 (Phase-out in 2035). From 2035 onwards, both scenarios are under full auctioning. CBAM leads to competitive gains in the CBAM sectors and leads to an increase in production in these sectors. On the other hand, downstream sectors (e.g., car manufacturers) are facing increased production costs as the imports of the materials become more expensive (e.g., steel). As a result, the production and exports of the downstream sectors are decreasing especially in 2050 where the tax on imports is higher due to the carbon price. The latter effect dominates in our results and leads to a reduction of GDP in the overall period (2020-2050)

Figure 8: Annual EU GDP growth in the scenarios 6,7,8 and 9



Source: GEM-E3

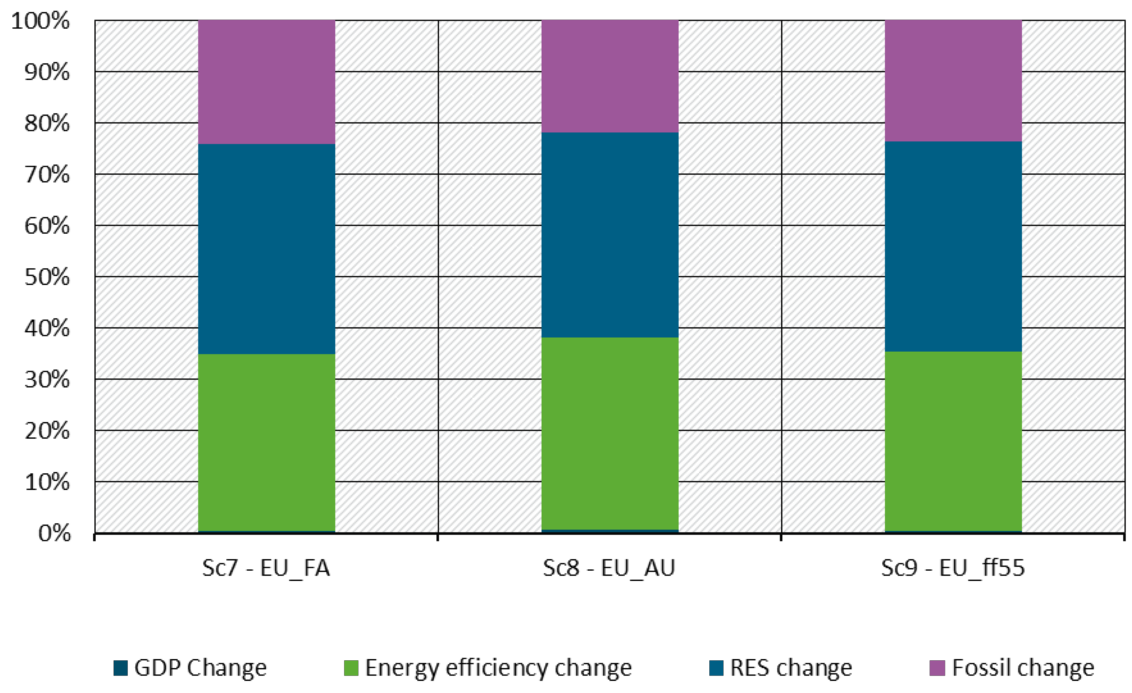
Figure 9 shows the KAYA decomposition[7] of the GHG emission reduction for each scenario examined. Essentially in all scenarios examined the pattern remains the same: The deployment of RES technologies is the major factor behind the GHG emission reduction, followed by energy efficiency measures that lead to a lower energy intensity per unit of GDP ("energy efficiency change") and changes in the fossil fuel mix ("fossil change", primarily from coal to natural gas[8]). The impact of activity is marginal. In scenario 8 full auctioning of allowances strengthens the decarbonization signal to industries hence they further intensify their abatement efforts and adopt higher (compared to the other scenarios examined) energy efficiency options.

[7] Kaya decomposition: Shows the contribution of 4 components (GDP change, Energy intensity change, RES deployment and fossil change) to changes in GHG emissions.

Kaya, Y. (1990). Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios

[8] The study has not taken into account the implications on gas demand/supply after the Russia-Ukraine war

Figure 9: Kaya decomposition of EU GHG emissions reduction in Sc. 7,8,9 (2030)



Source: GEM-E3

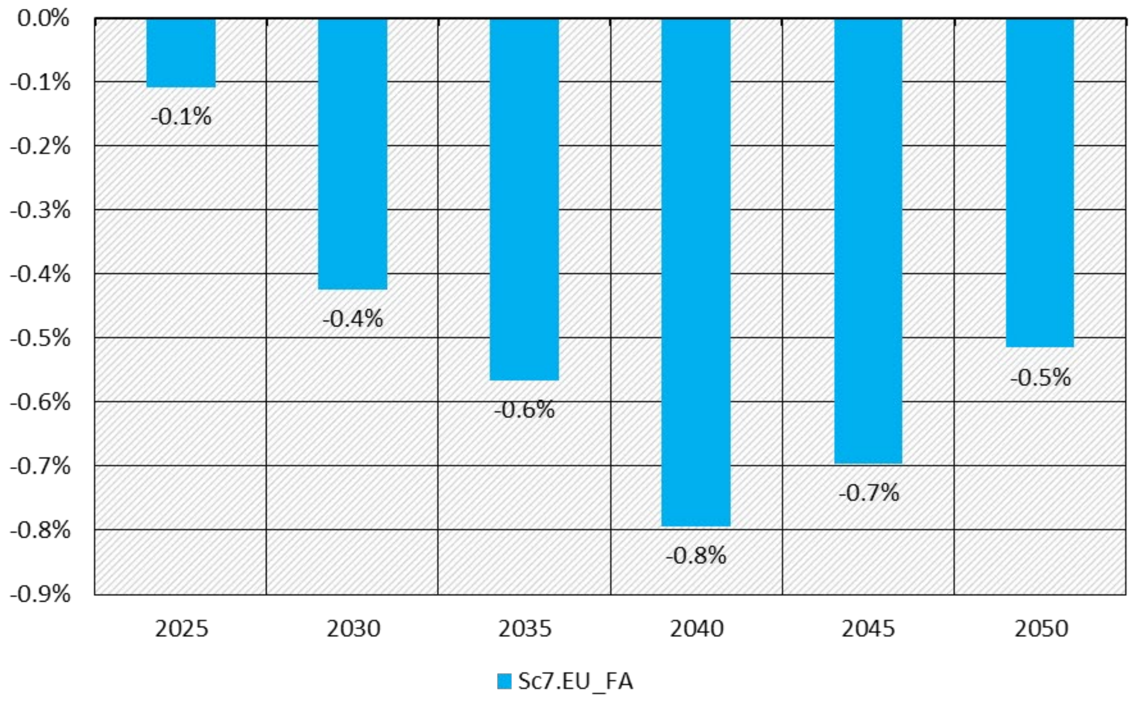
Increasing the EU GHG mitigation targets has a small but negative impact on the EU GDP (Figure 10). The following factors impact the EU economy in Scenario 7:

1. Adoption of more expensive fuels and production processes
2. Crowding out effect: The shift from a low CAPEX/high OPEX to a high CAPEX/low OPEX business model requires significant upfront payments from firms and households – while benefits are spread over a long time period. In the GEM-E3 model the default[9] assumption regarding the financing of investments is "self-finance". This entails that economic agents have to cancel investment/consumption projects of equal value to finance the purchase of the clean energy technologies (this is a direct consequence of the fact that in the reference scenario all savings are used to finance investments – no idle financial resources).
3. Competitiveness: Change in production costs affect export/imports.
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.
5. Allocation of allowances: Gradual phase out of allowances increase the productions costs.

From a temporal point of view the impact on the EU economy peaks in 2040 where free allocation is almost phased out and carbon prices have escalated. In addition, after 2040 the capital costs of newly adopted technologies are reduced facilitating further the adjustment process.

[9] A loan-based option is available where economic agents receive from the banks financing in order to implement the necessary investment/consumption expenditure. In this way agents create a debt and need to return back the loan at a predefined interest rate and time period.

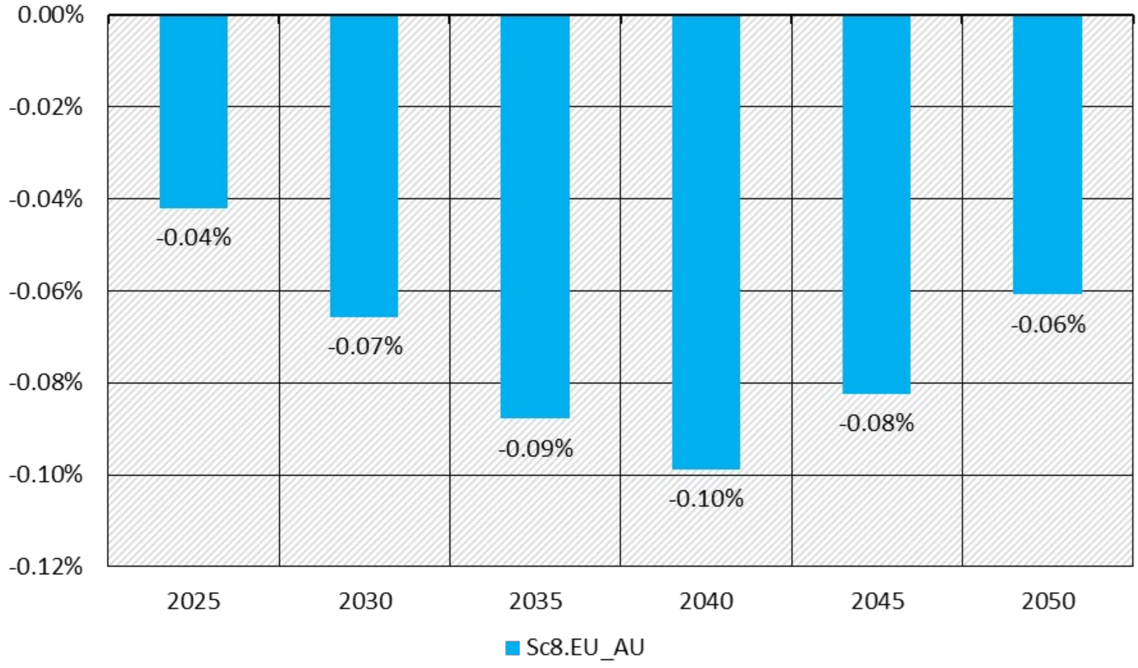
Figure 10: EU GDP in scenario 7 compared to scenario 6



Source: GEM-E3

In order to assess the importance of free allowances versus full auctioning the impacts on GDP of Scenario 8 are compared to the GDP of scenario 7 (Figure 11). The removal of free allowances acts negatively on EU industrial production costs hence the GDP is marginally reduced throughout the simulation period - the temporal profile of the adjustment process however remains the same. An essential element in this scenario is the use of auctioned revenues – how they are recycled in the EU economy. In this scenario it is assumed that they are used to reduce public budget deficits.

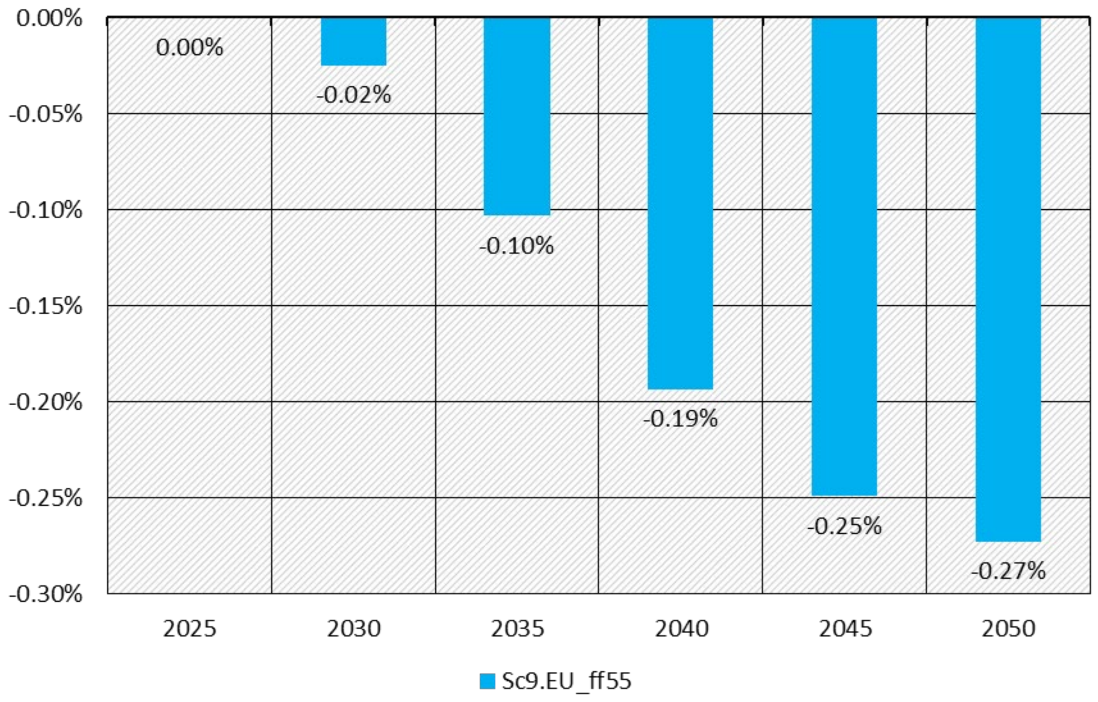
Figure 11: EU GDP in scenario 8 vs 7



Source: GEM-E3

In order to study the impact of CBAM the GDP results of scenario 9 are compared to scenario 7 (Figure 12). The imposition of CBAM at the early stages has very small negative impact. In the longer term it seems that the CBAM on imports is not very effective overall: although it manages to level the production costs differences for upstream sectors (e.g. increase the import price of steel to EU so as production costs of steel are comparable) it increases the production costs for downstream sectors while there is no effect on EU exports (steel produced in Germany - subject to carbon price – will be exported to Turkey where the price of carbon is virtually zero). In addition, the generation the CBAM revenues are significant over time but in our analysis are not used for any other purpose than reducing public budget deficits.

Figure 12: EU GDP in scenario 9 vs 7



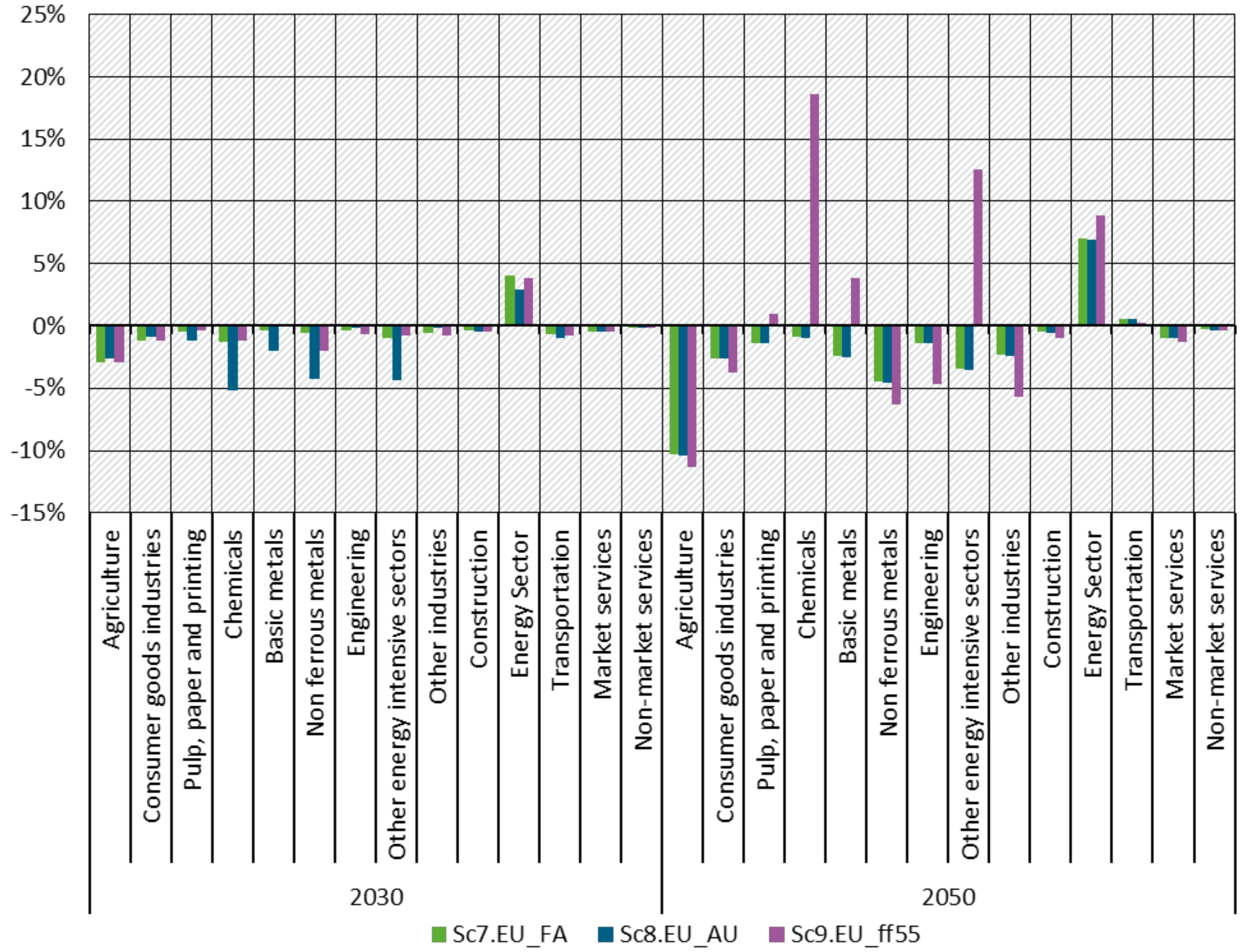
Source: GEM-E3

The results are not uniform across countries and sectors: those that contribute to the reduction of GHG emissions and energy consumption (e.g., producers of clean energy technologies) benefit whereas the fossil fuel and carbon intensive sectors reduce their production. In Figure 13 the difference in sectoral production for key industrial groups between scenarios 7, 8, 9 and scenario 6 are shown. Full auctioning is the worst option for carbon-intensive sectors, while a CBAM mechanism can significantly reduce production changes. Production effects of free allocation and CBAM are very similar (Figure 14).

Increasing the EU target in 2030 and 2050 has a small but negative effect on GDP if constraints in the capital market prevail and financing of clean energy investments crowds out other investments. Free allowances are effective in protecting EU industrial competitiveness both in the internal and international market. CBAM increases the production costs in downstream sectors. Alternative recycling of emission allowances (and potentially also CBAM revenues, if deemed appropriate) could be more efficient from an economic perspective.

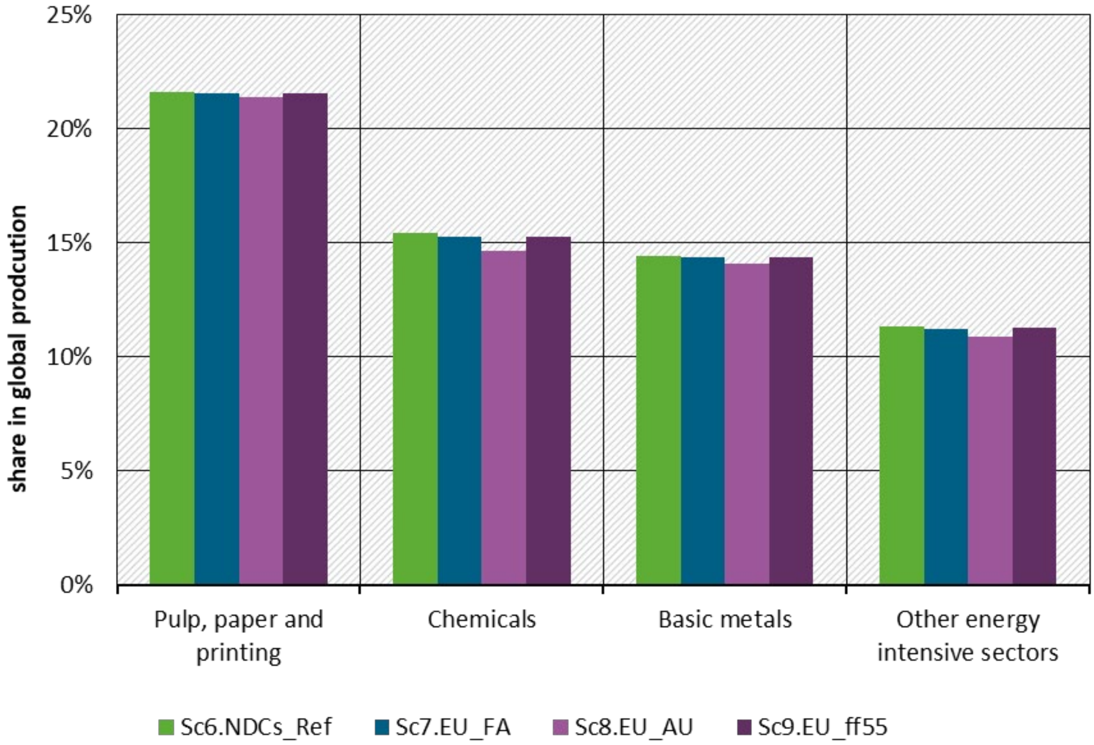
The key industries negatively affected are the energy/carbon intensive and export oriented like chemicals, non-metallic minerals and metal products. Agriculture is also negatively affected as process emissions (like CH_4 from livestock and N_2O from crops) is very hard to abate. The effect on agriculture becomes more evident towards the end of the simulation period where achieving carbon neutrality challenges the abatement potential of the sector. In 2050 the impact on production becomes more pronounced reflecting the escalation of the carbon prices. The electricity sector drives the results of the energy sector – electricity sales increase in all scenarios examined driven by the electrification of the economy (transport, heating/cooling in buildings) and the production of clean fuels. The positive effect of CBAM on the respective sectors is mostly evident in the long term – however it should be noted that at the same time downstream industries (most of them classified under the "Other industries") have significant lower production in Scenario 9 than the other scenarios examined.

Figure 13: EU sectoral production in scenarios 7, 8, 9 vs 6



Source: GEM-E3

Figure 14: EU production shares in 2030 in scenarios 6, 7, 8, and 9



Source: GEM-E3.

Table 10 shows the difference in bn USD in sectoral production between Sc8 and Sc6 in 2030. In the EU sectoral production decreases in energy intensive sectors driven from the rise of carbon prices and full auctioning. This results to competitive gains for countries outside EU as EU products become more expensive. In the EU, the chemicals industry presents the highest decrease in sectoral production (absolute numbers) - market share increases mostly in China and India. CO_2 energy emissions follow the changes in production (Table 11) where chemicals and basic metals shows the highest carbon leakage rate mainly in India and Russia.

Table 10: Differences in production between Sc8 and Sc6 in 2030 in bn USD

	EU28	United States	China	India	Japan	Turkey	Russia
Pulp, paper and printing	-5,6	0,3	0,3	0,1	0,1	0,0	0,7
Chemicals	-39,6	3,3	5,9	4,4	1,1	0,5	2,6
Basic metals	-20,5	0,6	2,4	1,3	0,5	0,4	3,3
Non-ferrous metals	-11,2	0,3	-0,3	0,0	0,0	0,1	3,2
Non-Metallic Minerals	-18,5	0,7	2,2	0,9	0,2	0,3	1,3

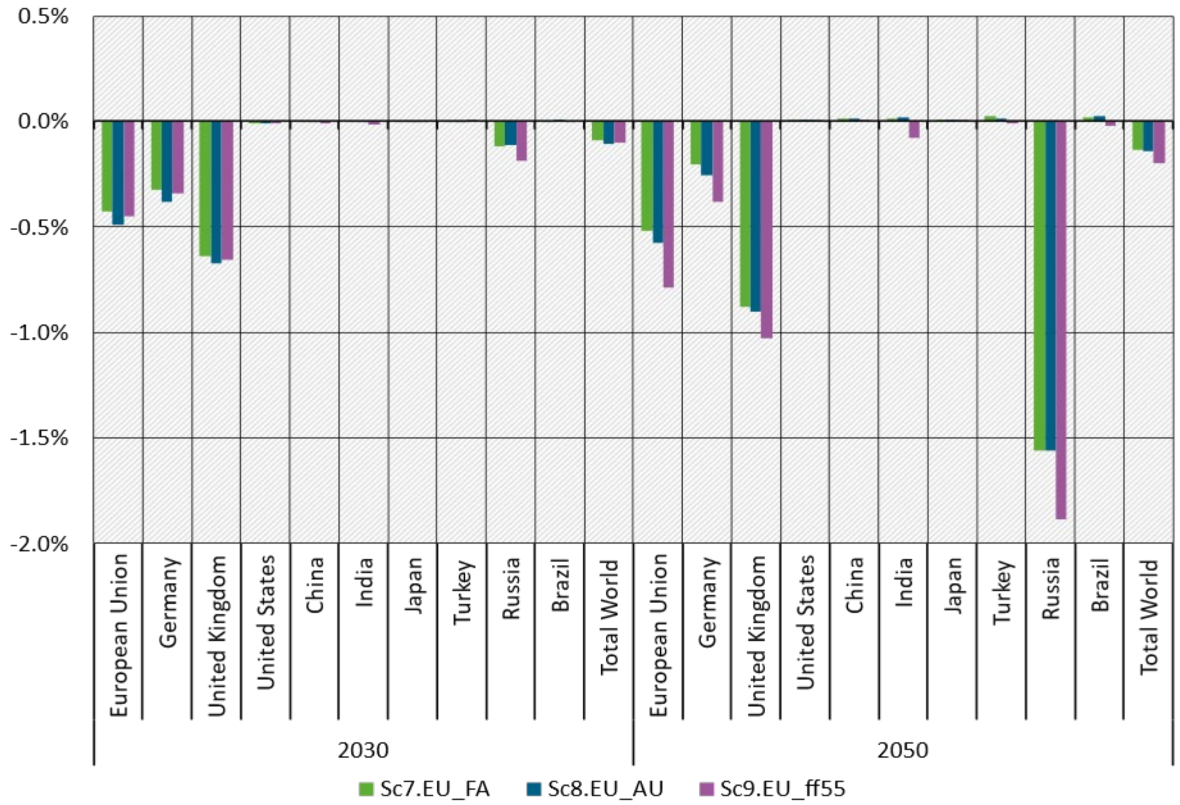
Source: GEM-E3

Table 11: Differences in CO_2 emissions between Sc8.EU_AU and Sc6.NDCs_Ref in 2030 in Mt CO_2

	EU28	United States	China	India	Japan	Turkey	Russia
Pulp, paper and printing	-3.3	0.0	0.0	0.0	0.0	0.0	0.1
Chemicals	-11.6	0.4	0.9	2.0	0.2	0.2	2.0
Basic metals	-14.8	0.1	1.5	2.8	0.1	0.2	5.5
Non-ferrous metals	-2.3	0.0	0.0	0.0	0.0	0.0	0.0
Non-Metallic Minerals	-16.9	0.1	0.8	1.3	0.1	0.2	1.3

Source: GEM-E3

Figure 15: Regional GDP impacts in scenarios 7, 8, 9 vs 6

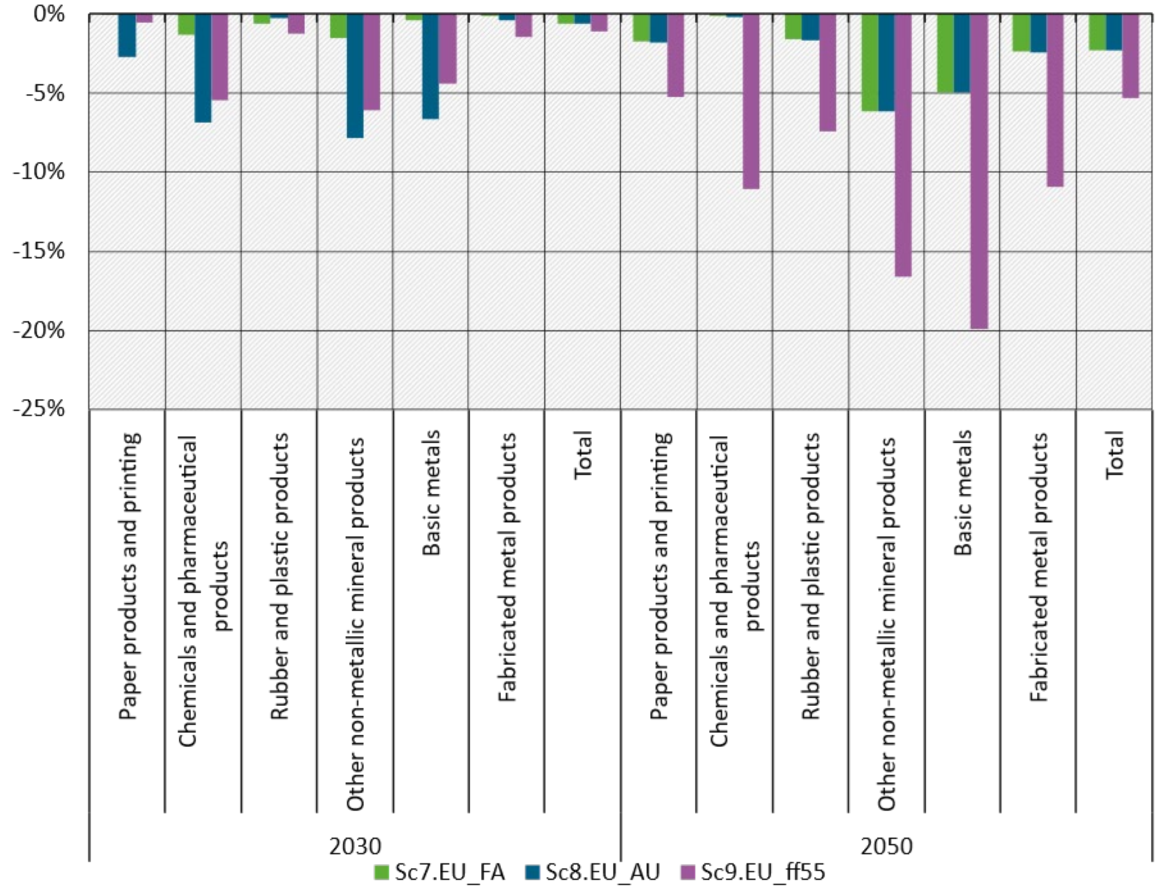


Source: GEM-E3

Figure 15 shows the changes in GDP in scenarios 7, 8, and 9 compared to scenario 6. Russia has significant reduction in GDP as the decarbonization of EU reduces the demand for its main exporting commodities (gas and oil). For example, in scenario 8 the domestic demand for crude oil in EU has declined almost 50% due to the decarbonization of the economy and a huge part had been covered from Russian exports. This channel has a significant impact in Russian economy as Russia has a significant share of crude oil production in its overall production. At the same time overall EU imports of Russian products are reduced as GDP growth decelerates.

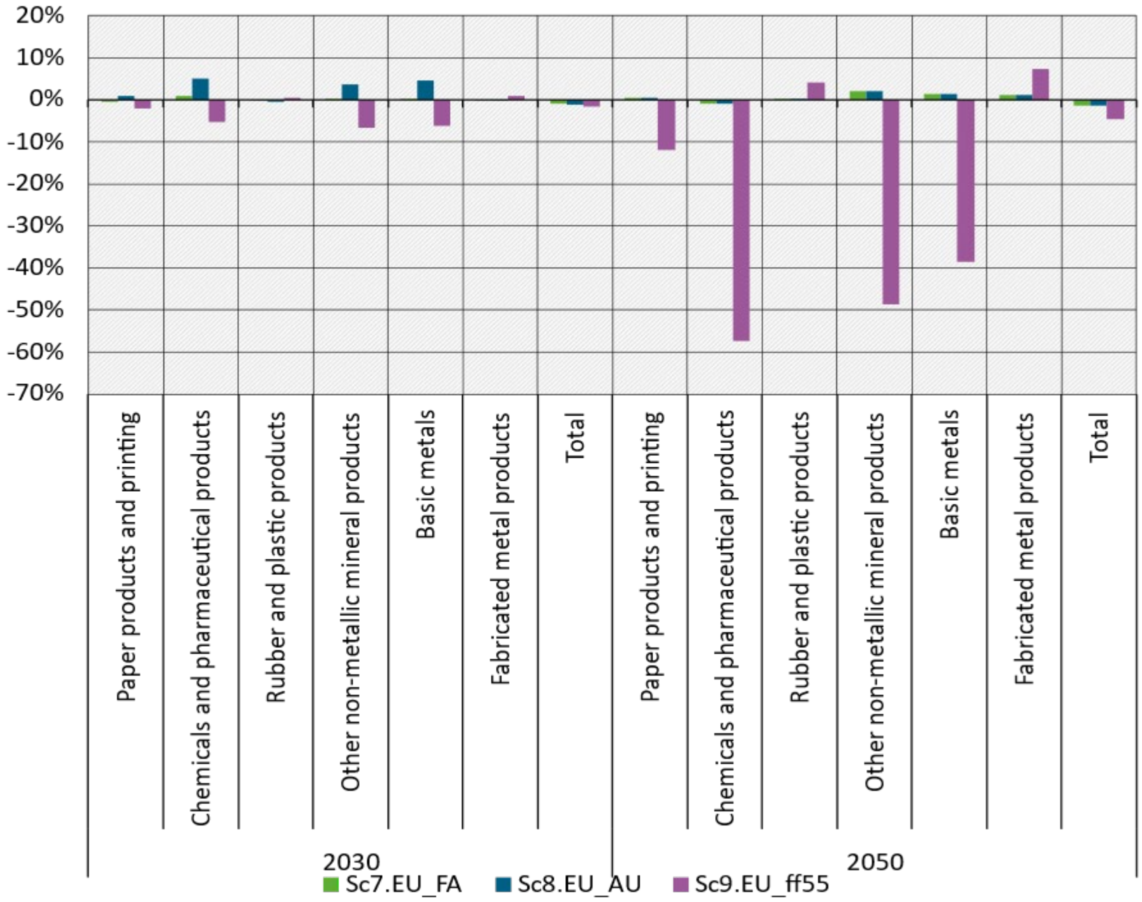
Figure 16 and Figure 17 show the sectoral EU exports and imports (% change of scenario 7,8,9 compared to 6) respectively. Increasing production costs driven by the rise of the carbon price in EU reduce the sectoral exports of EU. The implementation of CBAM reduces the imports of the corresponding sectors as imports becomes more expensive.

Figure 16: EU sectoral exports in scenarios 7, 8, 9 vs 6



Source: GEM-E3

Figure 17: EU sectoral imports in scenarios 7, 8, 9 vs 6



Source: GEM-E3

Table 12, Table 13, and Table 10 show the difference in exports for the three scenarios compared to Scenario 6 (countries in row are exporting to countries in column). Trade partners demand less EU products as these become more expensive from the rise of carbon price. EU28 decarbonization results to lower demand of fossil fuels especially from Russia thus and decline of exports from Russia to EU (EU energy bill related to fossil fuels decreases).

Table 12: Differences in total exports from country (row) to country (column) Sc7.EU_AU compared to Sc6.NDCs_Ref in 2030 (bn USD).

	EU28	United States	Japan	China	India	Turkey	Russia
EU28		-2.81	-0.78	-4.26	-1.08	-0.82	-3.30
United States	-2.68		-0.04	0.12	-0.06	0.00	-0.42
Japan	-0.43	0.04		0.13	-0.01	0.00	-0.16
China	0.18	0.05	-0.04		-0.24	-0.01	-1.24
India	-0.25	0.06	0.00	-0.09		-0.02	-0.21
Turkey	0.11	0.01	0.00	0.01	0.00		-0.14

	EU28	United States	Japan	China	India	Turkey	Russia
Russia	-14.05	0.96	0.63	1.67	0.43	0.45	

Source: GEM-E3

Table 13: Differences in total exports from country (row) to country (column) Sc8.EU_AU compared to Sc6.NDCs_Ref in 2030 (bn USD).

	EU28	United States	Japan	China	India	Turkey	Russia
EU28		-2.94	-0.64	-2.79	-1.49	-2.15	-3.13
United States	-4.55		-0.01	0.08	0.00	0.03	-0.47
Japan	-0.71	0.07		0.14	0.03	0.00	-0.17
China	-0.92	-0.27	-0.19		-0.01	0.06	-1.29
India	1.43	-0.13	-0.04	-0.38		0.09	-0.19
Turkey	-0.15	0.02	0.00	0.01	0.00		-0.16
Russia	-15.28	1.08	0.67	1.75	0.48	0.64	

Source: GEM-E3

Table 14: Differences in total exports from country (row) to country (column) Sc9.EU_AU compared to Sc6.NDCs_Ref in 2030 (bn USD).

	EU28	United States	Japan	China	India	Turkey	Russia
EU28		-5.77	-1.29	-7.03	-3.10	-2.16	-4.91
United States	-3.16		-0.04	-0.02	-0.25	0.02	-0.54
Japan	-0.34	0.08		0.12	-0.04	0.01	-0.19
China	-2.92	0.43	0.03		-0.46	0.13	-1.51
India	-10.00	1.15	0.25	1.08		0.17	-0.10
Turkey	-0.24	0.03	0.00	0.03	0.00		-0.18
Russia	-20.40	1.32	0.84	2.21	0.56	0.69	

Source: GEM-E3

Carbon leakage is calculated comparing Sc7 (CNEU_FA) and Sc6 (NDCs_Ref) GHG emissions. Over the 2020-2050 period leakage is found to be small (3.6%) and is mainly directed to Russia, India, Brazil, Japan and Turkey (given the competing imports and (in the case of Russia and Turkey) the close proximity – low transportation costs)[10]. Carbon leakage describes the increase

[10] In the report, Türkiye is referred to using the old name Turkey, in deviation from the official name since 2022, The reason is that the old name was used at the beginning of the project and was still stored in the data sets when the calculations were completed.

in CO_2 emissions in the rest of the world in relation to the decrease in emissions in the EU. Leakage is substantially higher in Scenario 8 with full auctioning – particularly in the Basic metals and the chemicals industry. Full auctioning increases the production costs of the ETS sectors, and the scale of the carbon leakage rates are affected by the trade openness and the carbon intensity of the sector. The leakage is fully eliminated in Sc9 (CNEU_ff55) where the carbon adjustment mechanism is applied. There are two main reasons that explains the negative leakage: 1) The tax on imports covers all imports and not the additional imports resulted from the increased GHG emission reduction targets. Also, imports are taxed with the full carbon price (e.g., 524 USD in 2050). While the carbon leakage is calculated compared to the reference where the carbon price is 301 USD in 2050. 2) The CBAM mechanism reduces the GDP in EU28 but also in other non-EU countries. This leads to a further reduction of imports.

Table 17 represents the carbon leakage rates in 2030. The carbon leakage rates are smaller in the short-term (2030) compared to the overall period (2020-2050) due to lower carbon prices in the early period, the difference of the carbon leakage rates between Sc7 and Sc8 in 2030 are higher due to the assumptions of share in free allowances. In Sc6 EU reduces its GHG emissions by 40% by 2030 and by 80% by 2050 compared with 1990 levels. This indicates that there is carbon leakage in Sc6 compared to a scenario in which the EU has zero carbon prices (Sc0). In Sc7 and Sc8 we increase the carbon price in EU compared to Sc6 which creates additional carbon leakage. In this case, the introduction of CBAM reduces the carbon leakage that occurs in Sc7, Sc8 compared to Sc6 and also the carbon leakage from Sc6 compared to Sc0.

Leakage rates of over (-)100% may come as a surprise, but they are possible in a global model because, unlike in a partial model with a fixed global production volume, e.g. for the steel industry, equilibrium or induced effects can lead to further effects in the total model, which in principle can lead to higher positive or negative effects globally on production and related emissions than in the EU itself. In addition, there is the reason for negative leakage rates, which arises from the specific scenario design and is explained in more detail in the following text box.

Textbox: Illustrative example for the steel sector

To illustrate the above point an example of the sector of steel is presented in Table 15. In Sc0 of the example the EU has a carbon price of zero, and the price of domestic steel is equivalent of the price of steel that EU imports. In the case where the GHG mitigation effort in EU increases (Sc6) will result in the price of domestic steel increasing due to the higher carbon price compared to Sc0 and this will result to a carbon leakage of 20 t.CO_2 equivalent. The carbon leakage will be even higher (40 t.CO_2 equivalent) when we further increase the GHG emissions reduction in the EU (Sc7 Mitigation Scenario). In Sc9 (Mitigation with CBAM) we level the price of domestic steel with the price of EU import by introducing a tax on EU imports to the same scale as the carbon price that EU steel industry pay domestically. CBAM will eliminate a part of the carbon leakage (30 t.CO_2 out of 40 t.CO_2), but not fully as international leakage exists due to no compensation in EU exports. However, if we compare the Sc9 to Sc6 the carbon leakage would be negative.

Table 15: Indicative example of carbon leakage for the steel sector

	Price of steel in EU	Price of steel in EU imports	Carbon Leakage
Sc0, (not simulated)	600€	600€	0 t.CO_2
Sc.6, Reference	650€	600€	20 t.CO_2

	Price of steel in EU	Price of steel in EU imports	Carbon Leakage
Sc7, Mitigation Scenario	700€	600€	40 t.CO2
Sc9, Mitigation with CBAM	700€	700€	10 t.CO_2

*The numbers in the table are indicative

Table 16: Carbon Leakage in scenarios 7, 8, 9 vs 6 (Cumulative 2020-2050)

	(Sc7 vs Sc6)	(Sc8 vs Sc6)	(Sc9 vs Sc6)
ETS Sectors	11.6%	24.4%	-36.2%
Pulp, Paper and printing	11.2%	14.2%	-15.2%
Chemicals	34.6%	75.4%	-98.2%
Basic metals	72.0%	157.7%	-525.5%
Non-ferrous metals	51.2%	66.2%	52.5%
Non-Metallic Minerals	18.9%	47.8%	-103.4%
Total (all sectors)	3.6%	8.5%	-14.3%

Source: GEM-E3

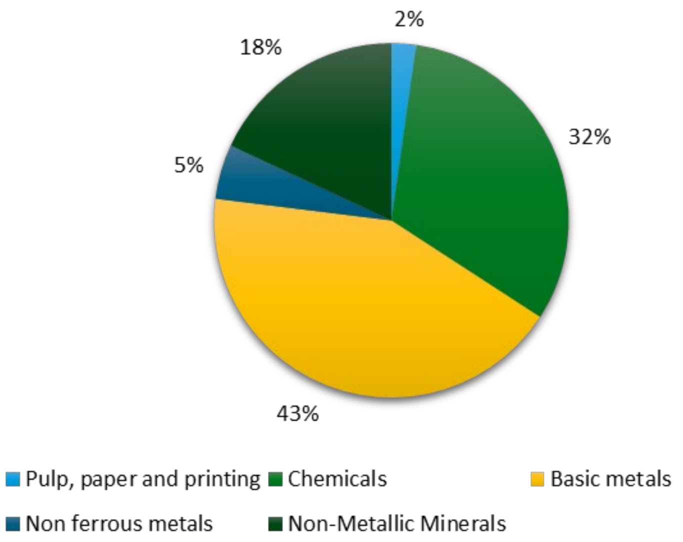
Table 17: Carbon Leakage in scenarios 7, 8, 9 vs 6 in 2030

	(Sc7 vs Sc6)	(Sc8 vs Sc6)	(Sc9 vs Sc6)
ETS Sectors	2.2%	16.2%	-8.0%
Pulp, Paper and printing	0.9%	9.2%	-2.2%
Chemicals	37.2%	88.7%	6.6%
Basic metals	10.5%	95.8%	-124.8%
Non-ferrous metals	4.5%	33.3%	11.5%
Non-Metallic Minerals	1.8%	33.9%	-23.7%
Total (all sectors)	1.0%	7.5%	-3.8%

Source: GEM-E3

The model does not account for geopolitical risks when firms relocate. Chemicals and Metals are the key sectors exposed to leakage as presented in Figure 18.

Figure 18: Distribution of leakage in CBAM sectors



Source: GEM-E3

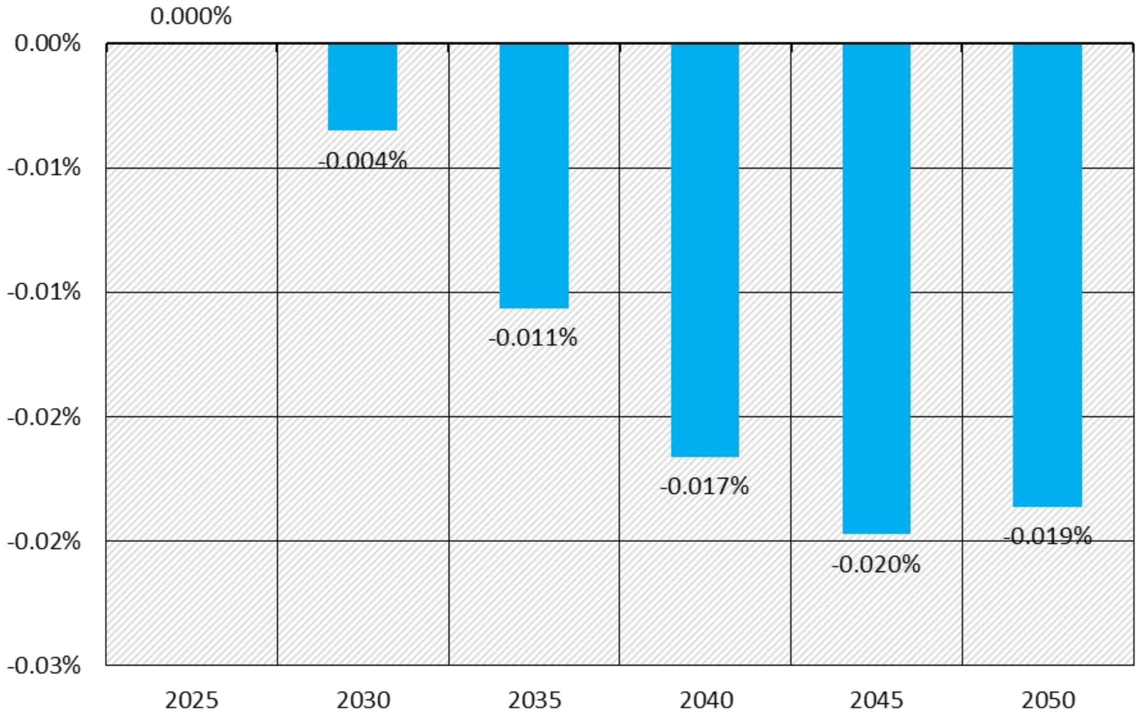
3.3 Other scenarios and sensitivities

3.3.1 CBAM extended to indirect emissions

As the carbon adjustment mechanism restores a level playing field with imported products with regard to the carbon costs of production, it reduces imports and enhances domestic production of the products that it covers. As it is shown above in Figure 13 in 2030 and 2050 the production of Chemicals, Basic metals and Non-metallic minerals benefit from the implementation of the measure. To further evaluate the sensitivity of the model results on the CBAM implementation two alternatives were considered: Scenario 9a: where CBAM is imposed on direct and indirect emissions (compensation for indirect emissions is phased out until 2035), Scenario 9b: CBAM applies only to direct emissions.

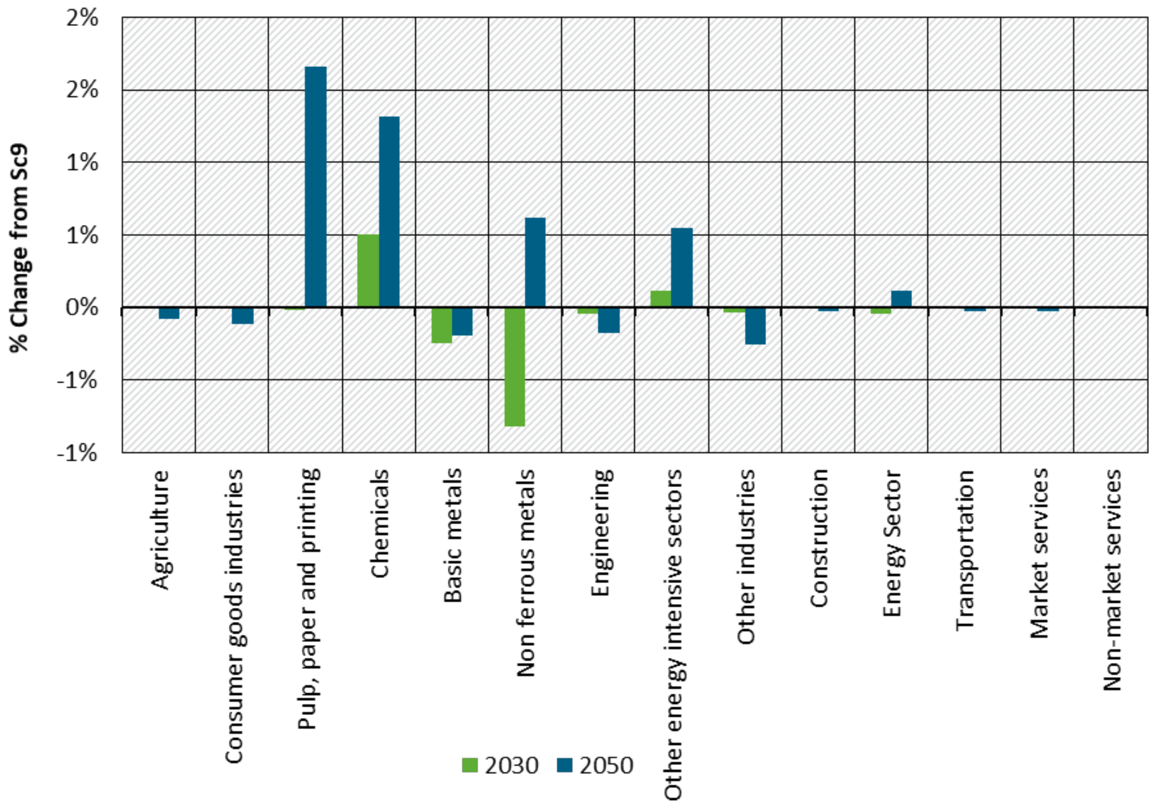
The impact on GDP (Figure 19) is small but negative as the positive effects on the CBAM sectors are counterbalanced by the negative effects on the downstream sectors. This notion is supported by the sectoral production results (Figure 20).

Figure 19: EU GDP impact by including indirect GHG emissions in CBAM (Sc9A vs Sc9)



Source: GEM-E3

Figure 20: Impact on EU production when considering indirect GHG emissions in the CBAM mechanism (Sc9A vs Sc9)

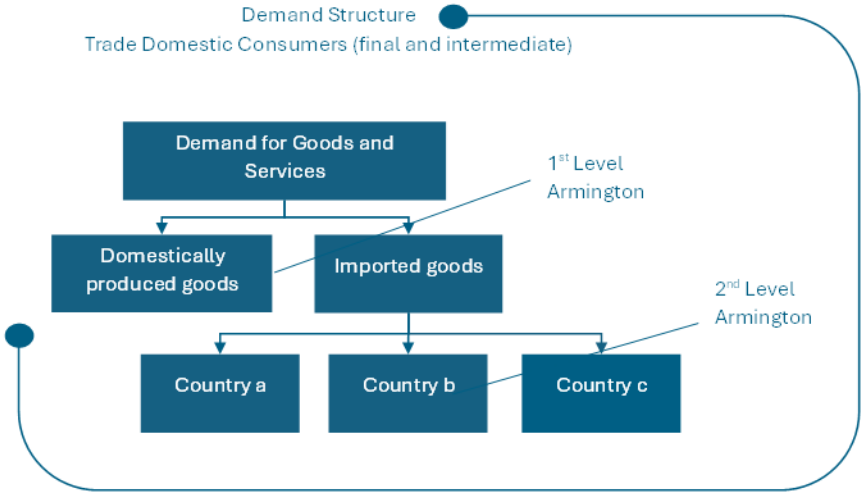


Source: GEM-E3

3.3.2 (Halved) trade elasticities

In GEM-E3 the total demand for goods and services is satisfied through a mix of domestic and imported products, following the Armington specification. In this specification, branches and sectors use a composite commodity which combines domestically produced and imported goods, which are considered as imperfect substitutes. Each country buys and imports at the prices set by the supplying countries following their export supply behaviour. The buyer of the composite good (domestic) seeks to minimize his total cost and decides the mix of imported and domestic products so that the marginal rate of substitution equals the ratio of domestic to imported product prices.

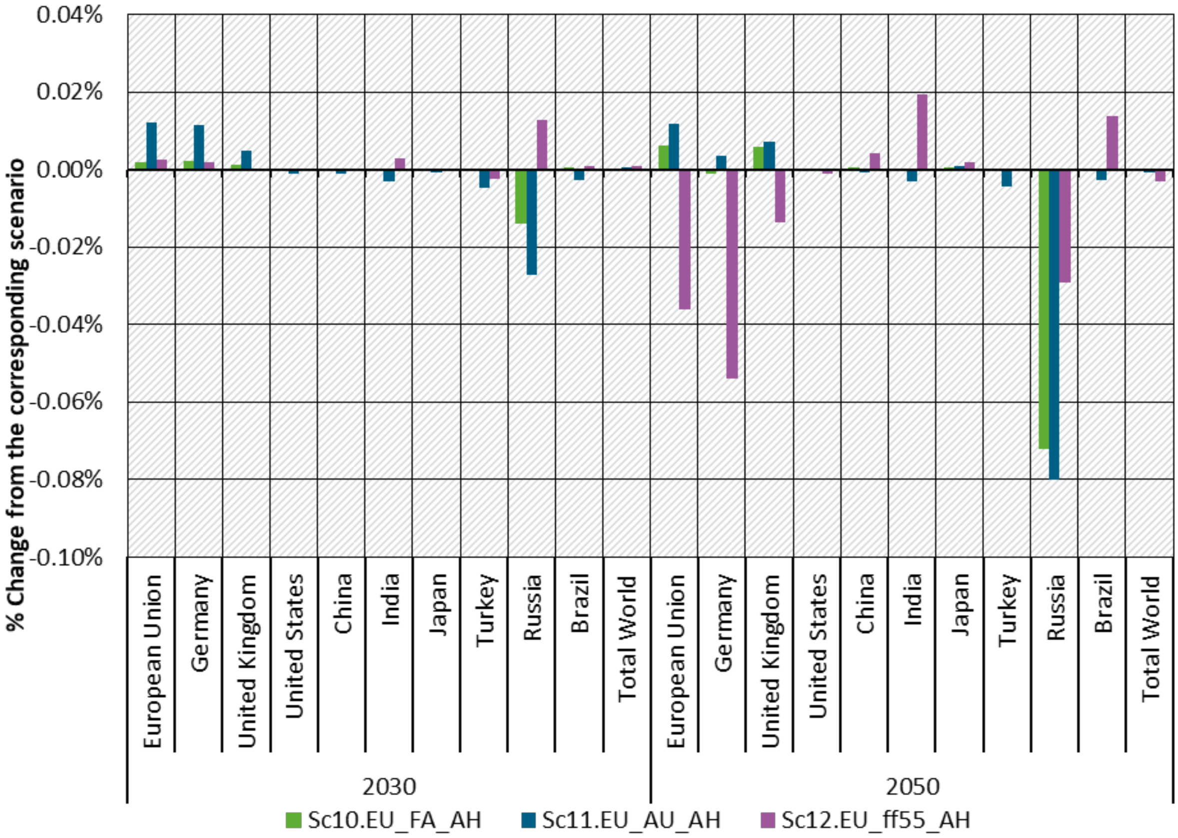
Figure 21: Total demand and trade structure in GEM-E3



Source: E3-Modelling

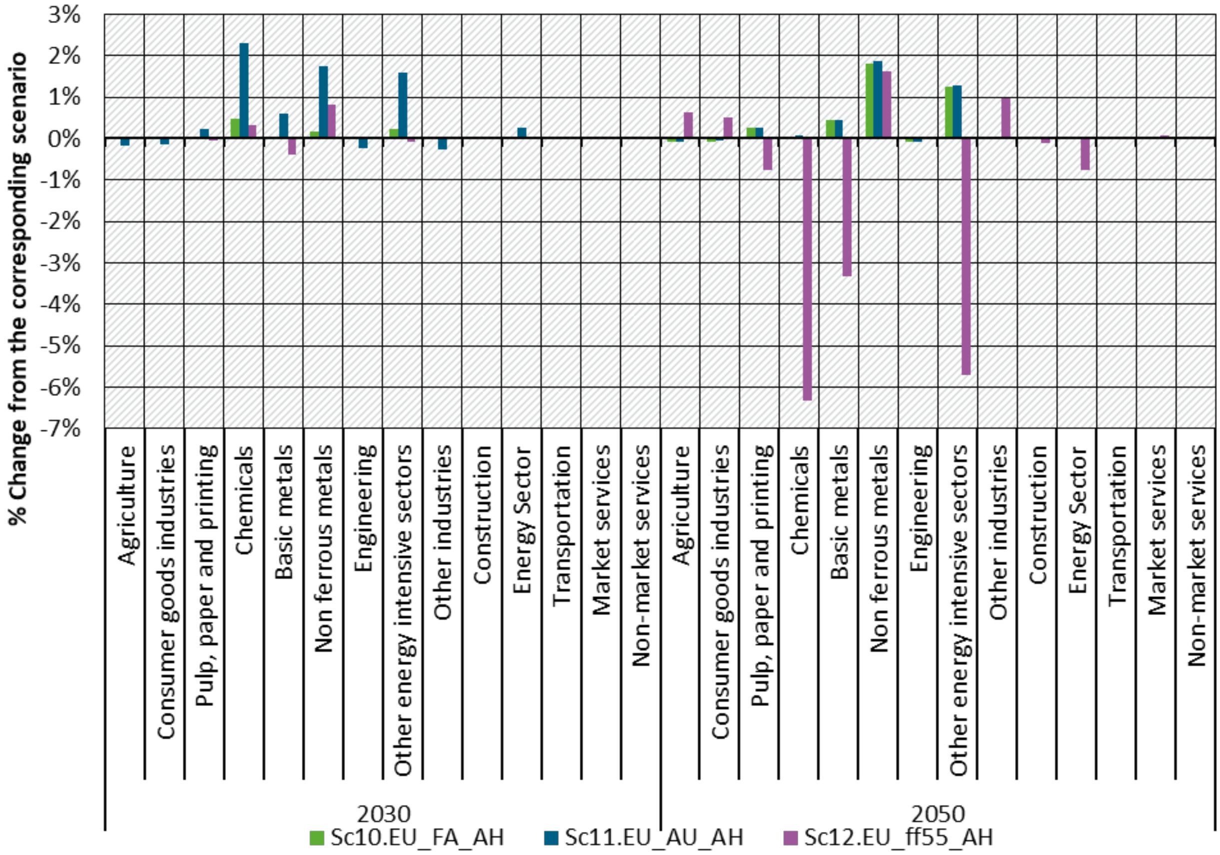
The scale of the impact on sectors that are driven by changes in their competitiveness (relative production costs) greatly depends on the Armington elasticity (the degree to which the products are substitutes). Figure 22 and Figure 23 represent the impact on GDP and production by country when the Armington elasticities are reduced by half. Reduction of the elasticities implies that consumers consider that domestically produced goods are harder to substitute with imported (e.g. better quality, design etc.). As a result, the impact on the EU GDP is positive since changes in production costs are not sufficient to shift demand to imports – sustaining this way the domestic demand. The result however is not sizeable (less than 0.01%) indicating that the results of the main scenario are robust.

Figure 22: Regional GDP impact of halved Armington elasticities



Source: GEM-E3

Figure 23: EU sectoral production impact of halved Armington elasticities



Source: GEM-E3

The reduction of trade elasticities reduces the carbon leakage almost by half as industries and households do not easily change suppliers of products and services.

Table 18: Carbon leakage rates change from halved Armington elasticities

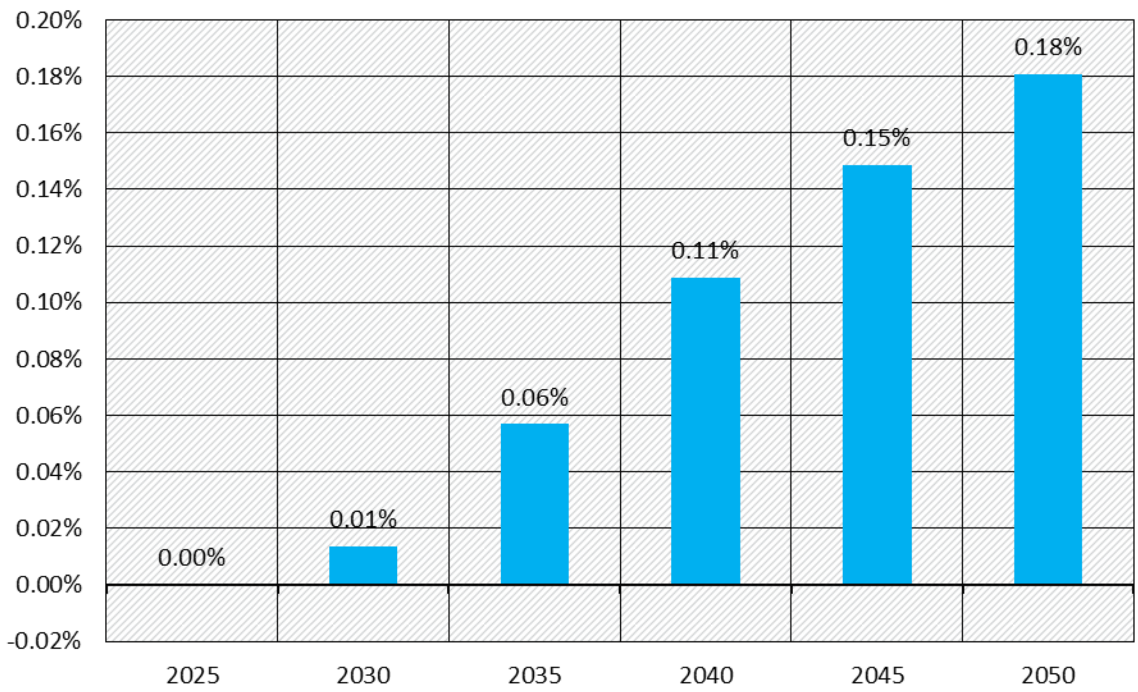
	(Sc7 vs. Sc6)	(Sc10 vs. Sc6)
Overall	3.6%	2.1%
ETS Sectors	11.6%	7.5%
Pulp, Paper and printing	11.2%	7.9%
Chemicals	34.6%	23.7%
Basic metals	72.0%	40.6%
Non ferrous metals	51.2%	37.7%
Non-Metallic Minerals	18.9%	7.6%

Source: GEM-E3

3.3.3 Recycling of revenues into programmes for energy efficiency investments

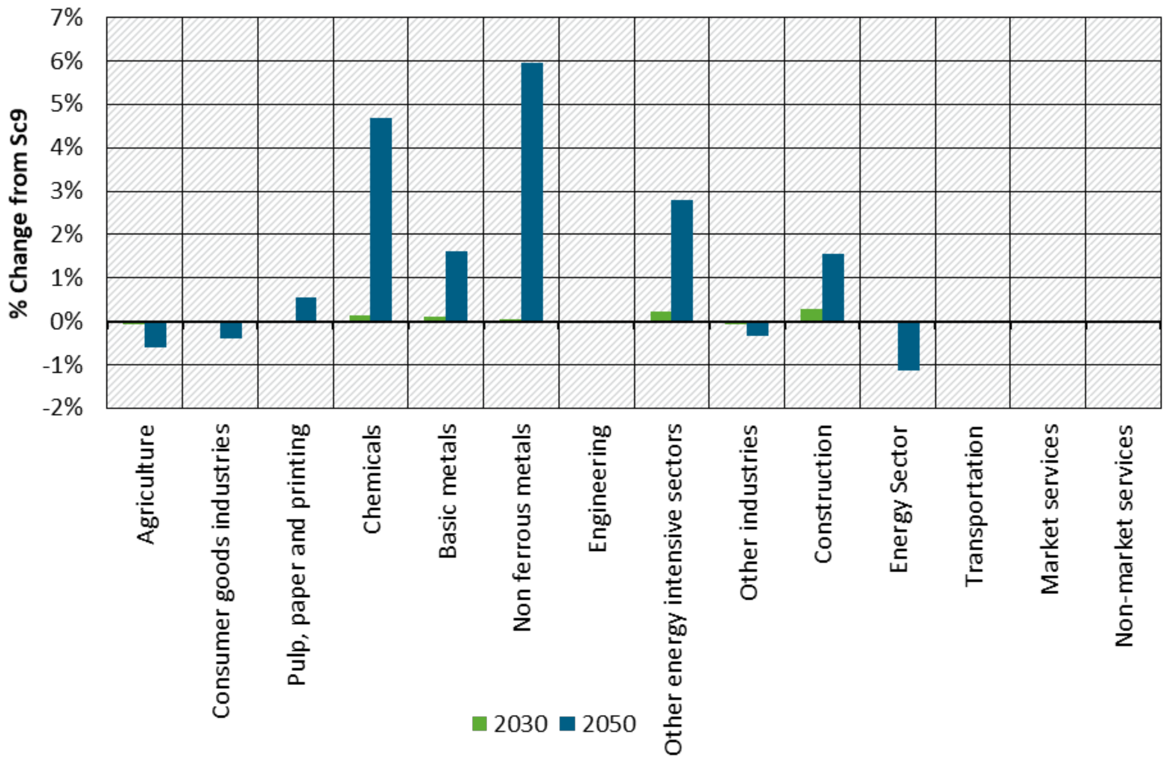
In this section we examine the implications of using the additional public budget revenues in Sc9.EU_ff55 (compared to Sc6) not for the general public budget (as in Sc9.EU_ff55), but instead specifically to promote the adoption of energy efficient technologies in the industries covered by the CBAM. Allocating the revenues to the CBAM sectors so that they adopt new production processes that increase energy productivity has a positive effect on domestic GDP. This is due to the fact that in scenarios 6 to 9 the additional revenues were used to improve the public budget of the EU and its Member States (with small effect on EU economy). In addition, the low-cost adoption of energy efficient technologies by the CBAM industries lead to a reduction in energy cost per unit of output. Energy efficiency has a lasting effect which explains the larger effect in the latest years and explains the huge increase in production in 2050 in the associated sectors. The investment in energy efficient equipment and processes also creates a short-term positive effect on the economy as new products and services have to be produced – demand stimulus. As expected, the production in the energy sector is decreasing. Table 13 presents the revenues recycled and the reduction in energy costs for the CBAM sectors.

Figure 24: GDP impact in Sc9.REC compared to Sc9.EU_ff55



Source: GEM-E3

Figure 25: Impact on EU sectoral production with recycling of the additional public budget revenues (Sc9.REC vs Sc9.EU_ff55)



Source: GEM-E3

Table 19: Amount (bn USD) of recycled revenues and energy cost reduction (Sc9.REC vs Sc9.EU_ff55)

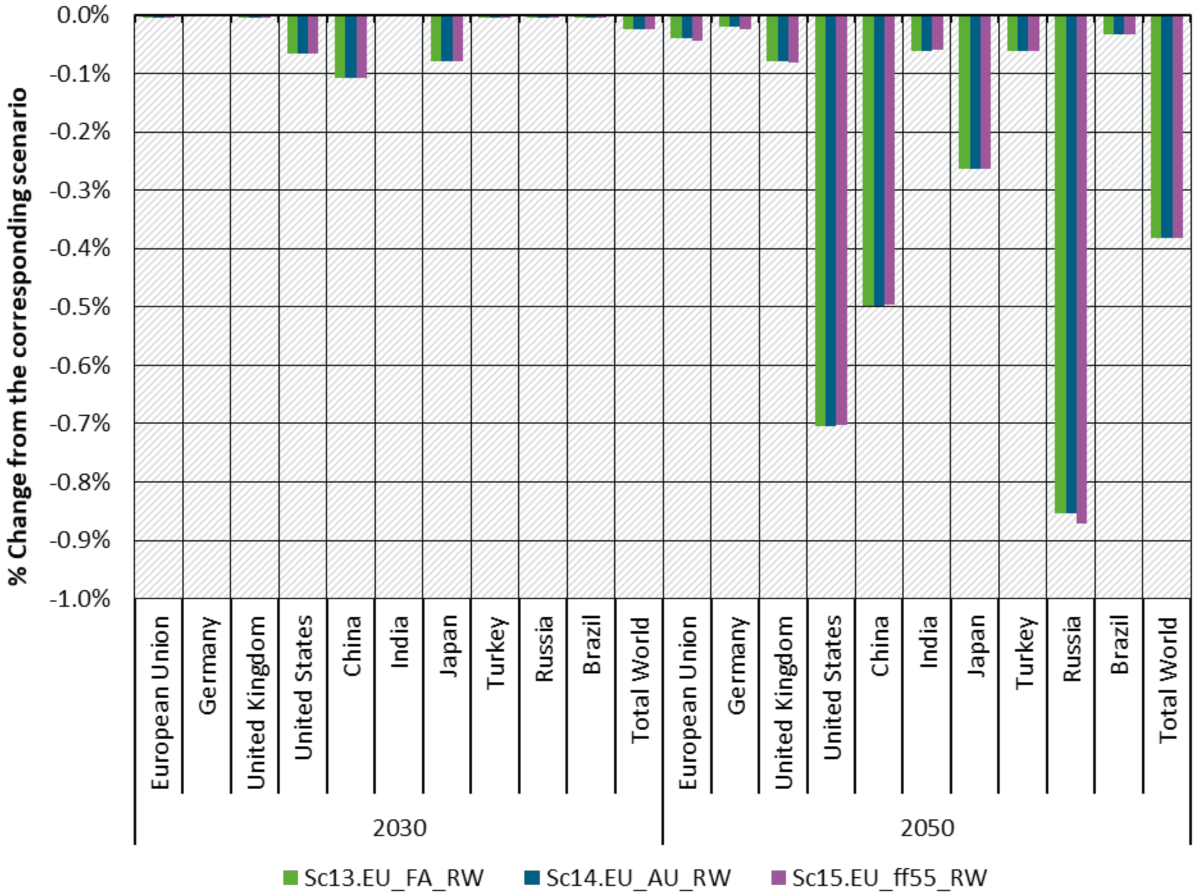
	2025	2030	2035	2040	2045	2050
Revenues recycled	0.00	11.67	35.53	54.11	68.12	83.47
Energy Cost Difference	0.00	-0.67	-3.94	-9.80	-15.45	-20.07

Source: GEM-E3

3.3.4 Non-EU Ambition in GHG emission reduction

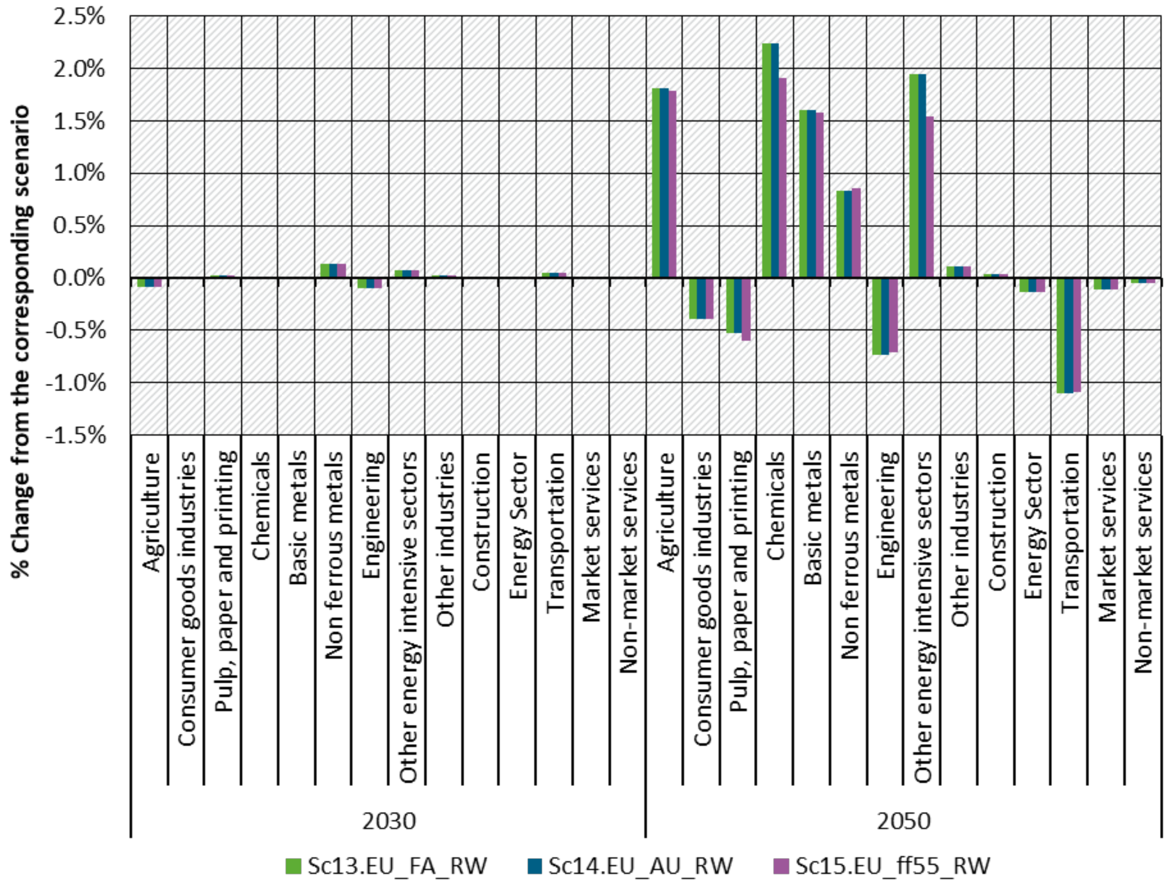
Increasing the GHG mitigation targets has a negative impact to the countries examined. Countries that are fossil fuel energy producers present the highest adjustment costs as they have to restructure their economic and energy systems towards low GHG emissions. The positive effect that the international deployment of clean energy technologies has into the economies supplying the equipment is counterbalanced by the crowding out effects of the investments and the increase in production costs that reduce households' disposable income and demand. However, it should be noted that the net negative impact on GDP is small as it decelerates the growth of Gross World Product only marginally (0.01%).

Figure 26: Regional GDP impact of higher non-EU ambition in scenarios 13, 14, 15



Source: GEM-E3

Figure 27: EU sectoral production impact of higher non-EU ambition in scenarios 13, 14, 15



Source: GEM-E3

4 GINFORS-E – Scenario results

4.1 Introduction

In addition to the reference scenario used to harmonise the two models, which is described in the technical project report, other scenarios are described and compared below. A set of scenarios looks at the EU's climate policy to date and that of the other countries based on the reduction targets under the NDCs in 2020. The reference scenario for section 4.2 is Scenario 6 (**NDCs_Ref**). The other scenarios 7-9 assume a 95% GHG emission reduction in the EU by 2050 and a reduction of 55% by 2030 according to the Green Deal. All other countries remain at their insufficient ambition levels relative to the Paris agreement from 2020. The three scenarios differ in the allocation rule in the EU ETS: Free allocation in scenario 7 (**EU_FA**), full auctioning in scenario 8 (**EU_AU)**, and finally scenario 9 (**EU_ff55**), that is oriented at the fitfor55 package with a CBAM mechanism (see section 2 for details). In scenarios 7 and 9, there is compensation for indirect emissions for basic metals and paper, which will be phased out between 2030 and 2040, while scenario 8 does not assume this compensation.

The scenario comparison shows the macroeconomic and sectoral plus leakage effects plus changes in energy use and the associated emissions, of ambitious unilateral climate policy in the EU compared to the reference. Different effects occur in GINFORS-E, which are shown in a simplified form in Figure 28: Higher CO_2 prices lead to higher prices of and reduced demand for fossil fuels. As a result, fossil energy imports also decline, which puts a burden on the fuel extracting and exporting countries. On the other hand, investments in low and zero carbon technologies increase, which in turn can be produced domestically or imported. Other investments will be reduced by assumption. No crowding out is assumed in a sense, that financial conditions will deteriorate due to higher low or zero carbon investment, as is the case in GEM-E3.

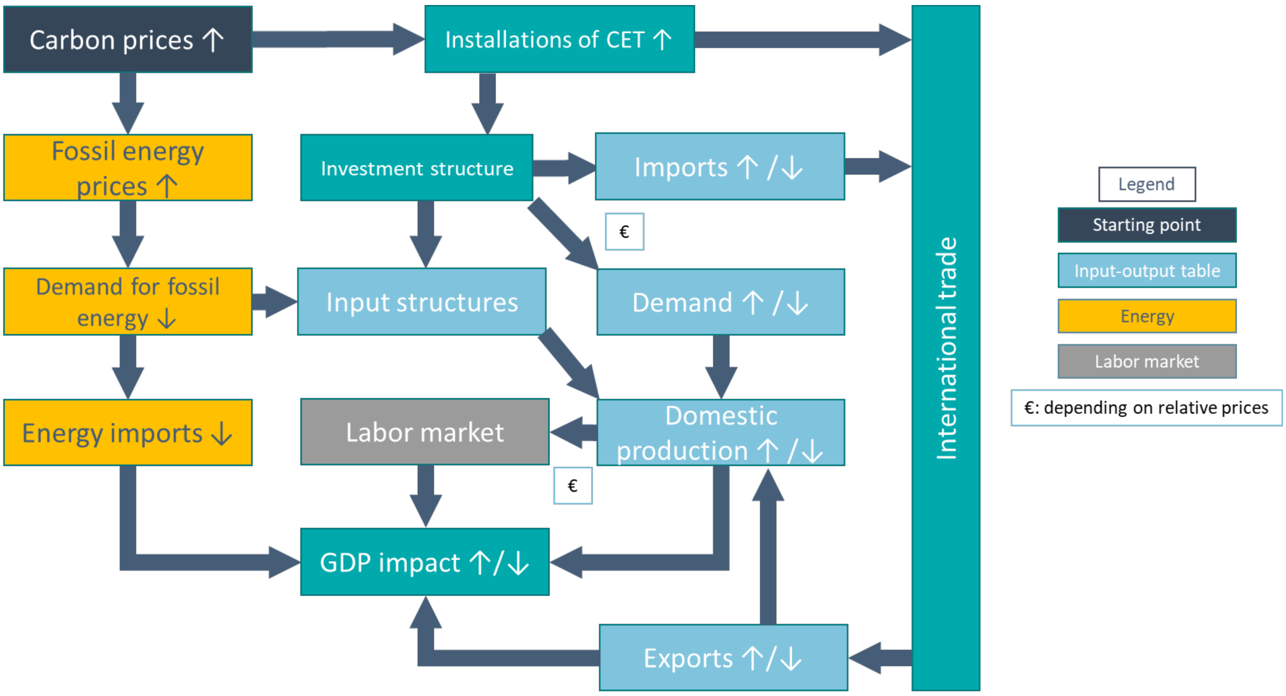
Relative prices play an important role for substitution between domestic production and imports, substitution between intermediate inputs, employment, and the choice between exports from different countries. Price changes of new energy goods and established energy intensive goods influence international trade, which also has an impact on domestic production and GDP. Imports of one country are always exports of another in the global model, so that shifts in international trade patterns can occur. The effects on national GDP are initially open and depend on a set of model specifications and interrelations, finally, on the relative impact of policies on a country compared to important competitors and trading partners.

At the same time, changes in the production structure in the energy supply due to the expansion of renewable energies, in the automotive industry due to the shift towards electromobility, and in carbon-intensive industries such as basic metals and chemicals are considered, which result from higher CO_2 prices and shifts in the energy carrier structure. In this context, it should be noted that it is assumed that the investments and the resulting changes in the respective CO_2 price are profitable from the investor's point of view, additional capital is available at the same costs as for other investment and that no additional government support is required. The result is that these industries can produce with somewhat less input per output unit, i.e., more efficiently than in the reference. Together with structural change away from carbon-intensive industries, this results in a slightly positive macroeconomic effect. Other countries also benefit from the climate mitigation measures in the EU. On the one hand, because they achieve slight competitive advantages in the case of carbon intensive goods. And on the other hand, because their costs for the expansion of renewable energies are somewhat lower, as global learning curves for wind and PV are modelled. In the end, the global economy is not a zero-sum game. Higher GDP in one country can also have a positive effect on other countries.

The use of the revenues can also play a role for the macroeconomic effects in GINFORS-E and other macroeconomic models. In this context, it is important, whether the necessary investments for the conversion to a low or zero carbon development are considered as additional or whether a restriction to empirically estimated ratios is assumed, which ultimately amounts to a crowding-out of other investments. It should be noted here that crowding-out influences the real economy, i.e., higher investments in low-carbon technologies lead to lower investments elsewhere, so that the macroeconomic investment correlations remain unchanged. A deterioration of financing conditions (financial crowding-out) as in GEM-E3 is not depicted.

The assumption of a complete crowding-out would lead to slightly more negative macroeconomic effects of climate mitigation policy, while the assumption of additional investments leads to slightly positive effects in the short term (e.g., Burret et al. 2020 as well as various modelling studies according to the review of Becker, Lutz 2021). Without crowding-out additional investments have a positive effect on the economy in the short term, while they lead to higher depreciation, i.e., capital costs, in the long term. The long-term effect of additional investments or changes in the investment structure is quite open.

Figure 28: GINFORS-E modelling – impacts of carbon price increase



Source: GWS, own illustration.

The carbon price is only a proxy for a wide range of policies, some of which could have quite different effects. For example, the promotion of electric cars massively favours the early and possibly additional purchase of electric vehicles compared to a pure carbon price, because the purchase premium of many thousands of Euros for example in Germany and tax breaks make electric cars more attractive than would be the case with a carbon price of currently €30/t CO_2 in non-ETS in Germany. In the model, it is therefore assumed that electric cars enter the market already at quite low carbon prices. The same applies to subsidy programmes for building insulation or the promotion of renewables through the EEG levy. A more explicit modelling of these measures in GINFORS-E would tend to lead to higher investments and thus to more positive GDP effects at least until 2030, if no crowding-out was assumed.

It should be noted that the revenues from the CO_2 price are accounted as revenues in the public budgets. This is the most economically unfavourable form of revenue recycling in the model. If, for example, part of the funds was used as additional investments in the low carbon transition, GDP effects would be more positive.

Table 20: Changes in GDP and CO_2 emissions from Sc6. NDCs_Ref

	GDP (2050)		GHG (2020-2050)		Cumulative CO_2 emissions (2020-2050)
Scenario	World	EU	World	EU	World
Sc7.EU_FA	0.16%	0.55%	-1.98%	-32.31%	1,048,858
Sc8.EU_AU	0.13%	0.42%	-2.00%	-32.77%	1,048,648
Sc9.EU_ff55	0.18%	0.54%	-2.00%	-32.46%	1,048,583

Source: GINFORS-E.

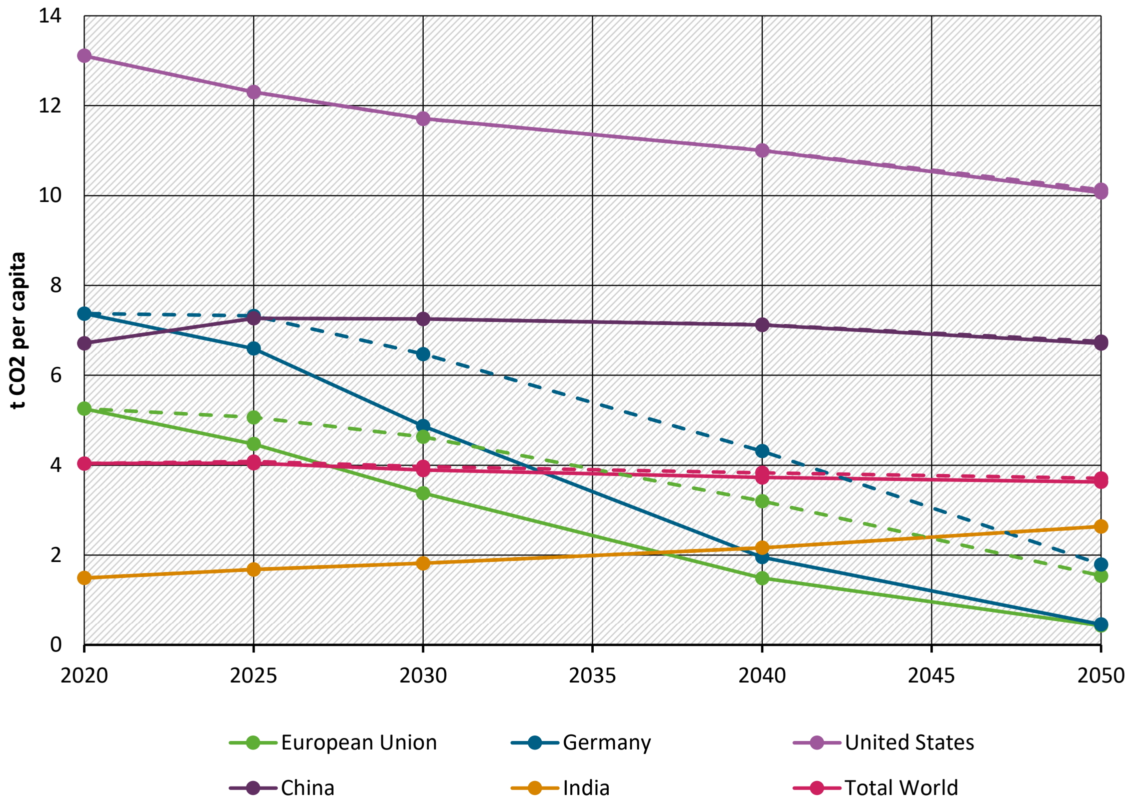
In scenarios 7 to 9, global GDP is not affected, and global emissions are only reduced by about 2% between 2020 and 2050 (Table 20). EU emissions will be about 32%-33% lower in the three scenarios with unilateral action. GDP impacts for EU are positive between 0.37% and 0.50% in 2050. The last column of the table shows global energy related CO_2 emissions in the period 2020 to 2050 in the scenarios, which are almost identical in the 3 scenarios.

4.2 Scenario Comparison: Unilateral EU action (7, 8, 9 vs 6)

In **scenario 6** the old NDC targets for GHG emissions from 2020 are reached in 2030 (**NDCs_Ref**). This means a GHG emission reduction in the EU of 40% until 2030 compared to 1990 and of 80% until 2050. Scenario 7 to 9 differ from Scenario 6 in that the EU tightens its reduction targets according to the Green Deal. The EU meets the new NDC targets (55% in 2030/95% in 2050). All other countries do not pursue more advanced mitigation targets compared to scenario 6. **In Scenario 7 (EU_FA)**, the sector split in EU ends after 2030 and a uniform CO_2 price in the ETS and non-ETS sectors is established. Allocation in the EU and the rest of the world is the same as in scenario 6. In **scenario 8 (EU-AU)**, emission allowances are now auctioned in full and in all sectors in the EU. Finally, **scenario 9 (EU_f55)** is strongly oriented towards the expected EU policy under the fitfor55 package. In the EU, the sector allocation between ETS and non-ETS remains until 2030. From 2026, a carbon border adjustment mechanism (CBAM) is gradually introduced until 2034. Free allocation is gradually reduced after 2030 and phased-out in 2050. In scenarios 7 and 9, there is compensation for indirect emissions for basic metals and paper, which will be phased out between 2030 and 2040, while scenario 8 does not assume this compensation.

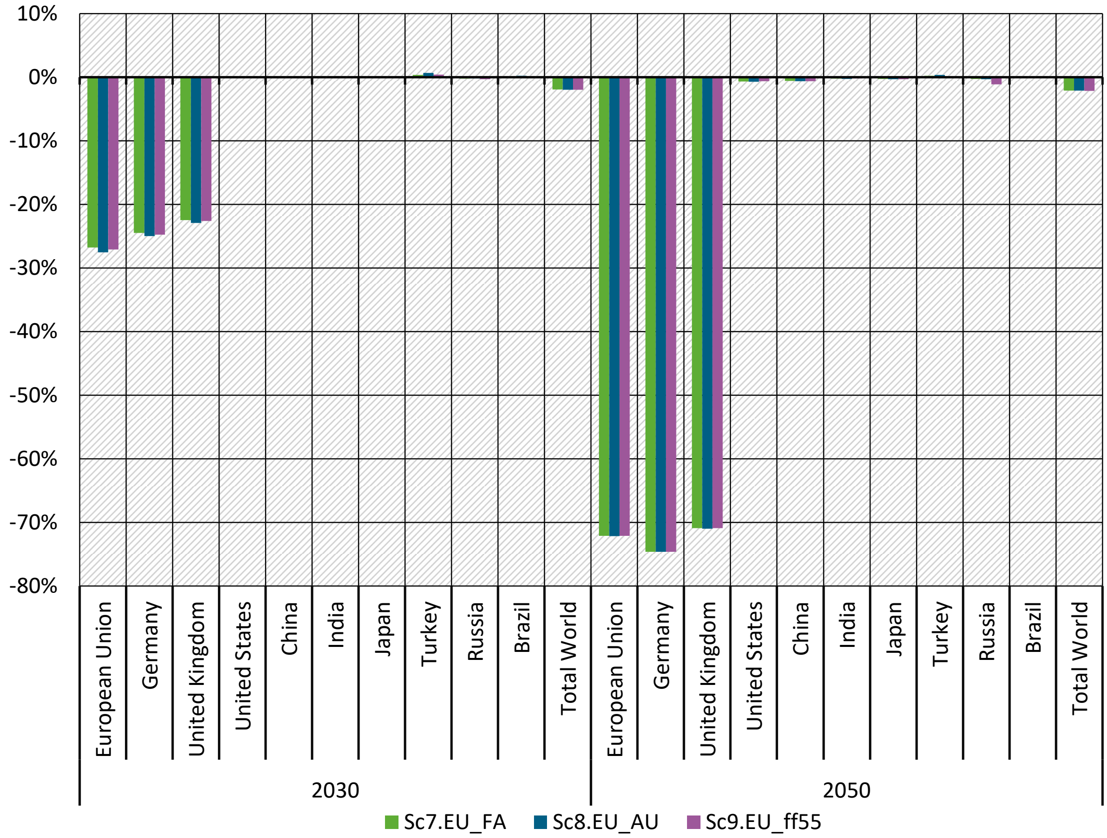
Because the emission pathways between scenarios 7, 8 and 9 hardly differ, some figures are shown below only for scenario 9 in comparison to scenario 6. If only the previous NDCs from 2020 are followed (dotted line), per capita emissions in the USA, the EU and especially in Germany will decrease until 2050. Globally, per capita emissions will decrease from around 4 t CO_2 today to 3.6 t by 2050 (Figure 29). The EU and Germany would reach values below 1 t CO_2 per capita in the other scenarios. In the US, per capita emissions will reach 10.1 t in 2050, per capita emissions in China will almost stagnate around 7 t and reach 6.7 t in 2050. In India, and other developing countries, per capita emissions will increase partly due to strong GDP growth. Only the EU plus the UK must reduce their emissions in scenarios 7 to 9 compared to scenario 6 (Figure 30). 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 is intended to show the impacts for 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 29: CO_2 per capita - Sc9.EU_ff55 (continuous) compared to Sc6.NDCs_Ref (dotted line) [t CO_2 /persons]



Source: GINFORS-E.

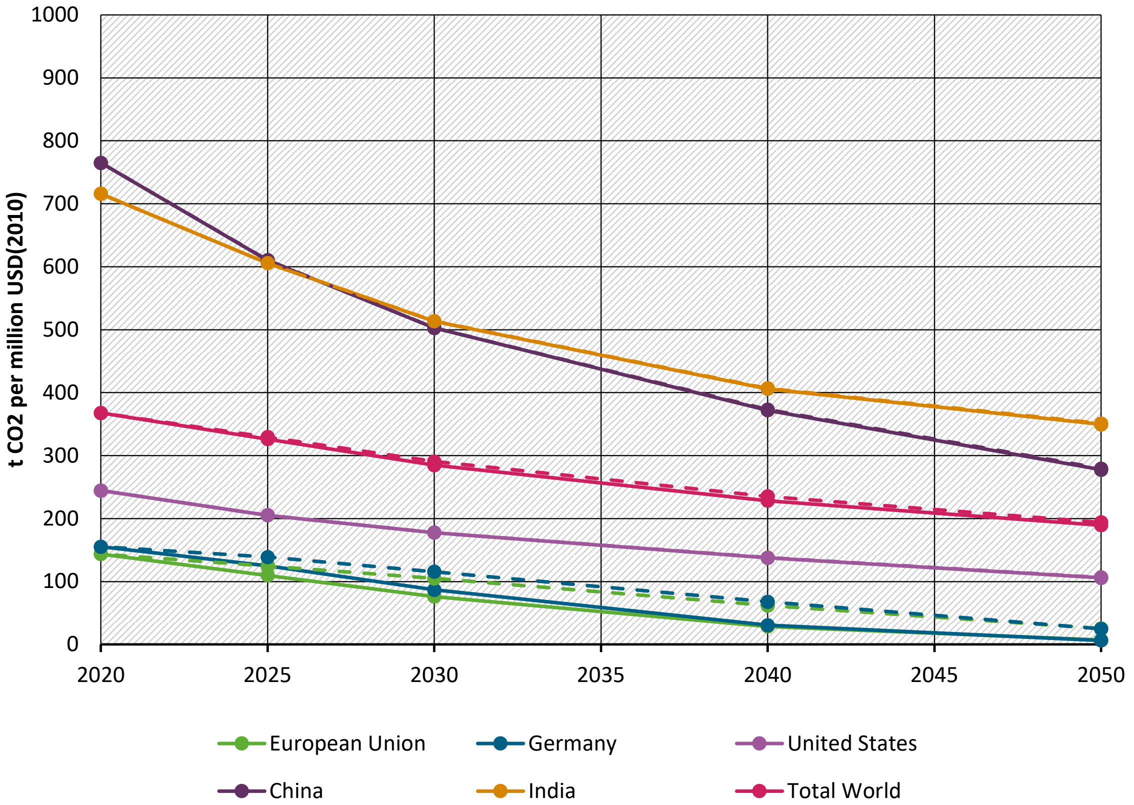
Figure 30: Deviations in CO_2 emissions per capita



Source: GINFORS-E.

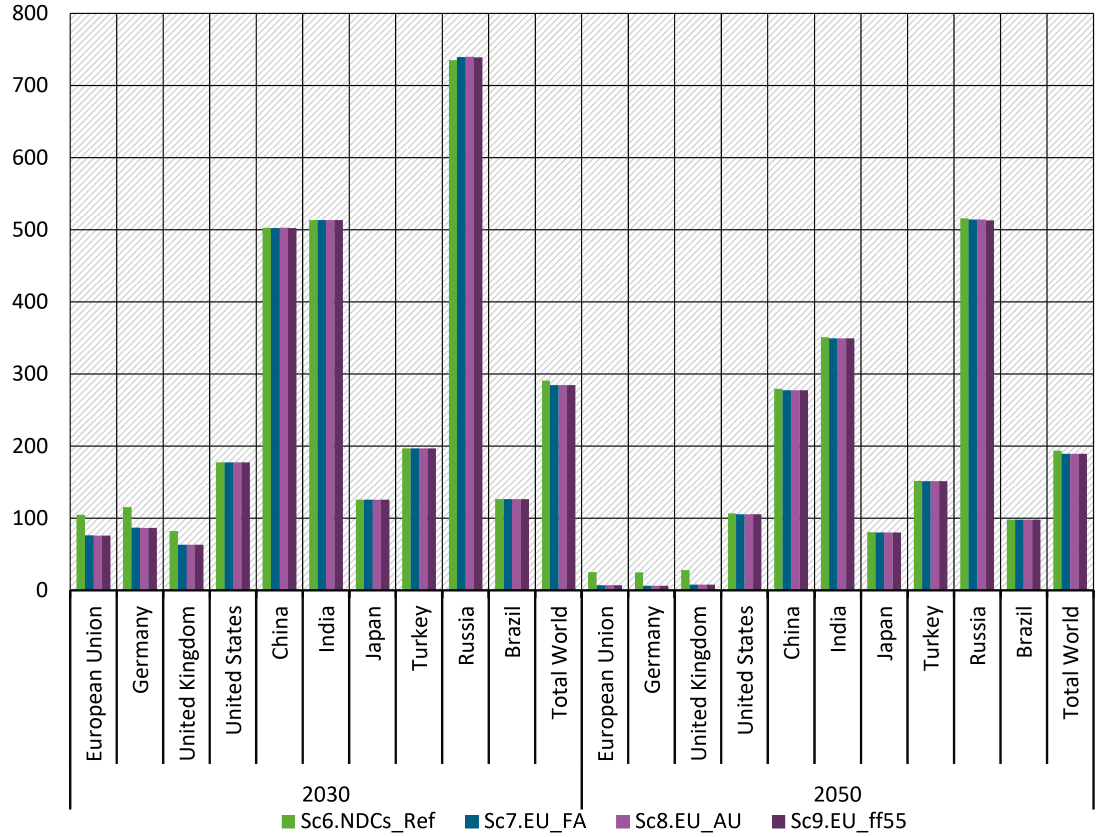
Figure 31 shows that even in scenario 6, the emission intensity of economic activity will decrease significantly in all countries and globally. However, the differences between individual countries remain high. China and India will still be emission-intensive economies in 2050, if they do not take any further climate protection measures (Figure 32).

Figure 31: CO_2 per unit of GDP - Sc9.EU_ff55 (continuous) compared to Sc6.NDCs_Ref (dotted line) [t CO_2 per million USD (2010)]



Source: GINFORS-E.

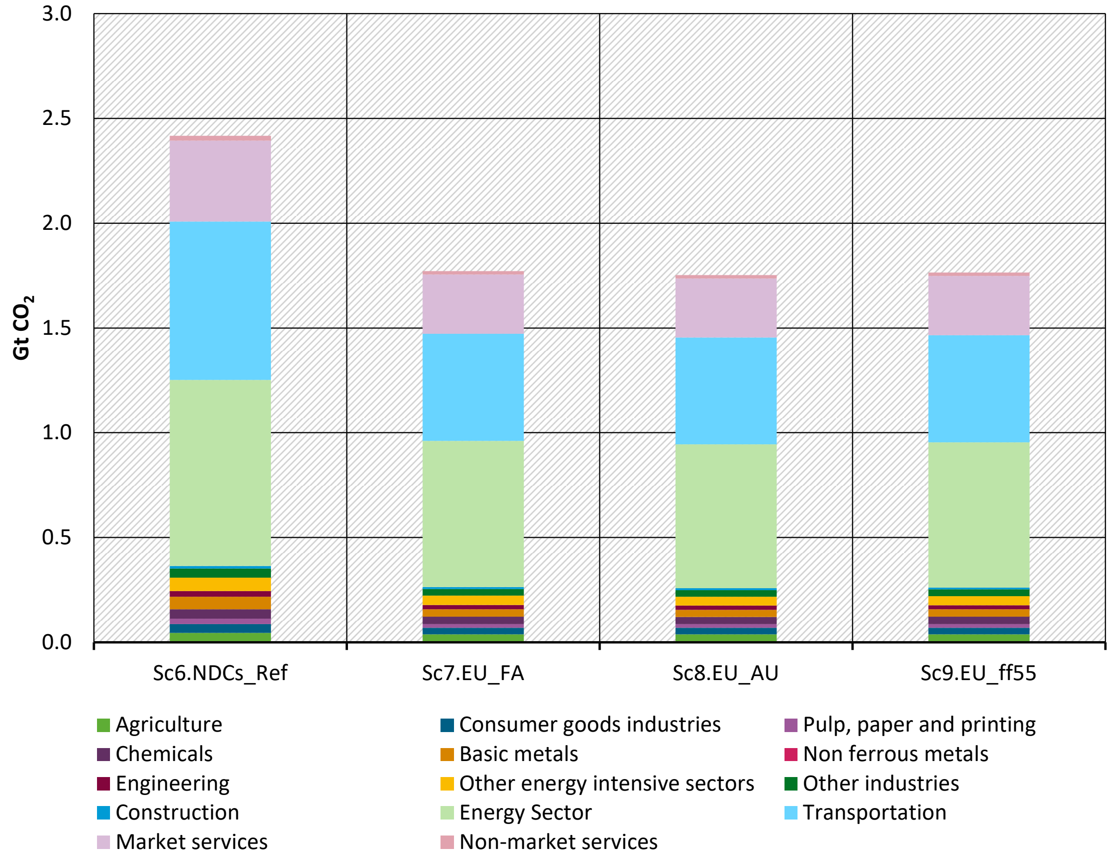
Figure 32: CO_2 per unit of GDP - Sc6.NDCs_Ref, Sc7.EU_FA, Sc8.EU_AU, Sc9.EU_ff55 in 2030 and 2050 [Mt CO_2 per trillion USD[2010]]



Source: GINFORS-E.

Scenarios 7 to 9 differ in the allocation of emission allowances. In this respect, it is not surprising that, as can be seen in Figure 33, total energy-related emissions in the three scenarios in 2030 are very similar and, of course, lower than in scenario 6, which serves as a reference. At first glance, the sector allocation also hardly differs between the three scenarios. The energy sector, transport, and market services, which include heating dominate. All industrial sectors account for about 250 Mt CO_2 in 2050.

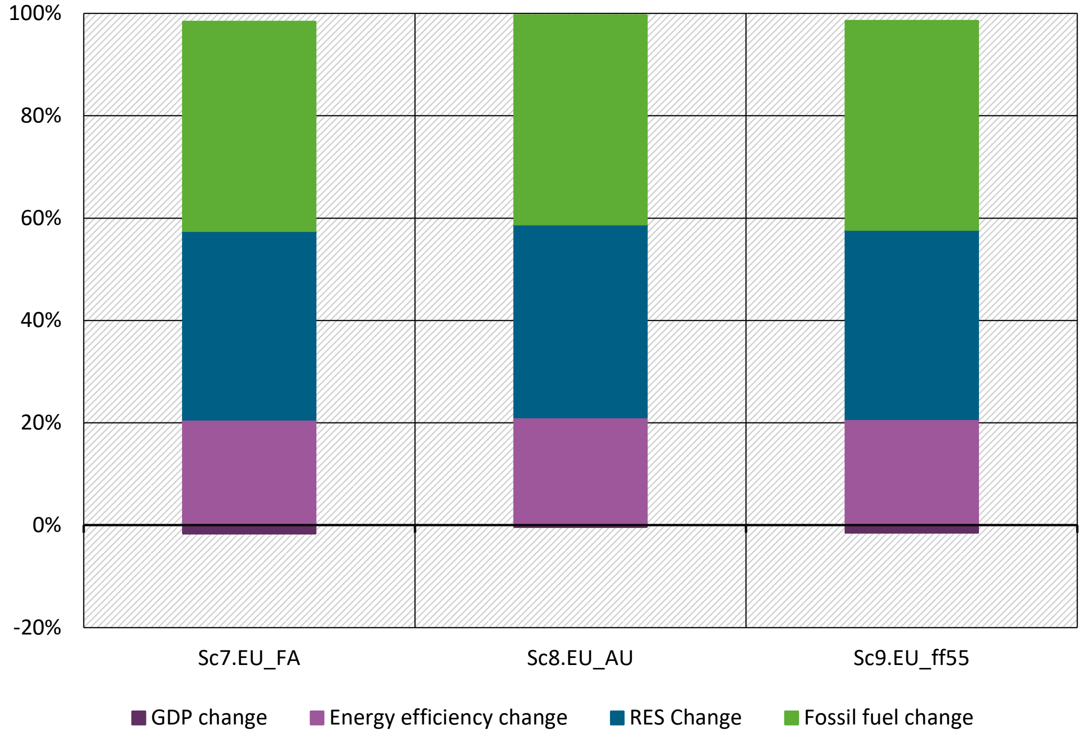
Figure 33: EU energy-related CO_2 emissions in 2030



Source: GINFORS-E.

As depicted in Figure 34 the changes in EU emissions can be decomposed into four different determinants in a "Kaya identity" (see brief explanation in the GEM-E3 chapter): changes in GDP, energy efficiency change, the usage of renewable energy systems (RES) instead of fossil fuels (RES change), and the substitution within fossil fuels (fossil fuel change). By 2030 the impact of these factors is largely the same across scenarios with the shift to renewable energy usage and the substitution within fossil fuels being the main contributors while energy efficiency improvement is less important with a share of about 20%. This is significantly lower than in GEM-E3, where this accounts for more than 30%. As GDP is slightly higher in the scenarios than in the reference, the GDP effect is counterbalancing and offsets the emission reduction to a small extent.

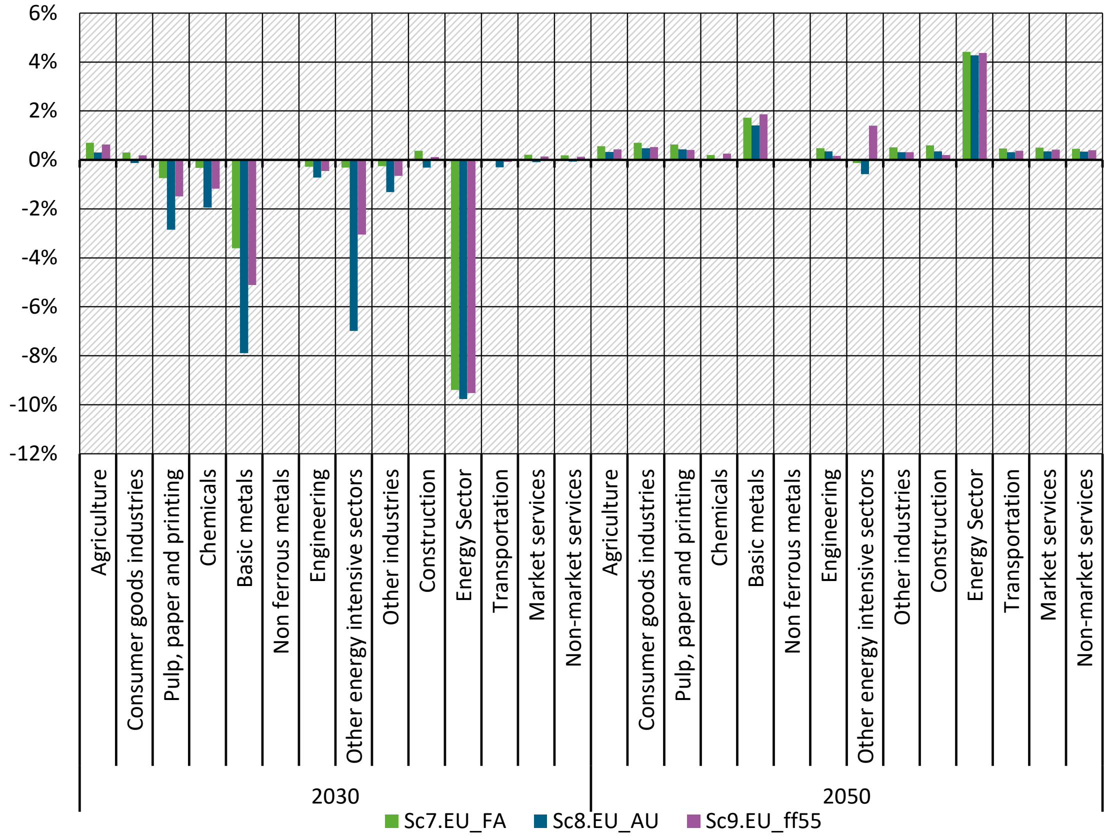
Figure 34: EU emission reduction Kaya decomposition for 2030 – compared to Sc6.NDCs_Ref in 2030



Source: GINFORS-E.

According to Figure 35 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). 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, and are presented in the figures that follow. In the year 2050, the production effects in the scenarios 7 to 9 are clearly positive for all sectors, and largest in energy sector and basic metals sector, i.e. the sectors affected most negatively in 2030. In 2050, the EU has successfully mastered the transformation to climate neutrality. The EU economy operates more efficiently than without transformation.

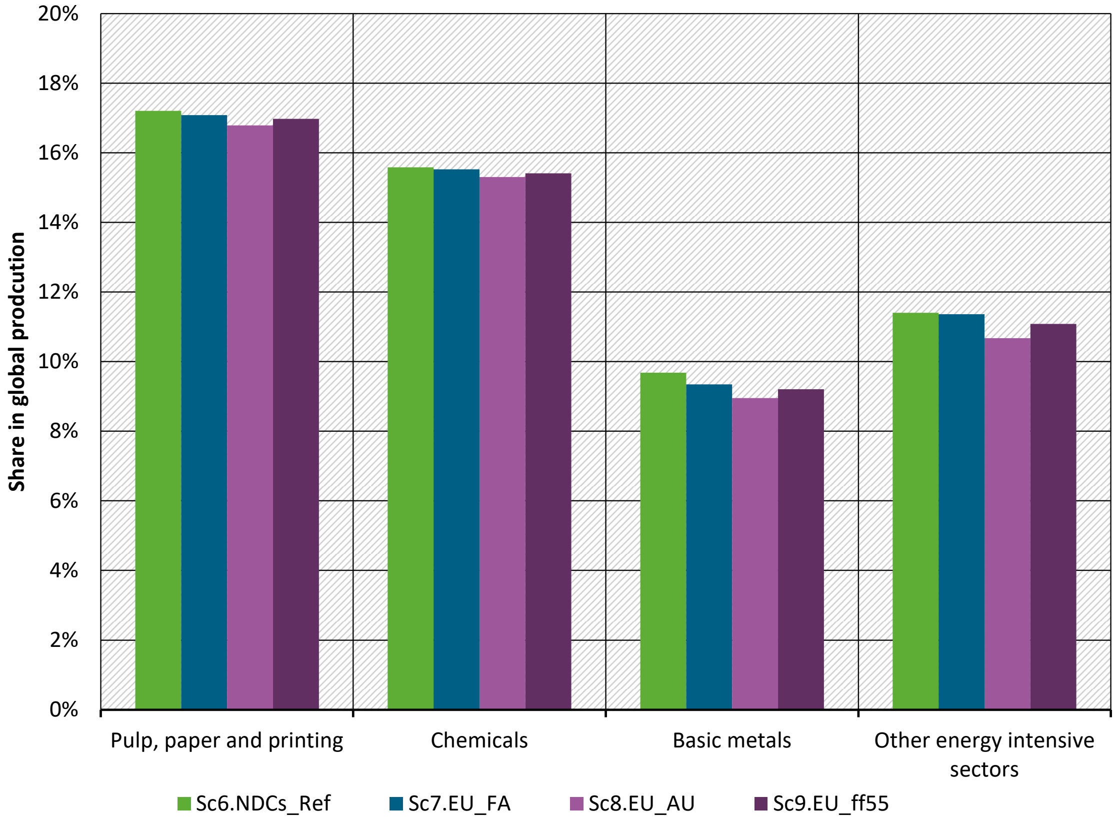
Figure 35: EU sectoral production – deviations from Sc6.NDCs_Ref



Source: GINFORS-E.

The EU's unilateral approach in scenarios 7 to 9 means that the share of global production for the carbon intensive sector will be slightly lower compared to scenario 6 in 2030. At the same time, Figure 36 shows that the design of the EU ETS plays a role for production effects for carbon-intensive sectors. The European production share in carbon intensive industries is highest with free allocation of allowances and lowest with full auctioning. The EU proposal with the CBAM leads to slightly lower global production shares than free allocation.

Figure 36: EU production shares by industry in 2030



Source: GINFORS-E.

The following Table 21 shows absolute changes in sectoral production in constant prices against the reference for scenario 8. While production goes down substantially in EU-28, impacts for other countries are mixed. Production in the USA and China are also slightly reduced, production in India, Japan, Turkey and Russia increases.

Significant production declines in scenarios 7 to 9 with ambitious climate targets in the EU are seen in 2030 in the energy sector and in some energy-intensive sectors such as basic metals, pulp, paper and printing, and chemicals.

Table 21: Differences in production between Sc8.EU_AU and Sc6.NDCs_Ref in 2030 in bn USD(2010)

Industry	EU-28	United States	China	India	Japan	Turkey	Russia
Pulp, paper and printing	-12.3	0.7	0.2	0.1	0.2	0.4	0.3
Chemicals	-24.7	2.7	1.5	1.5	0.8	1.5	1.4
Basic metals	-44.9	3.7	3.2	2.4	0.9	2.3	2.4
Other energy intensive sectors	-22.2	1.1	1.8	0.8	0.3	0.9	0.2

Source: GINFORS-E.

The decline in production in the EU-28 is somewhat in line with the decline in global production shares. Foreign manufacturers are gaining slight competitive advantages over their European competitors. However, there is also a shift in the sector structure away from carbon intensive industries. Higher prices in the EU are partly transmitted to other markets because the intensity of global competition decreases. As a result, there are also slight shifts away from carbon intensive products in the production structure in other countries outside the EU.

Changes in global production values in the carbon intensive sector also lead to corresponding effects on CO_2 emissions (Table 22), which is only shown for scenario 8 with full auctioning. Impacts with other allocation rules in scenarios 7 and 9 will be lower. In the EU, higher carbon prices by 2030 already lead to lower CO_2 emissions per unit of production, while the developments in the other countries are unchanged compared to the reference.

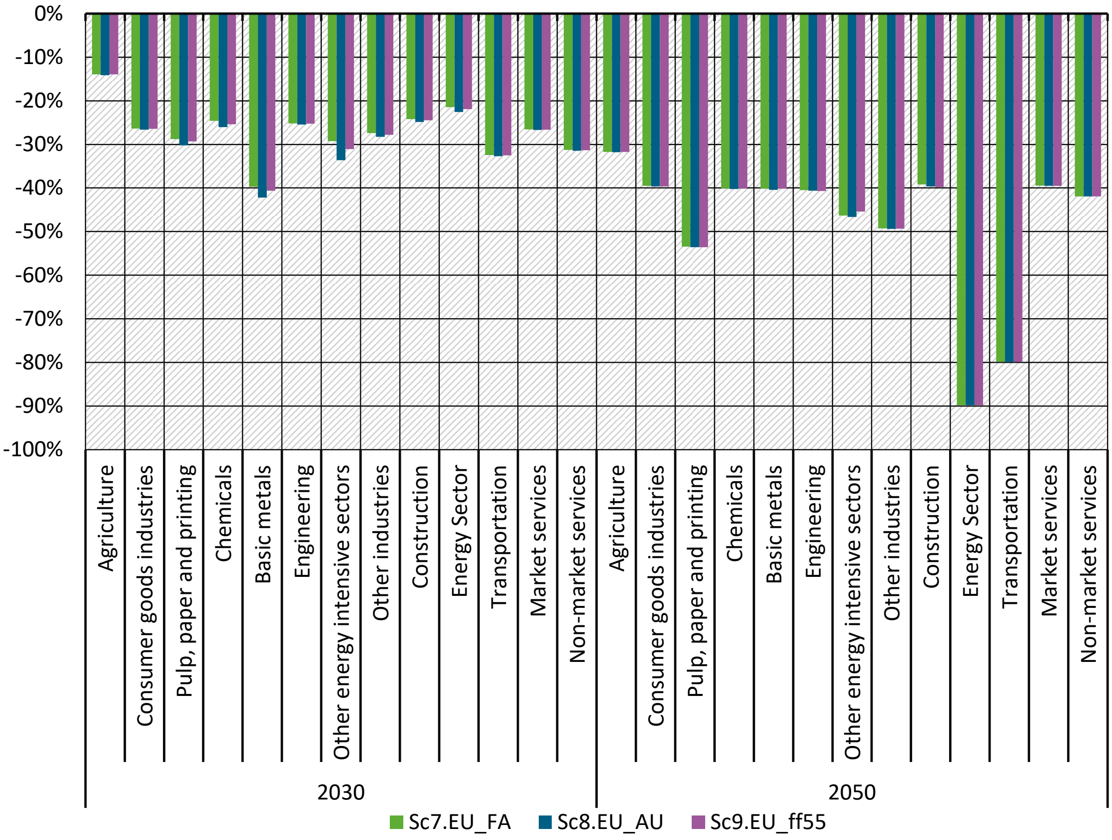
Table 22: Differences in CO_2 emissions between Sc8.EU_AU and Sc6.NDCs_Ref in 2030 in Mt CO_2

Industry	EU-28	United States	China	India	Japan	Turkey	Russia
Pulp, paper and printing	-7.5	0.0	0.0	0.0	0.0	0.0	0.0
Chemicals	-12.0	0.2	0.3	0.1	0.0	0.1	0.4
Basic metals	-25.2	0.3	1.4	1.6	0.1	0.2	0.6
Other energy intensive sectors	-21.4	0.2	1.9	0.6	0.1	0.2	0.1

Source: GINFORS-E.

Energy-related emissions are significantly lower in most energy-intensive sectors, especially in basic metals and "other energy-intensive sectors", which includes other non-metallic minerals, but also in other sectors such as chemicals, and pulp, paper, and printing (Figure 37). There are two reasons for this: On the one hand, production is declining compared to the reference, and on the other hand, production is less carbon intensive due to more low- or zero-carbon production facilities.

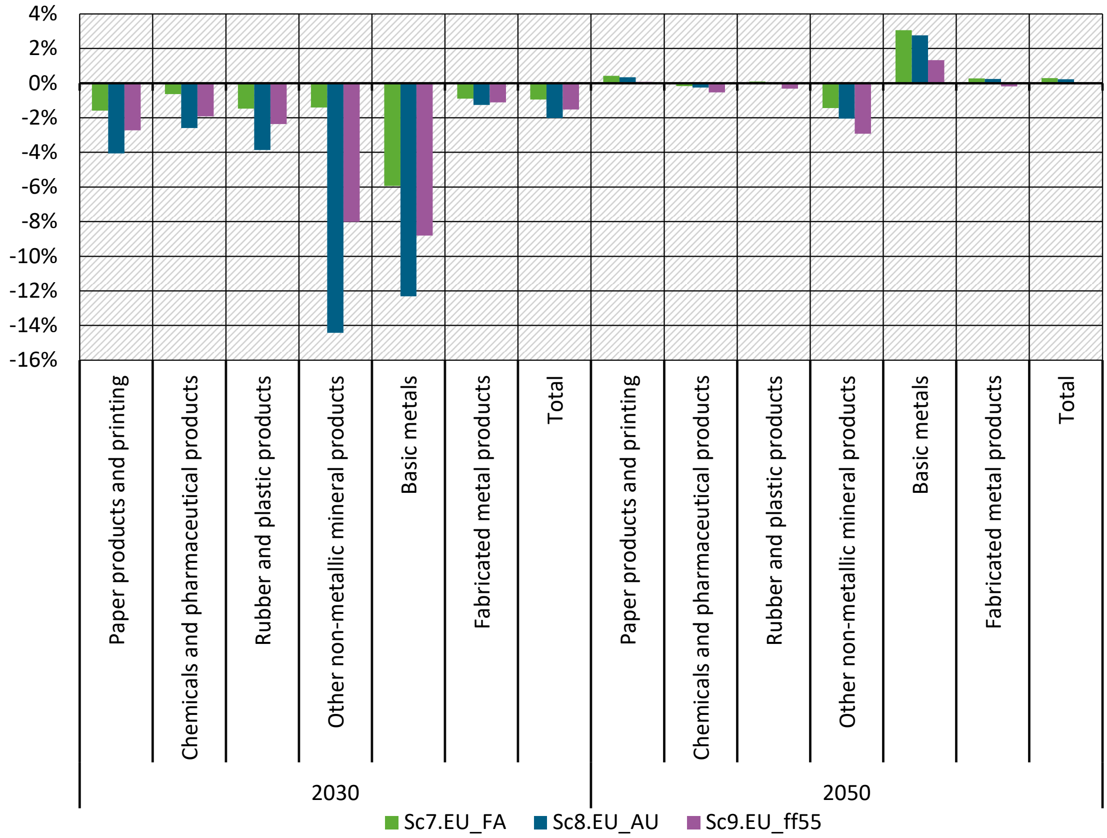
Figure 37: EU sectoral energy-related CO_2 emissions – deviation from Sc6.NDCs_Ref



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 38,Figure 39, Figure 40). 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 declines in exports in the case of full auctioning of emission allowances 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, which is not surprising, as we do not assume export rebates in Scenario 9. The slight decline in total exports in scenario 9, despite the introduction of the CBAM, is nonetheless 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 for them. 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.

Figure 38: EU exports – deviations from Sc6.NDCs_Ref

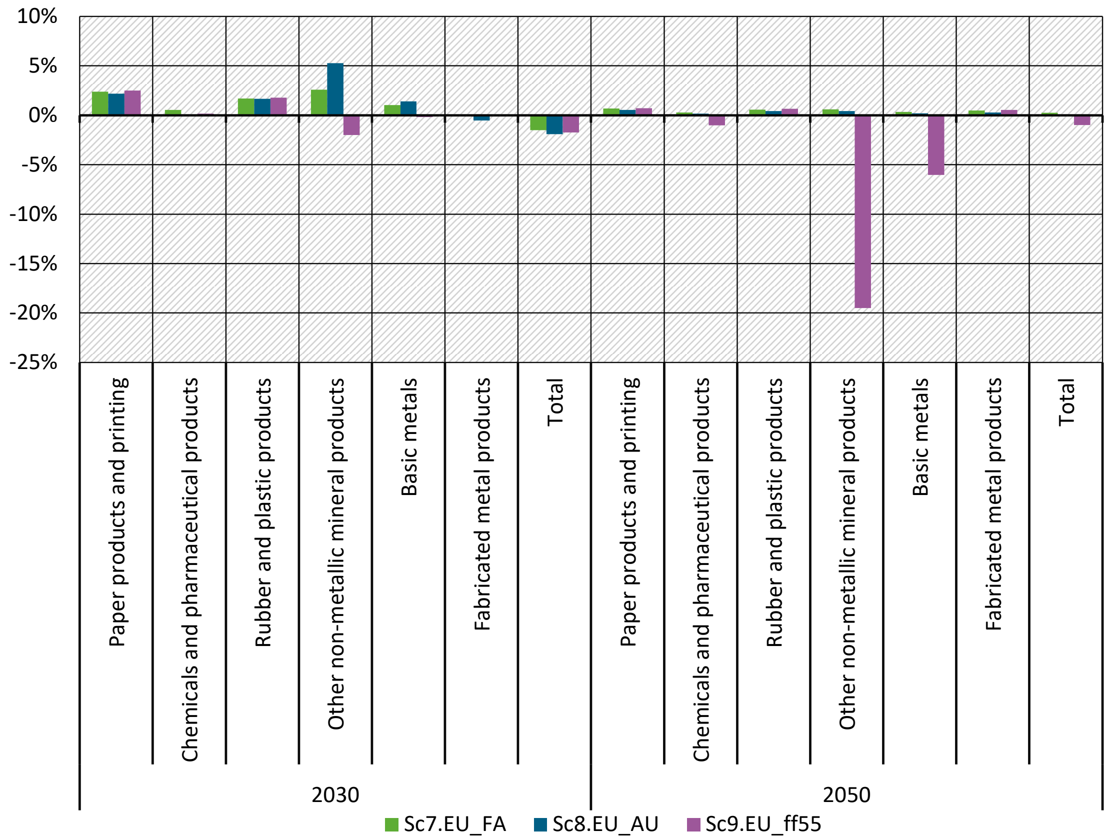


Source: GINFORS-E.

This picture is confirmed for imports. In 2030, they are slightly higher than in the reference in some sectors. In 2050, the differences are only small, and in some sectors imports in CBAM scenario 9 are even significantly lower than in the reference.

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 (Figure 40). 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.

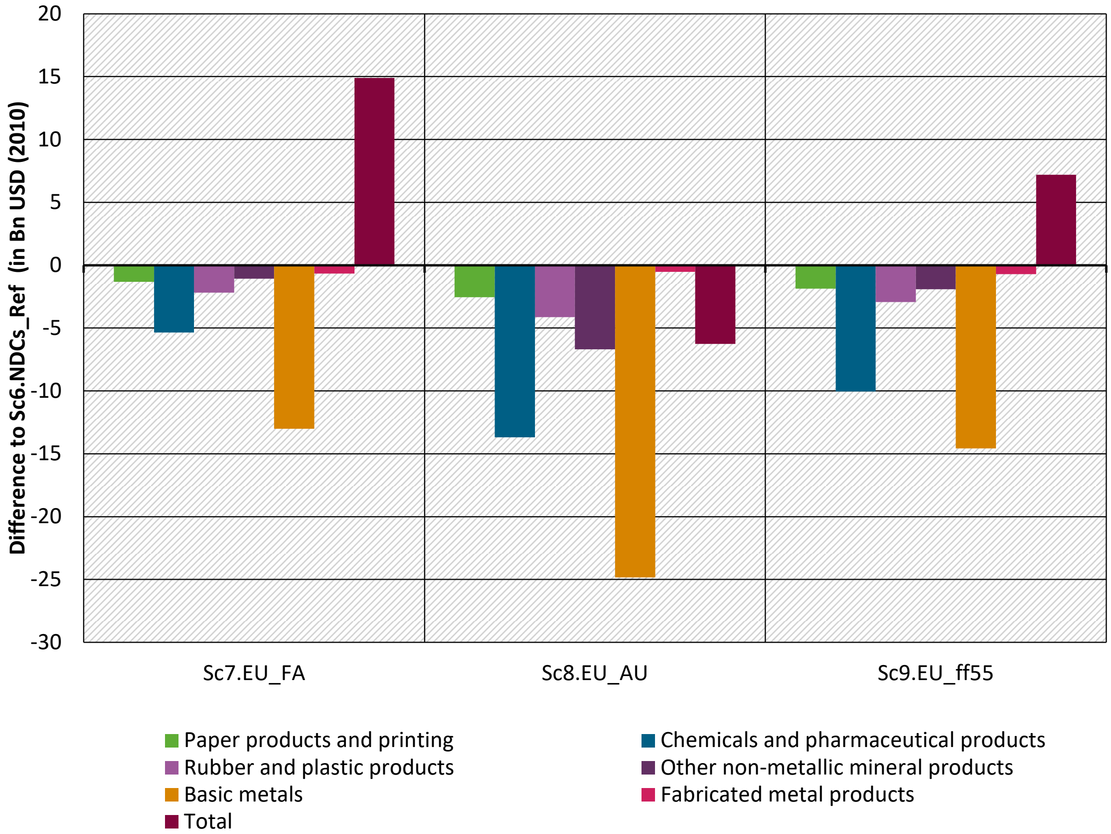
Figure 39: EU imports – deviations from Sc6.NDCs_Ref



Source: GINFORS-E.

The shifts in international trade linkages are shown in the following table for total exports between major countries and regions. Exports from the EU to all other countries (row EU-28) are lower in 2030 than in the reference. The decline in exports to China is particularly high. Conversely, all other countries export more to Europe than in the reference (column EU-28). Other shifts between countries are limited because the climate policies of these countries do not change. They can also only gain a very small share of the exports that the EU has supplied so far.

Figure 40: EU sectoral net-exports 2030 - deviations from Sc6.NDCs_Ref



Source: GINFORS-E.

Table 23: Differences in exports from country (row) to country (column) in bn USD (2010) - Sc8.EU_AU compared to Sc6.NDCs_Ref

	EU-28	US	China	India	Japan	Turkey	Russia
EU-28		-3.03	-9.13	-1.16	-0.24	-2.59	-0.55
US	1.38		0.84	0.00	0.02	0.03	0.02
China	1.42	-0.06		0.01	-0.01	-0.01	0.01
India	0.20	0.19	0.48		0.00	0.08	0.02
Japan	0.31	-0.02	-0.06	0.00		0.00	0.00
Turkey	0.64	0.25	0.03	0.00	0.00		0.01
Russia	2.00	-0.02	0.08	0.02	0.02	-0.01	

Source: GINFORS-E.

The leakage rates describe the part of the sectoral CO_2 reduction in the EU that is offset by increased global CO_2 emissions for the period from 2020 to 2050. In the case of basic metals, this is 22.1% in scenario 8, i.e. over one fifth. With auctioning of emissions allowances, the leakage rates are generally higher than with free allocation. A CBAM leads to a significant reduction in carbon leakage in the protected sectors. In absolute terms, the leakage effects are highest for basic metals, followed by non-metallic minerals and the chemical industry (Figure 41).

It should be emphasized that the macroeconomic leakage rates in GINFORS-E are even negative. Due to climate protection in Europe, e.g. renewable energies become cheaper, which leads to a reduction of technology costs and emissions even in countries without additional climate mitigation efforts. Totally, this more than offsets the GHG emission increase in the carbon-intensive sectors.

Table 24: Carbon leakage rates by sector for 2020 to 2050

	Sc7.EU_FA compared to Sc6.NDCs_Ref	Sc8.EU_AU compared to Sc6.NDCs_Ref	Sc9.ff55 compared to Sc6.NDCs_Ref
Paper products and printing	1.59%	1.91%	1.72%
Chemicals and pharmaceutical products	5.60%	7.84%	1.29%
Rubber and plastic products	5.65%	6.57%	6.19%
Other non-metallic mineral products	11.12%	16.45%	4.47%
Basic metals	17.10%	22.44%	11.91%
Fabricated metal products	0.66%	0.38%	0.37%
Total (all sectors)	-8.3%	-7.8%	-9.2%

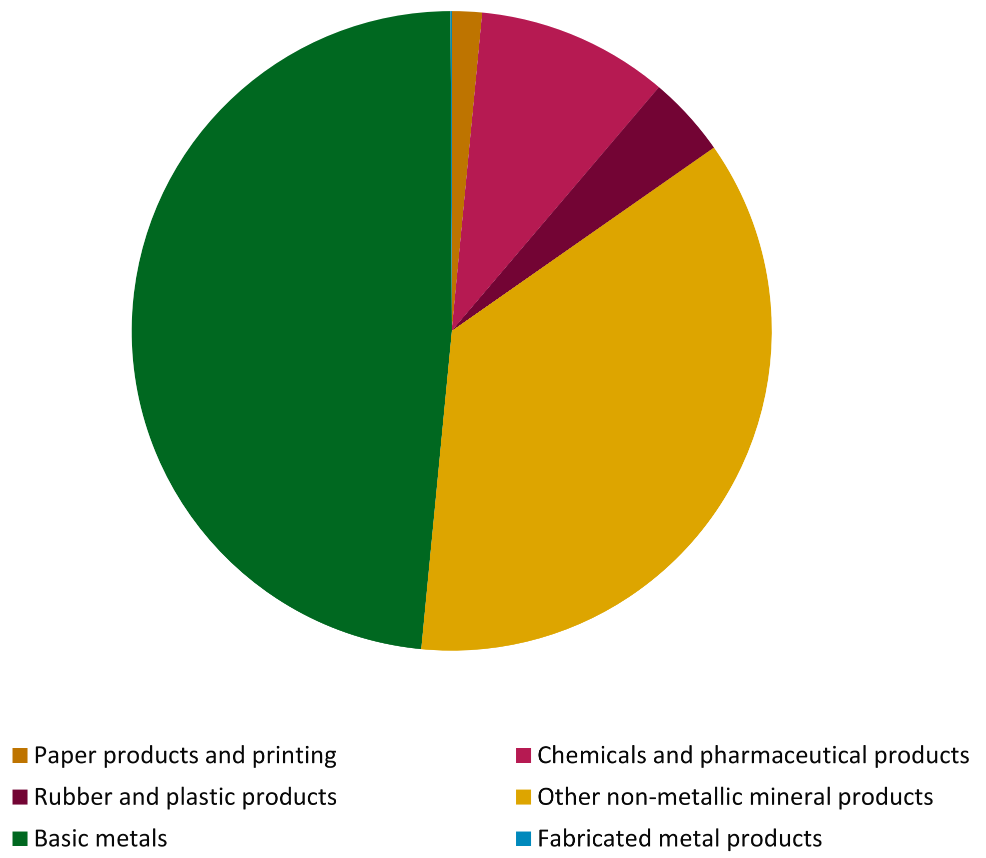
Source: GINFORS-E.

Table 25: Carbon leakage rates by sector for 2030

	Sc7.EU_FA compared to Sc6.NDCs_Ref	Sc8.EU_AU compared to Sc6.NDCs_Ref	Sc9.ff55 compared to Sc6.NDCs_Ref
Paper products and printing	1.10%	2.09%	1.35%
Chemicals and pharmaceutical products	5.87%	10.40%	5.63%
Rubber and plastic products	5.98%	7.77%	6.64%
Other non-metallic mineral products	10.07%	19.52%	9.26%
Basic metals	18.34%	26.97%	17.99%
Fabricated metal products	0.08%	0.15%	0.11%
Total (all sectors)	-1.6%	0.4%	-1.6%

Source: GINFORS-E.

Figure 41: Sector distribution of carbon leakage in Sc8.EU_AU compared to Sc6.NDCs_Ref for 2020 to 2050



Source: GINFORS-E.

Carbon leakage is mainly a problem for carbon-intensive sectors. For the German and the EU economy, there are small positive macroeconomic effects from increased climate mitigation efforts in 2030, especially in the case of free allocation. Other countries can profit from carbon leakage effects and from higher GDP in Europe, sectoral adjustments due to modern technologies as renewable energy and electric vehicles and cost reductions that are induced by higher global wind and PV capacity due to EU action. A negative impact on the economy is observed for Russia (Figure 42) and other energy exporting countries as Saudi Arabia.

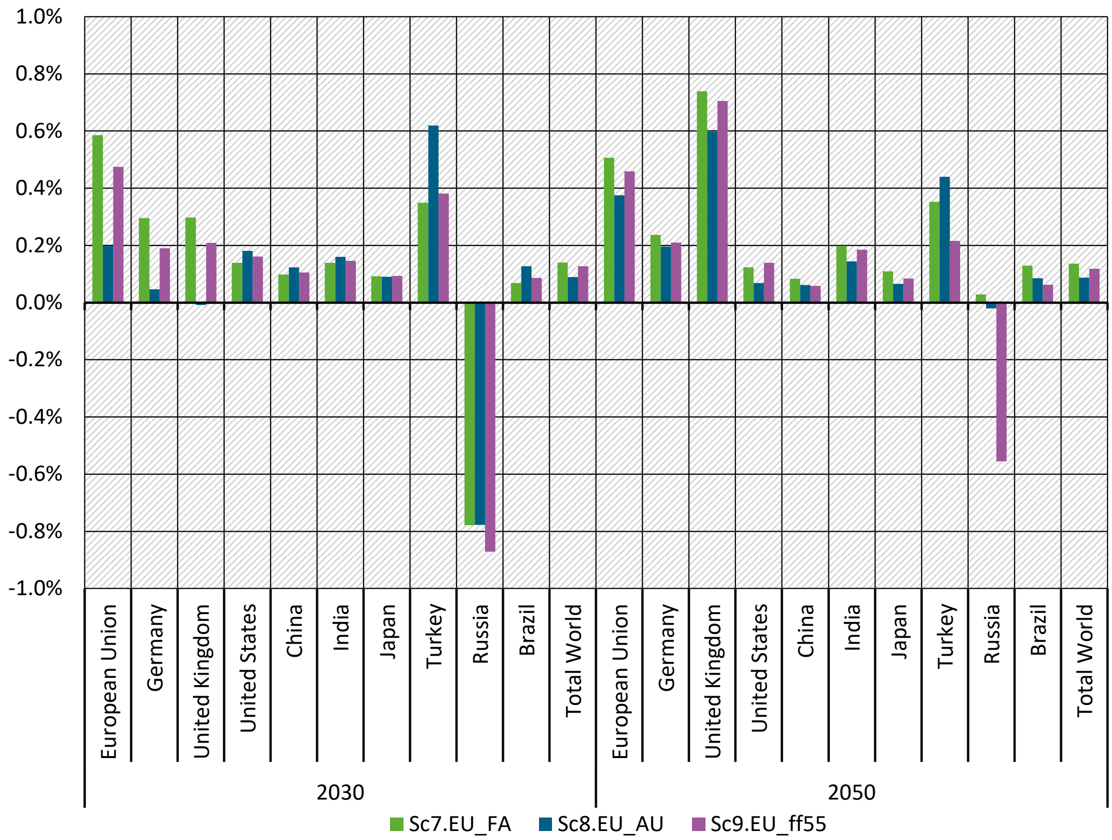
Increasing the EU GHG mitigation targets has a small but positive impact on the EU GDP. The following factors impact the EU economy in scenarios 7 to 9 compared to the reference due to the higher carbon prices:

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. Structural change: As carbon prices increase sectoral costs and prices in carbon-intensive industries, a shift towards low- and zero-carbon sectors takes place.

3. 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.
4. Lower energy use, structural change and technological change lead to a slightly positive effect on GDP.
5. Allocation of allowances: Free allocation is more favourable 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.

The GDP effects for the EU are most positive in the case of free allocation and lowest in the case of full auctioning. The reason for this lies in the different trade effects. GDP impacts on Russia are negative in 2030. In the project, the scenario design was already decided before 2022. It does not consider that the EU has already reduced its imports of fossil fuels from Russia and plans to reduce them further by 2030.

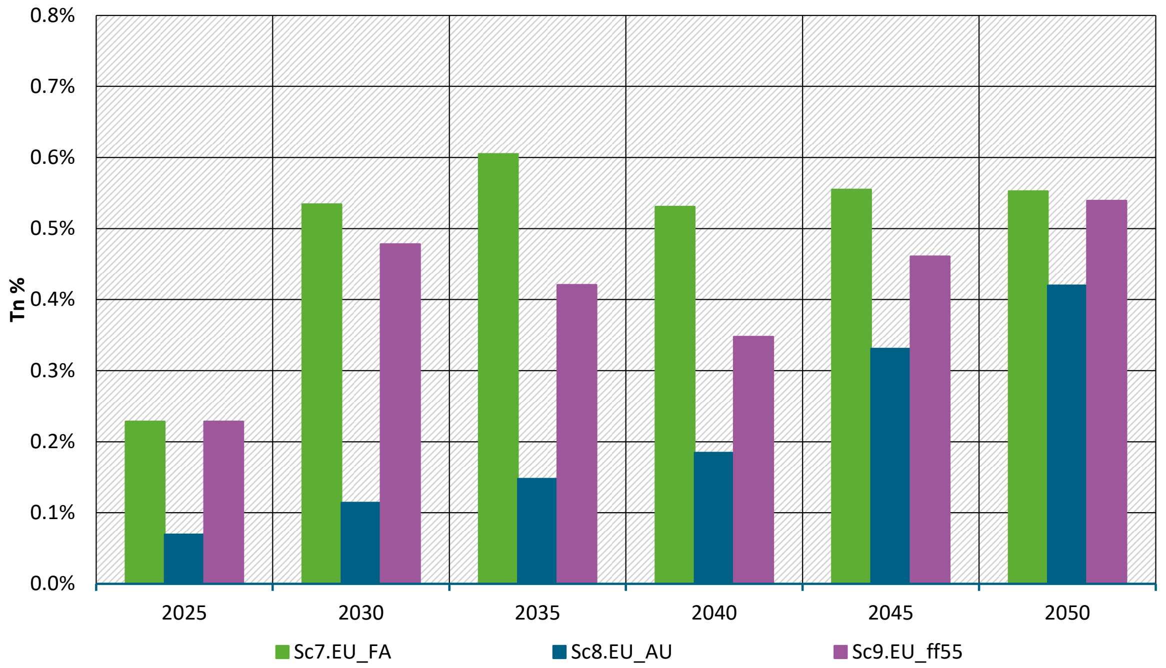
Figure 42: GDP by country – deviations from Sc6.NDCs_Ref



Source: GINFORS-E.

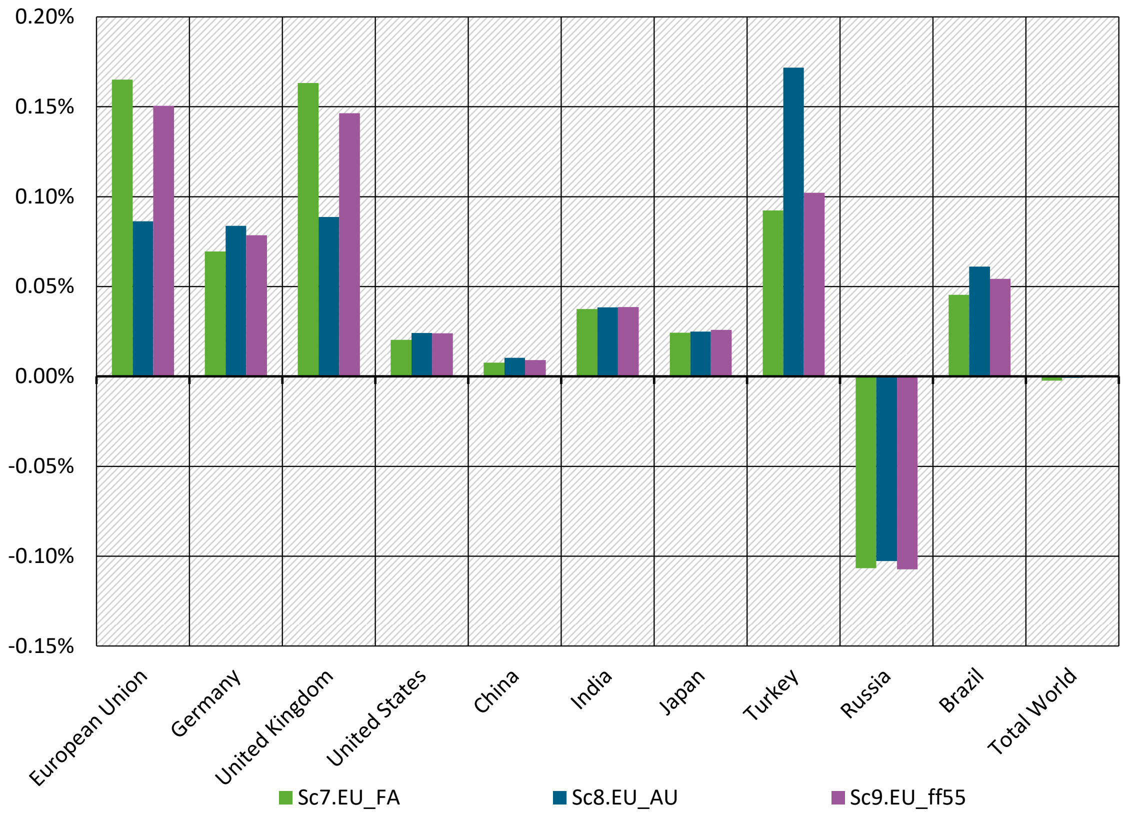
GDP in constant prices of the EU is consistently slightly higher in scenarios 7 to 9 than in the reference from 2025 to 2050. In scenario 7 with free allocation and in the scenario 9 with CBAM, introduced between 2026 and 2034, the effects are similar, with free allocation performing significantly better in 2035 and 2040. In the case of full auctioning, the positive effects are much lower until 2040, after which the gap becomes much smaller.

Figure 43: EU GDP – deviations from Sc6.NDCs_Ref



Source: GINFORS-E

Figure 44: Employment - deviations from Sc6.NDCs_Ref in 2030

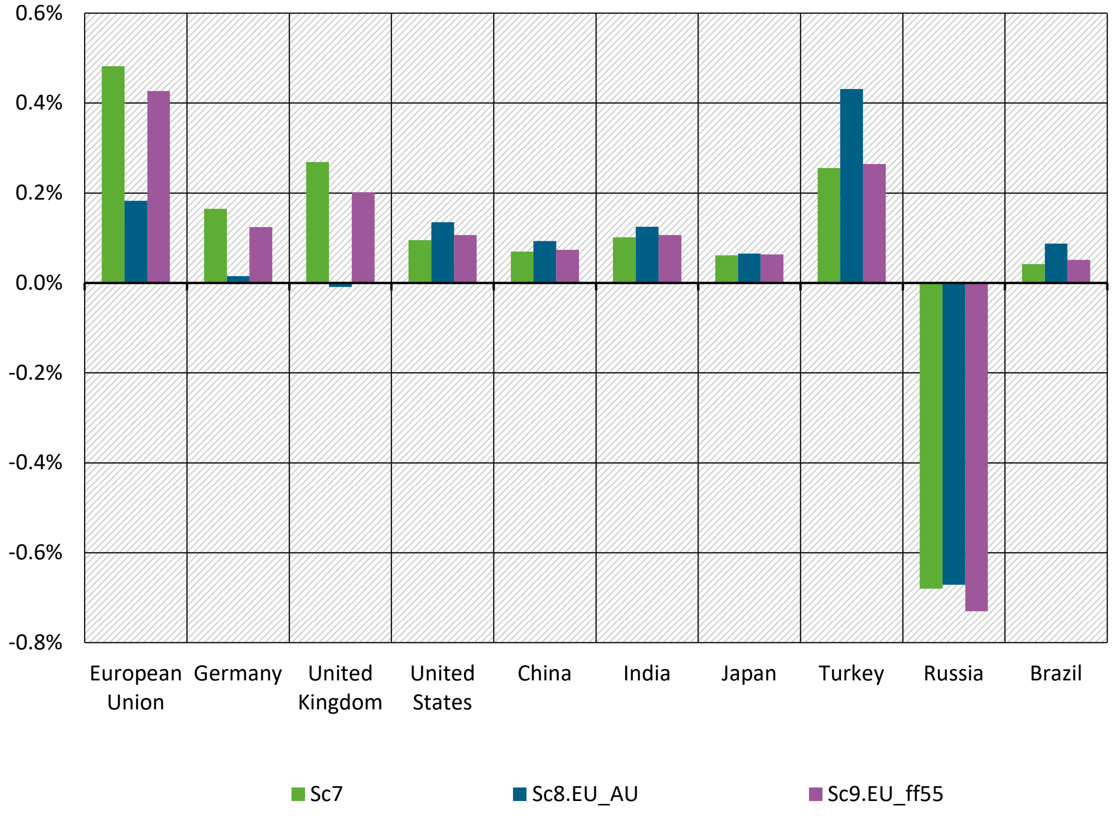


Source: GINFORS-E.

The effects on employment are generally lower than on GDP. This is due to adjustments in wage development and a lower dependence of employment demand on production development (Figure 44).

The development of private consumption largely follows the development of GDP, whereby the design of the allocation mechanism and a possible CBAM also influence foreign trade (Figure 45), which explains certain differences.

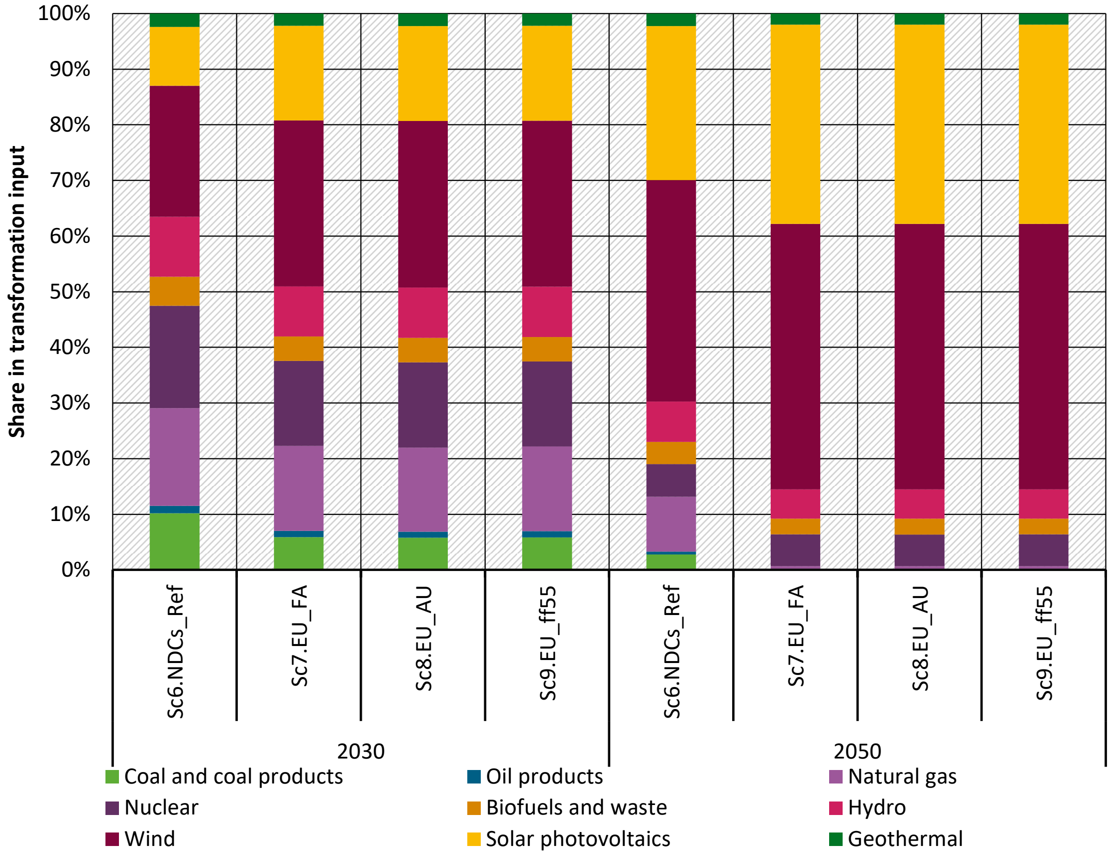
Figure 45: Private consumption - deviations from Sc6.NDCs_Ref in 2030



Source: GINFORS-E.

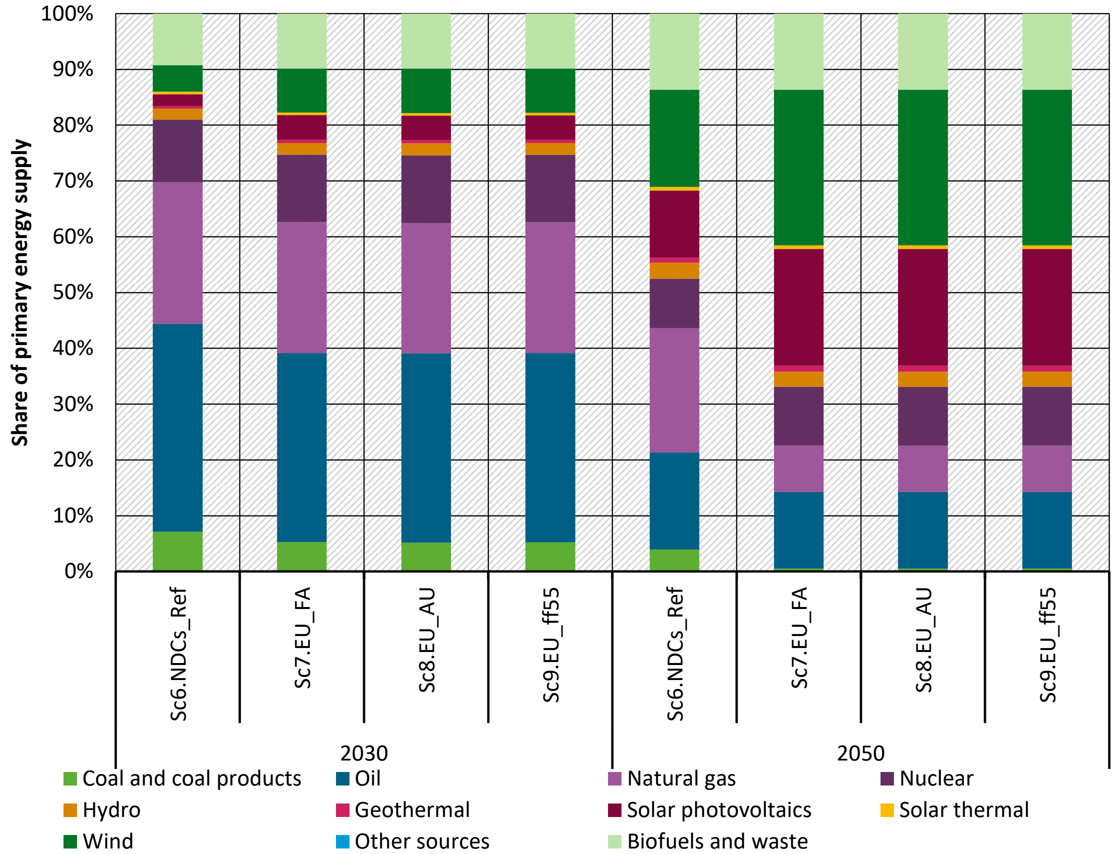
The reduction of total CO_2 emissions leads to a strong shift of the input mix in electricity generation away from fossil fuels towards renewables (Figure 46). The assumptions that there will be no further expansion of nuclear energy and that CCS will not be used in Europe are also driving this development. Changes in the total energy mix away from fossil fuels can be observed in Figure 47.

Figure 46: EU electricity generation – share by energy carrier and scenario



Source: GINFORS-E.

Figure 47: EU primary energy supply – share by energy carrier and scenario



Source: GINFORS-E.

4.3 Other scenarios and sensitivities

An overview of the additional scenarios and sensitivities can be found in section 2. They refer to the design of the CBAM, the Armington elasticities and the participation of other countries in climate protection.

4.3.1 CBAM extended to indirect emissions

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 for the whole period.

If the CBAM is also extended to indirect emissions (Sc9a.CBAM), the overall economic effects in terms of GDP for the EU are almost unchanged compared to Sc9. 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 48).

Figure 48: Deviation in GDP in 2030, compared to Sc6.NDCs_Ref

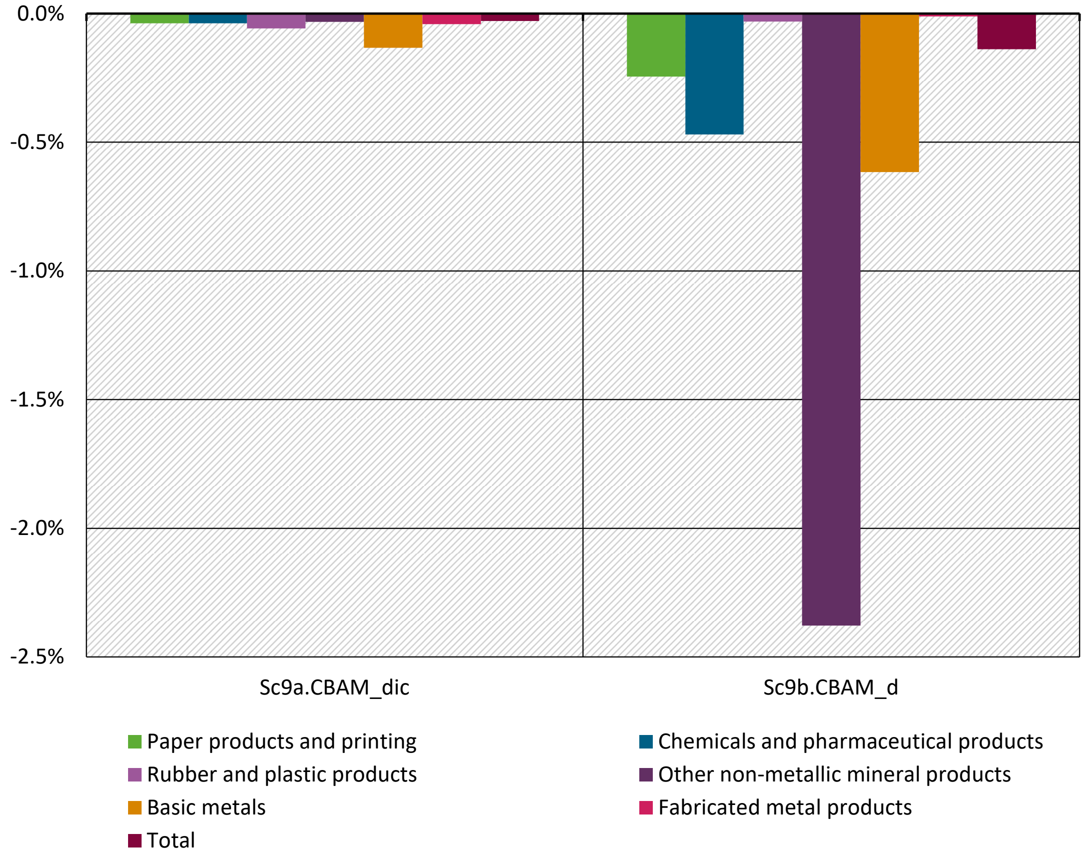
Source: GINFORS-E.

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 (Figure 49), although the elimination of compensation for higher electricity costs would reduce exports by more than 2% in the non-metallic minerals sector in 2030 (Figure 50). Ultimately, the openness, i.e. the relation of exports and imports to domestic production of this sector is limited.

Figure 49: EU sectoral production in 2030, deviation from Sc6.NDCs_Ref

Source: GINFORS-E.

Figure 50: EU exports in 2030, relative deviations compared to Sc9.EU_ff55



Source: GINFORS-E.

4.3.2 (Doubled) trade elasticities

In scenarios 10 to 12, the Armington elasticities are doubled compared to scenarios 7 to 9 in GINFORS-E. 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 6D repeats the Ref-NDCs scenario with the adjusted Armington elasticities.

A central question is to what extent the Armington elasticities influence the carbon leakage rates. As the following Table 26 shows in comparison to the corresponding Table 25, the leakage rates for most combinations of sectors and scenarios are slightly higher than with Armington elasticities at half the level. Exceptions are the scenarios with full auctioning in the areas of other non-metallic minerals and basic metals, where the increase is roughly in the order of 50%. For fabricated metal products, the leakage rates even become slightly negative. For all sectors together, differences are small. Overall, it can be concluded that the assumptions regarding Armington elasticities do not decisively influence leakage rates in GINFORS-E, especially in the politically particularly relevant scenarios with free allocation and with the CBAM.

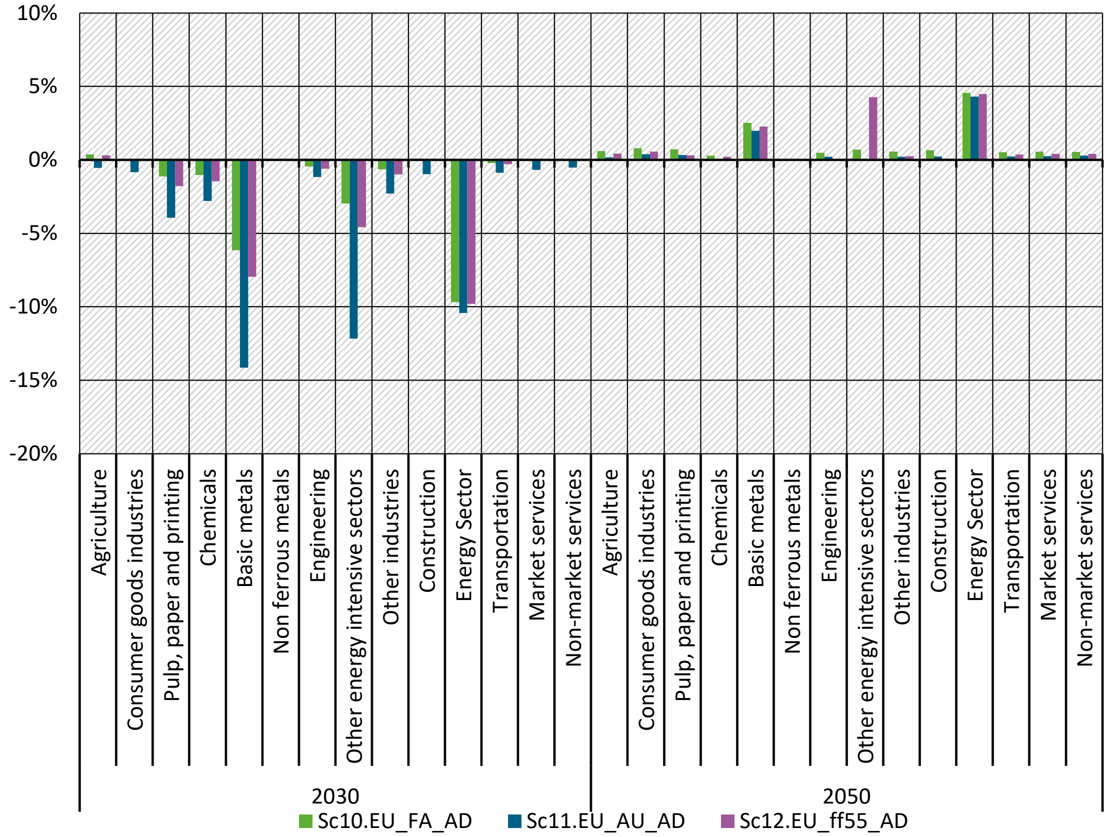
Table 26: Carbon leakage rates by sector for 2030 - Values for not doubled Armington elasticities from Table 25 in brackets

	Sc10.EU_FA_AD compared to Sc6D.NDCs_Ref_AD	Sc11D.EU_AU_AD compared to Sc6D.NDCs_Ref_AD	Sc12D.ff55 compared to Sc6D.NDCs_Ref_AD
Paper products and printing	1.33% (1.10%)	3.27% (2.09%)	1.83% (1.35%)
Chemicals and pharmaceutical products	6.15% (5.87%)	10.21% (10.40%)	5.93% (5.63%)
Rubber and plastic products	7.02% (5.98%)	9.21% (7.77%)	8.30 % (6.64%)
Other non-metallic mineral products	11.91% (10.07%)	32.41% (19.52%)	9.39% (9.26%)
Basic metals	23.51% (18.34%)	36.72% (26.97%)	23.55% (17.99%)
Fabricated metal products	-1.22% (0.08%)	-2.75% (0.15%)	-1.54% (0.11%)
Total (all sectors)	-1.6% (-1.6%)	0.5% (0.4%)	-1.8% (-1.6%)

Source: GINFORS-E.

The doubled Armington elasticities have a similar influence on EU sectoral output as on leakage rates. Particularly in the full auctioning scenario, the effects on basic metals and non-metallic minerals are more pronounced (see Figure 51 compared to Figure 36).

Figure 51: EU sectoral production – deviations from Sc6D.NDCs_Ref_AD

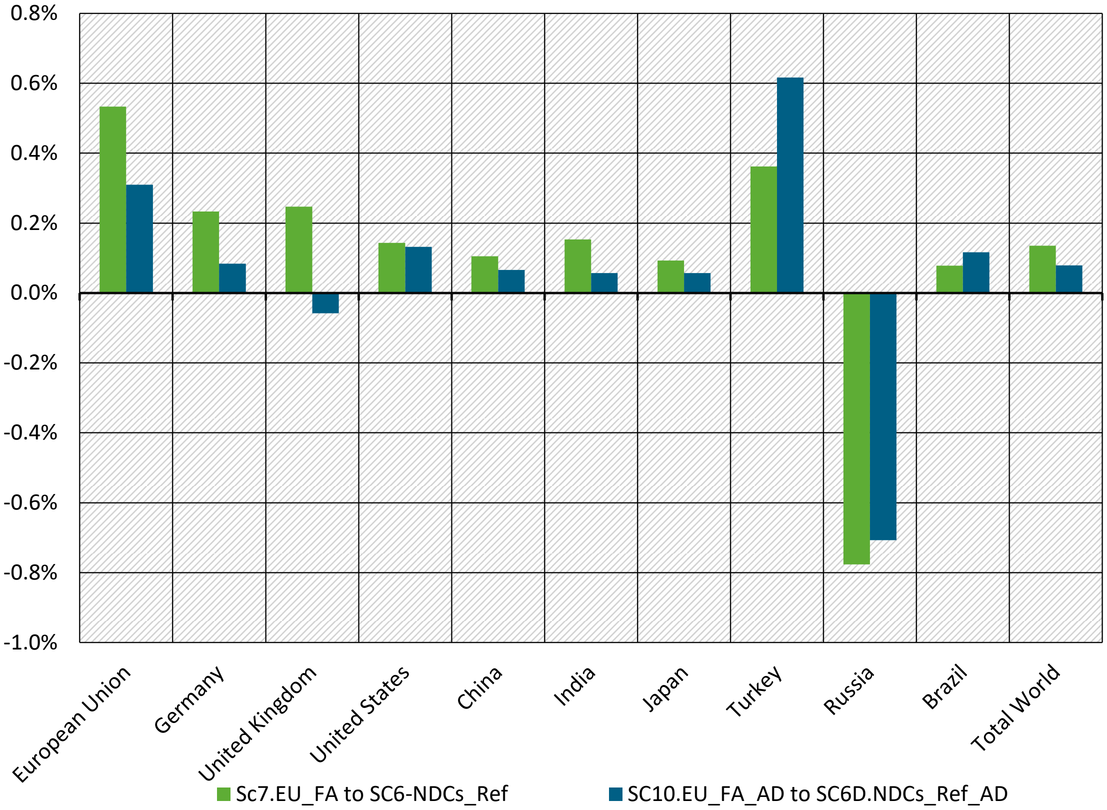


Source: GINFORS-E.

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 trade elasticities lead to less positive macroeconomic effects of climate protection for the EU. They decrease from around 0.5% to 0.3% 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. Neighbouring countries such as Turkey and Russia, on the other hand, can benefit a bit from higher trade elasticities (Figure 52).

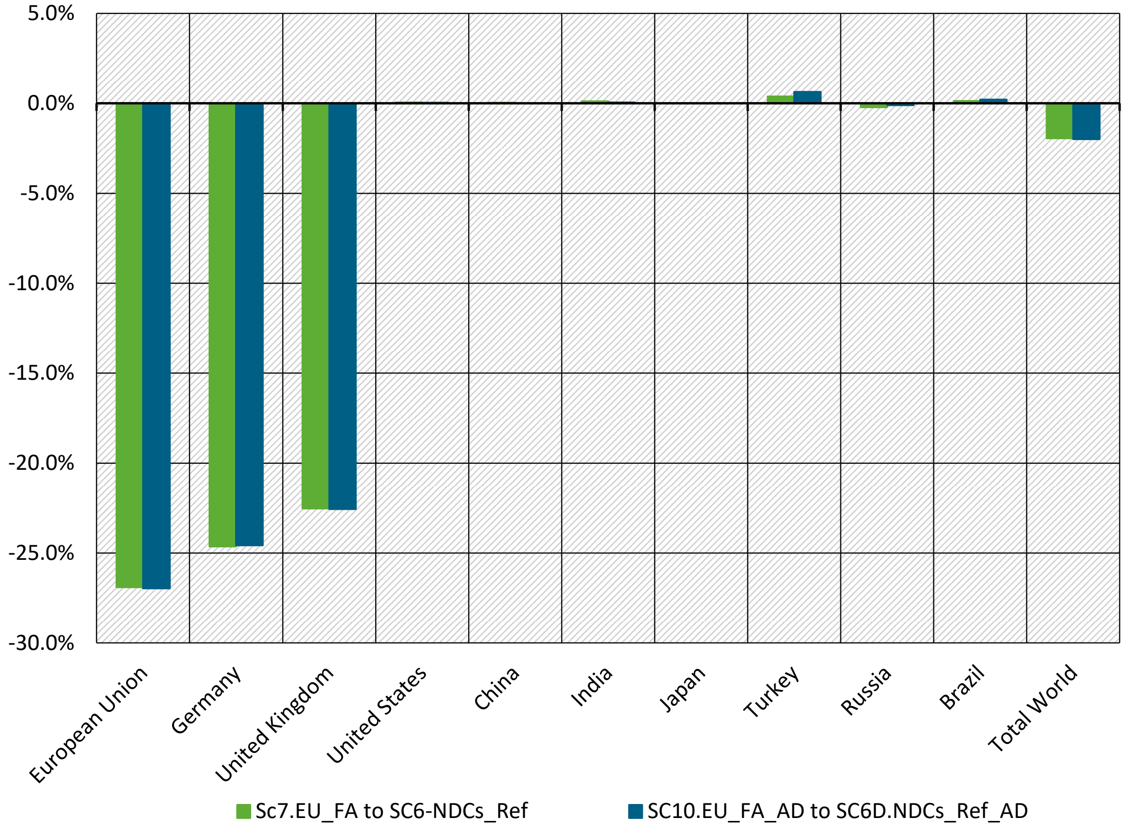
This effect mainly stems from foreign trade with carbon intensive products (Figure 53). The effect on net exports is significantly stronger for most industries due to the higher substitution possibilities. The effect on basic metal exports is particularly high in 2030 (Figure 54).

Figure 52: GDP deviations – Sc 7.EU_FA compared to Sc 6.NDCs_Ref and Sc10.EU_FA_AD compared to Sc6D.NDCs_Ref_AD in 2030



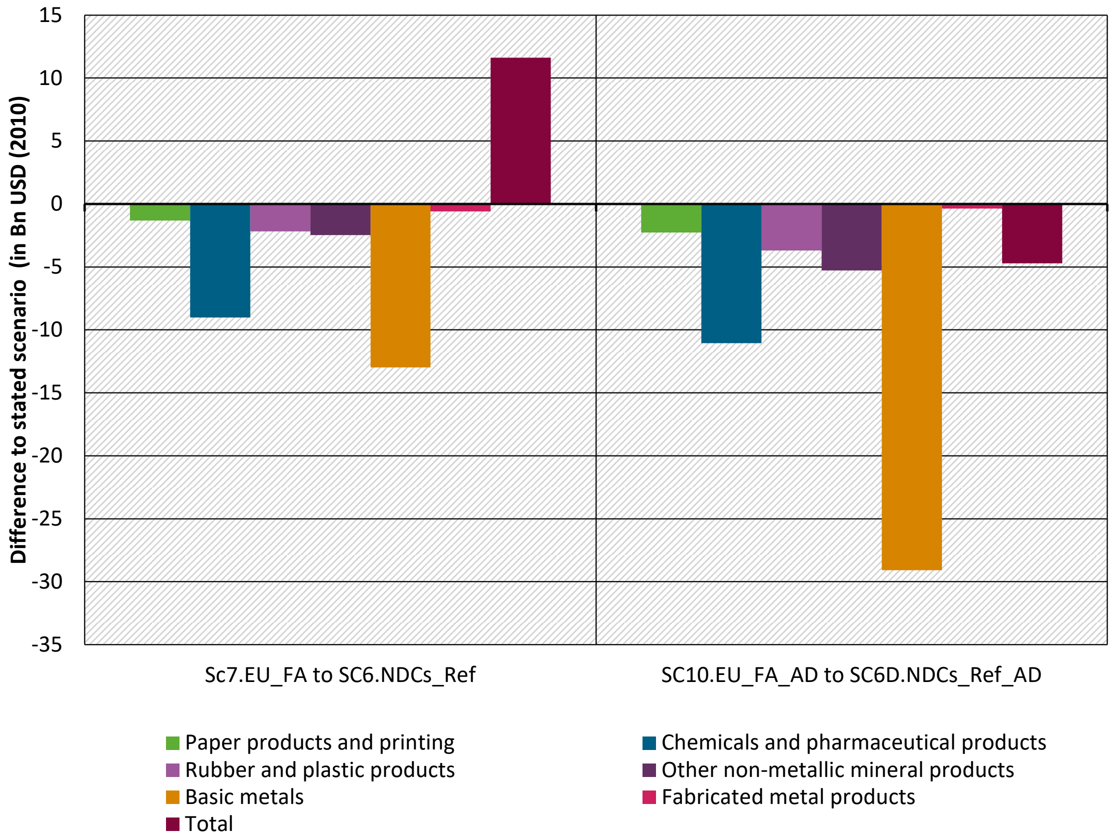
Source: GINFORS-E.

Figure 53: Deviations in energy related carbon emissions – Sc 7.EU_FA compared to Sc 6.NDCs_Ref and Sc10.EU_FA_AD compared to Sc6D.NDCs_Ref_AD in 2030



Source: GINFORS-E.

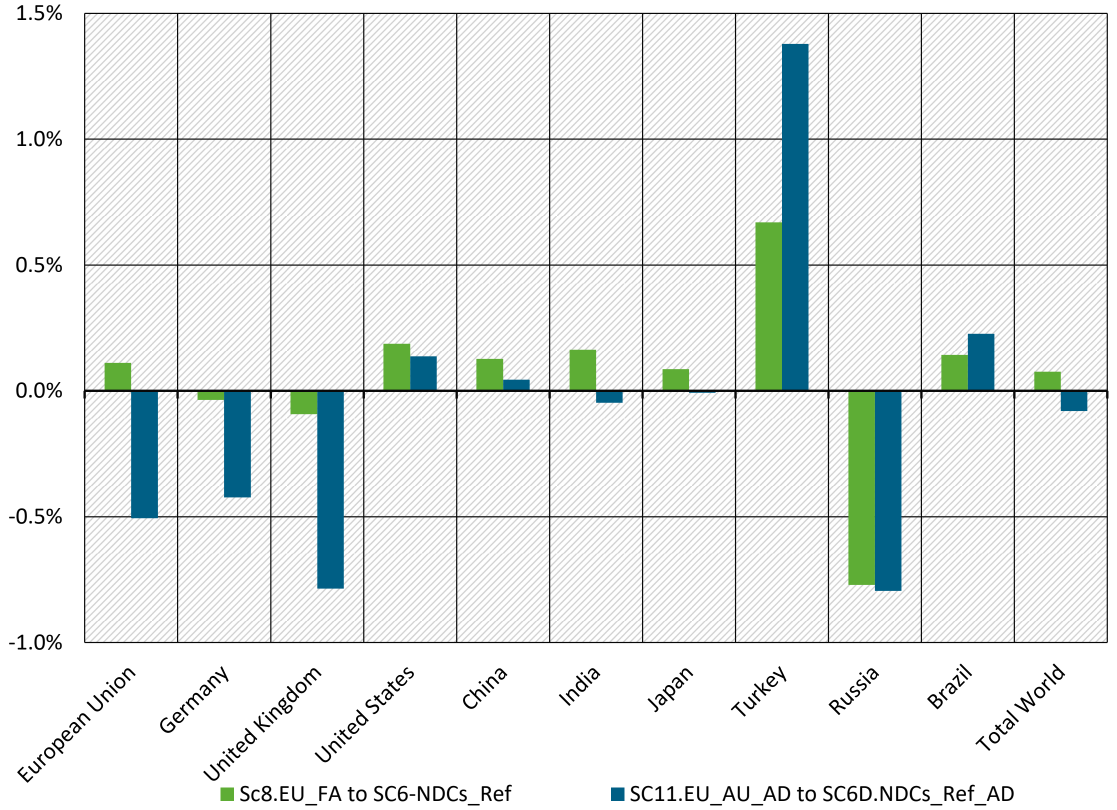
Figure 54: EU net exports, Sc 7.EU_FA compared to Sc 6.NDCs_Ref and Sc10.EU_FA_AD compared to SC.6D.NDCs_Ref_AD in 2030



Source: GINFORS-E.

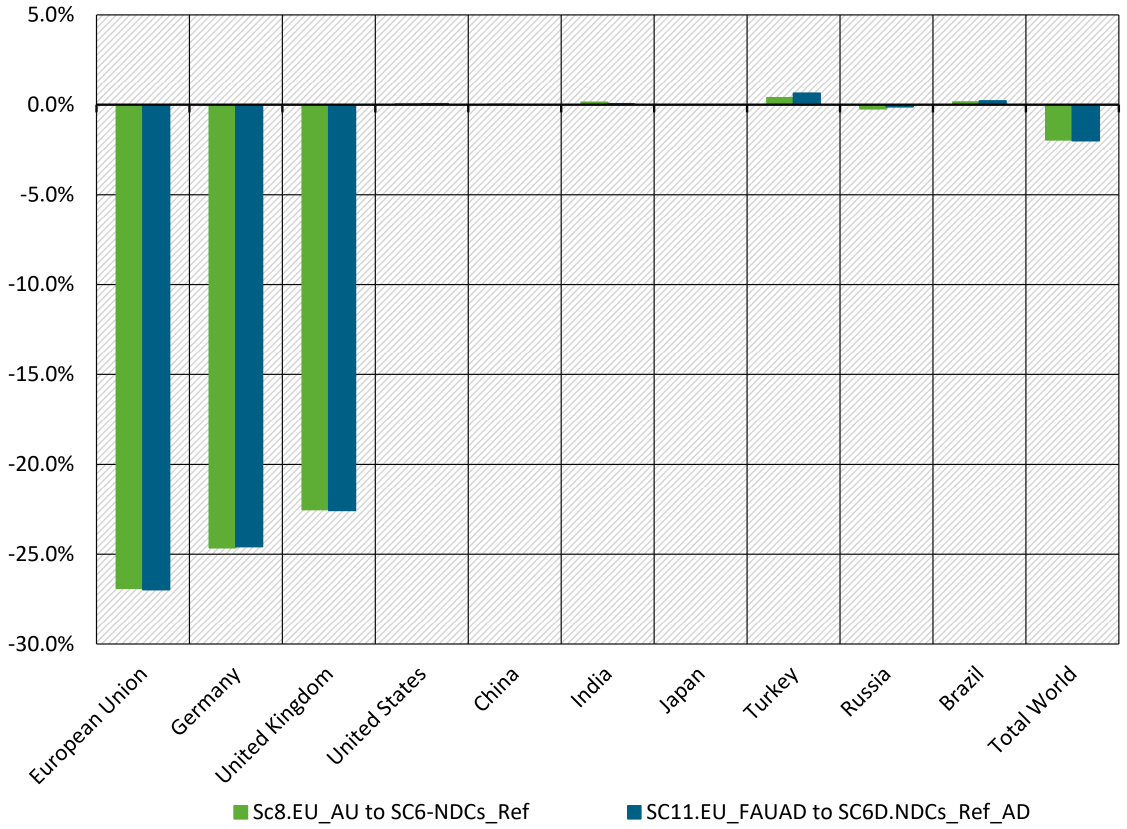
A similar picture emerges for the scenario comparison if the emission allowances are fully auctioned (Scenario 8 vs. 11, Figure 55) or the policy is oriented towards the fitfor55 package (Scenario 9 vs. 12, Figure 57). It is interesting that in the first case the sign of the GDP effect changes in the 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. The same is visible for net exports, which are the main drivers for the macroeconomic effects. 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 favours neighbouring countries with strong trade relations with the EU, such as Turkey.

Figure 55: GDP deviations – Sc8.EU_AU compared to Sc6.NDCs_Ref and Sc11.EU_AU_AD compared to Sc6D.NDCs_Ref_AD in 2030



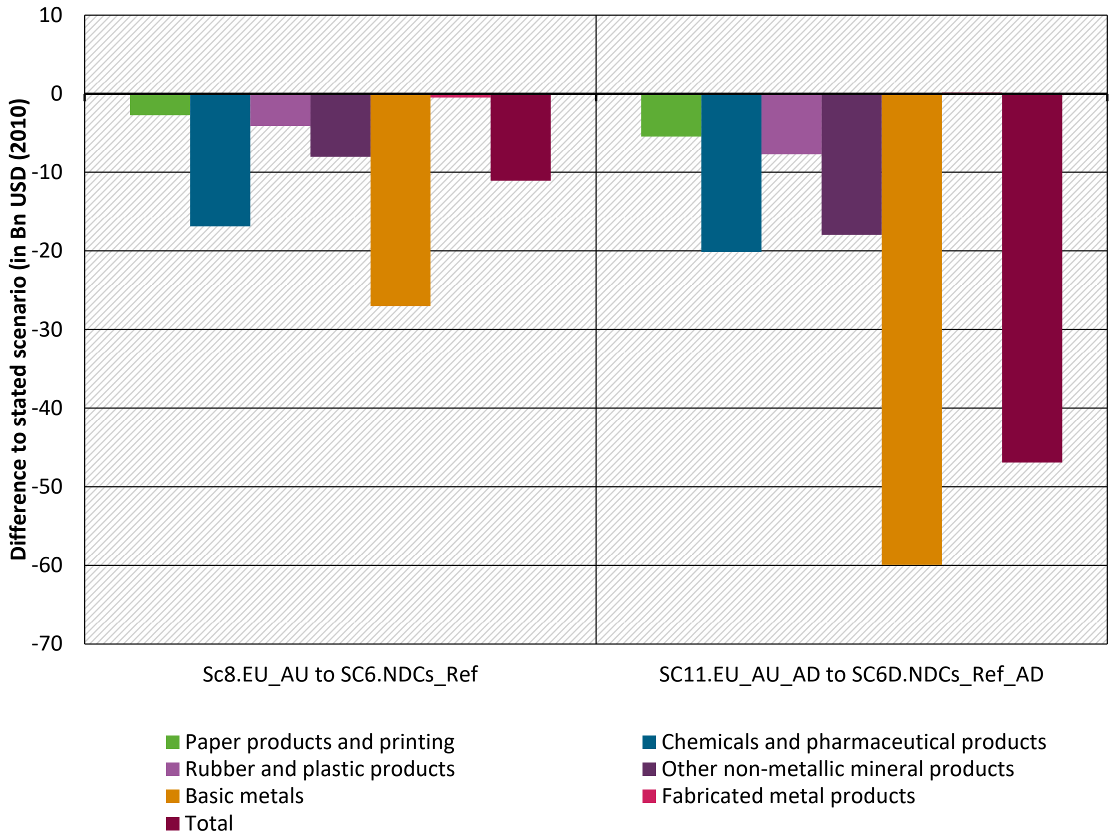
Source: GINFORS-E.

Figure 56: Deviations in energy related carbon emissions – Sc8.EU_AU compared to Sc6.NDCs_Ref and Sc11.EU_AU_AD compared to Sc6D.NDCs_Ref_AD in 2030



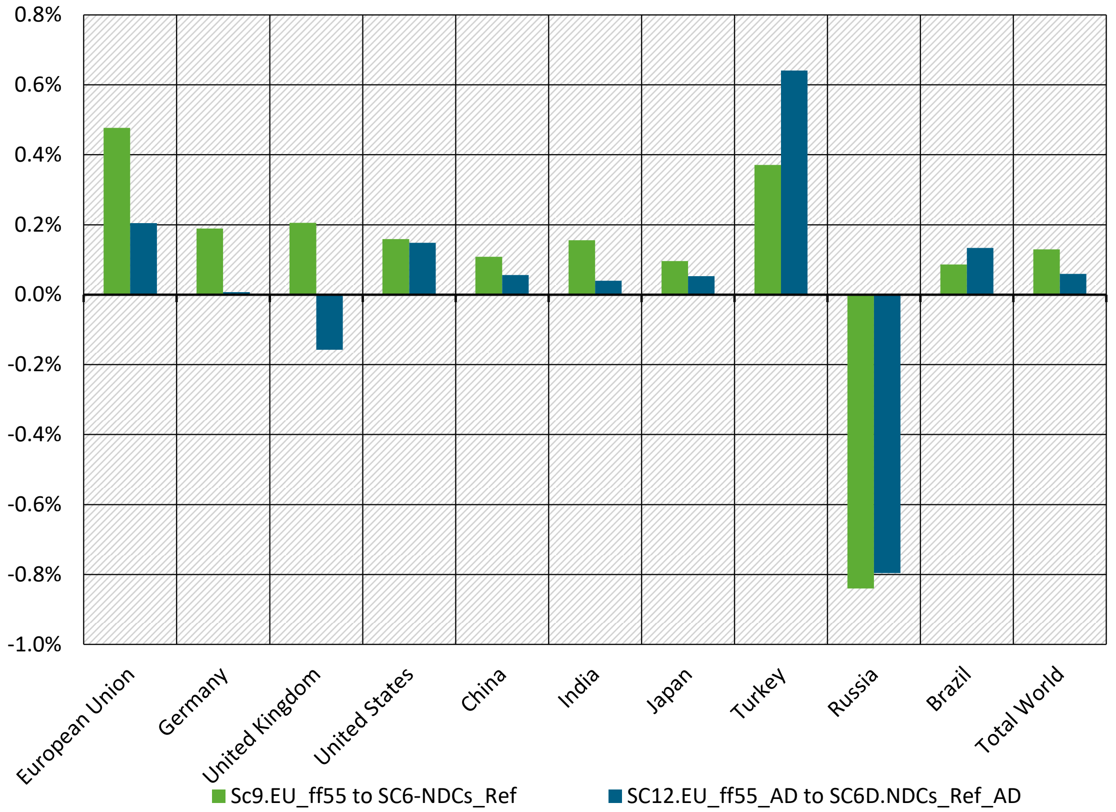
Source: GINFORS-E.

Figure 57: EU net exports– Sc8.EU_AU compared to Sc6.NDCs_Ref and Sc11.EU_AU_AD compared to Sc6D.NDCs_Ref_AD in 2030



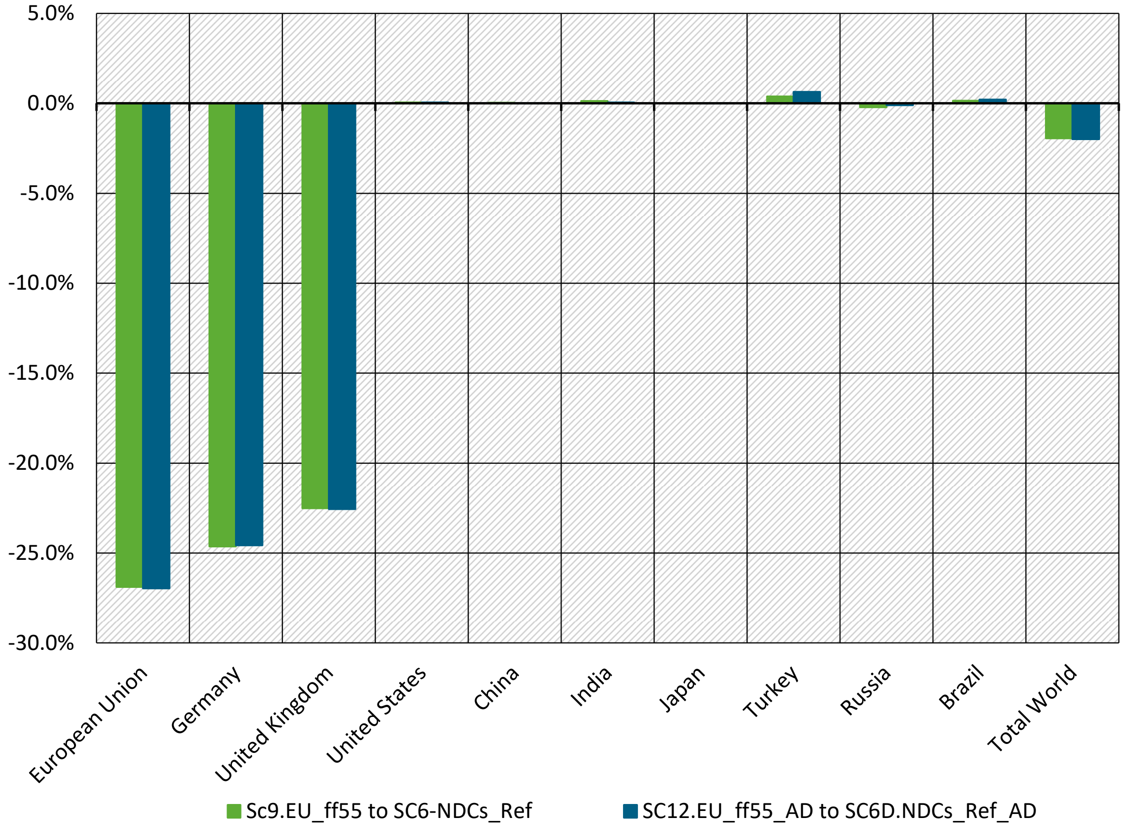
Source: GINFORS-E.

Figure 58: GDP deviations – Sc9.EU_ff55 compared to Sc6.NDCs_Ref and Sc12.EU_ff55_AD compared to Sc6D.NDCs_Ref_AD in 2030



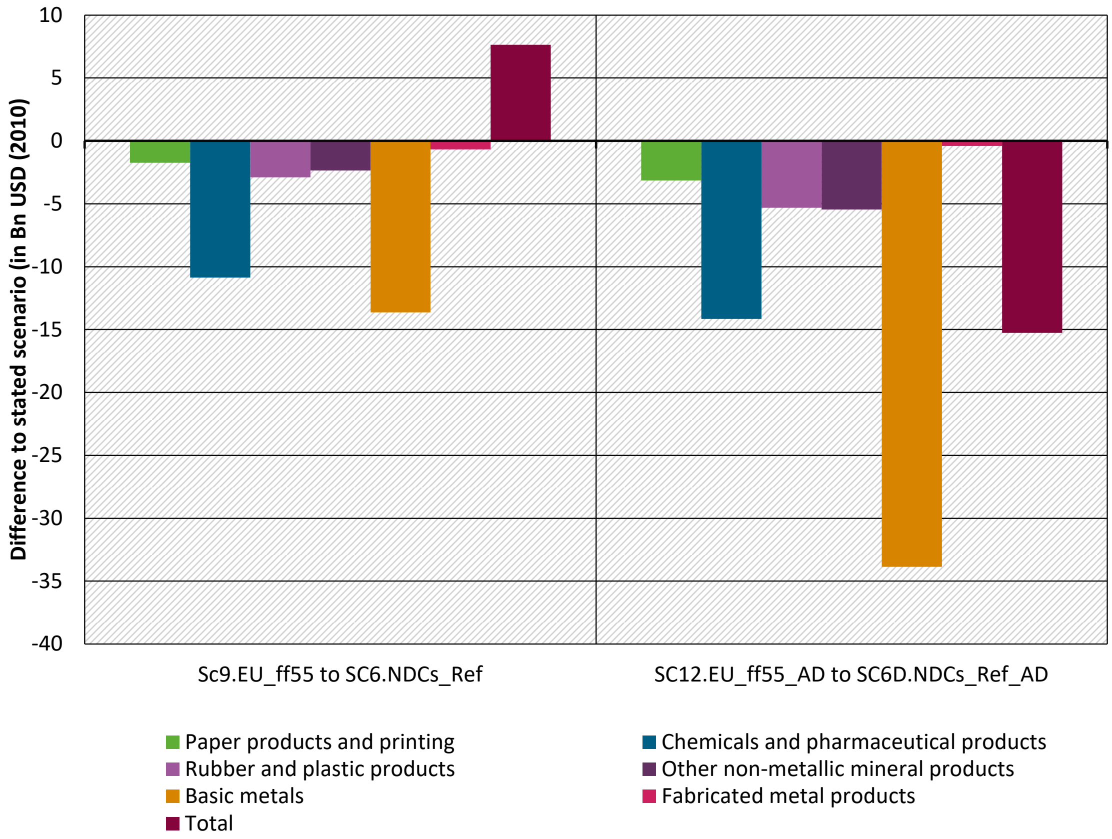
Source: GINFORS-E.

Figure 59: Deviations in energy related carbon emissions – Sc9.EU_ff55 compared to Sc6.NDCs_Ref and Sc12.EU_ff55_AD compared to Sc6D.NDCs_Ref_AD in 2030



Source: GINFORS-E.

Figure 60: EU net exports – Sc9.EU_ff55 compared to Sc6.NDCs_Ref and Sc12.EU_ff55_AD compared to Sc6D.NDCs_Ref_AD in 2030



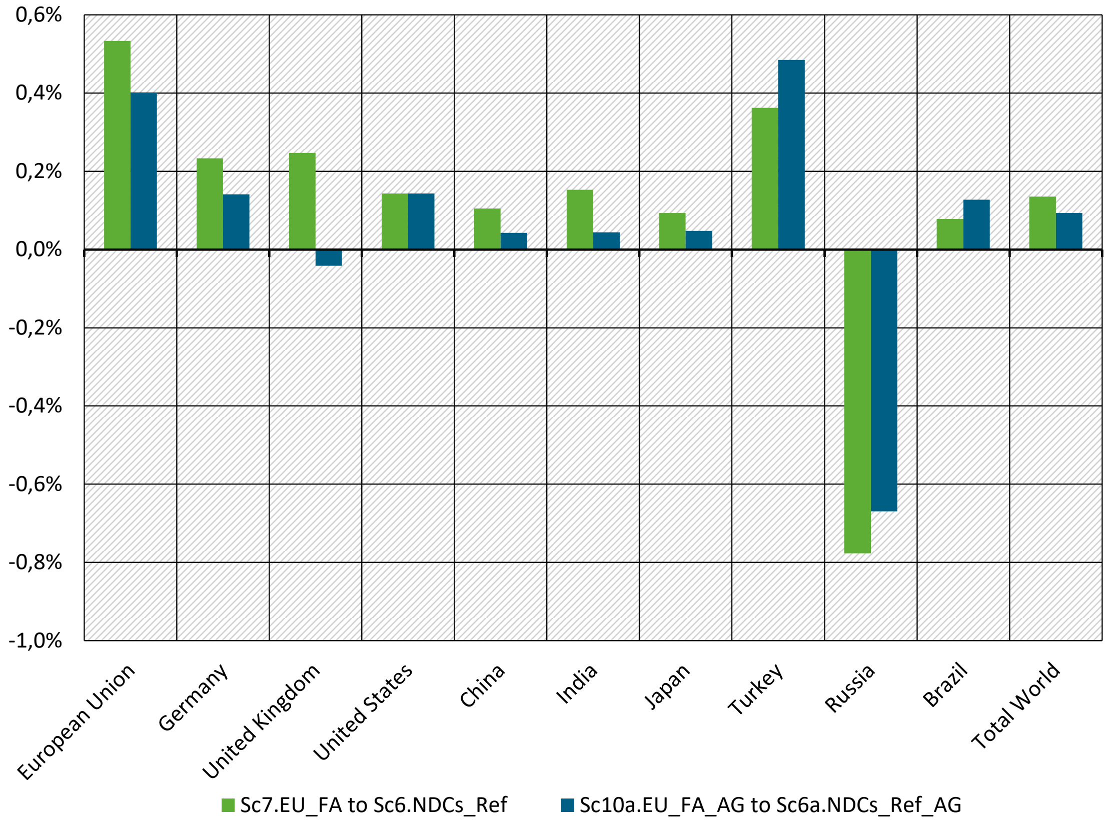
Source: GINFORS-E.

4.3.3 Trade elasticities from GEM-E3

In scenarios 10a to 12a, the Armington elasticities from GEM-E3 are used for scenarios 7 to 9 in GINFORS-E (see Table 5). An additional scenario 6a 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 elasticities lead to less positive macroeconomic effects of climate protection for the EU. Thus, the positive GDP change compared to the reference scenario decreases from around 0.5% to 0.4% in 2030. Effects are similar as in the section before with doubled elasticities, but a bit lower, as also elasticities increase less compared to scenarios 7 to 9. Neighbouring countries such as Turkey and Russia, can benefit a bit from higher trade elasticities (Figure 52).

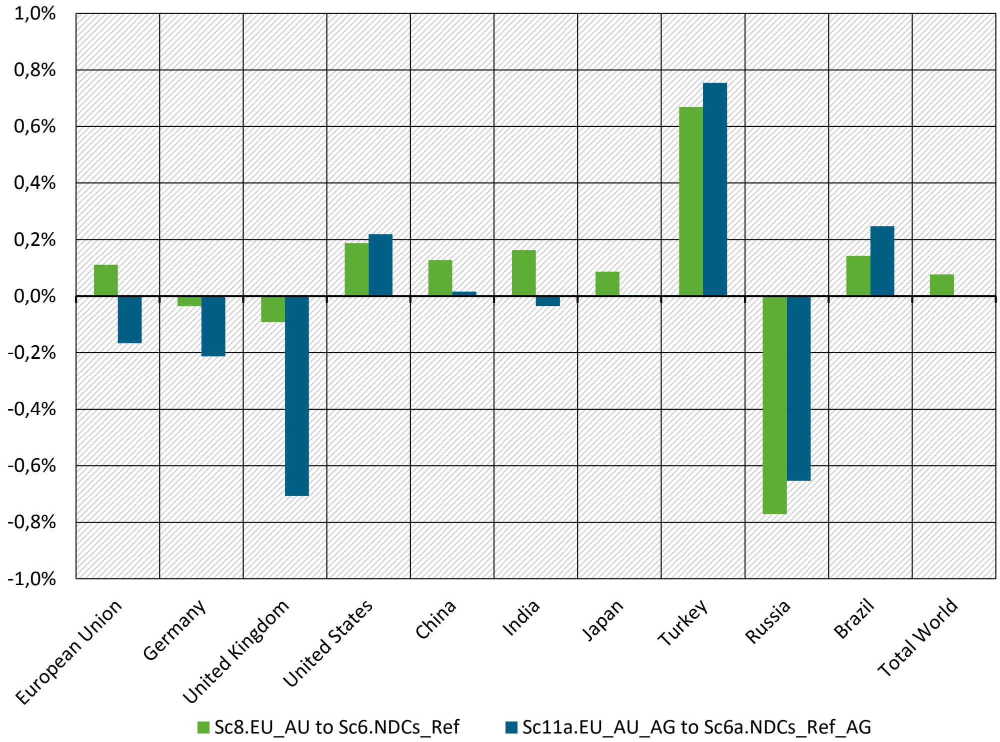
Figure 61: GDP deviations – Sc 7.EU_FA compared to Sc 6.NDCs_Ref and Sc10a.EU_FA_AG compared to Sc6a.NDCs_Ref_AG in 2030



Source: GINFORS-E.

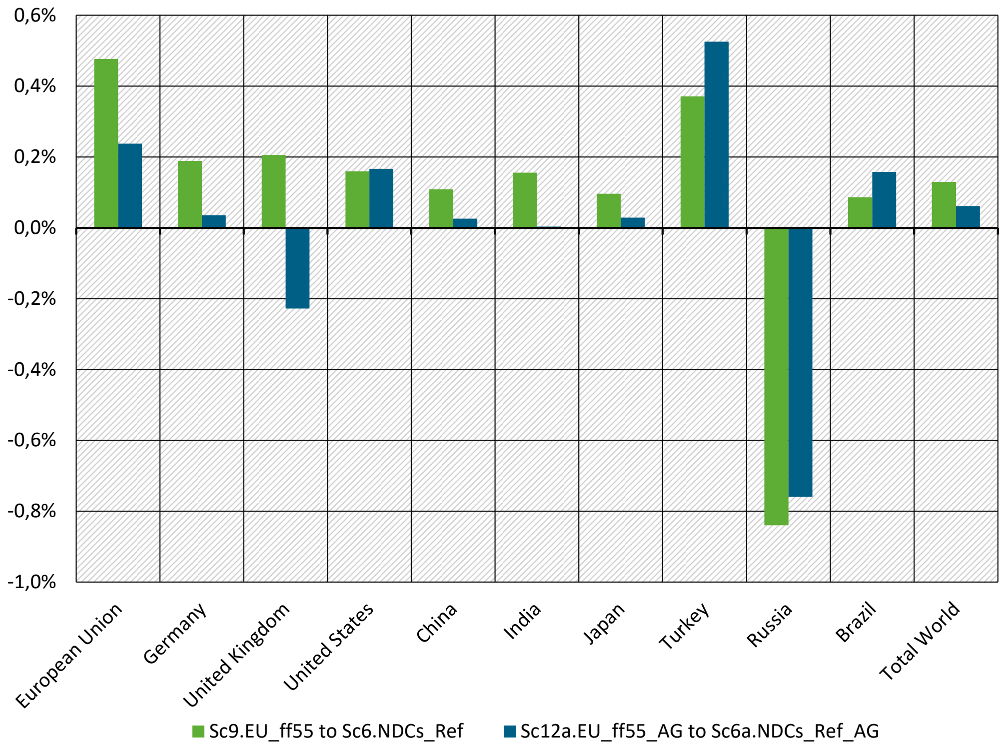
A similar picture emerges for the scenario comparison if the emission allowances are fully auctioned (Scenario 8 vs. 11, Figure 55) or the policy is oriented towards the fitfor55 package (Scenario 9 vs. 12, Figure 57). It is interesting that in the first case the sign of the GDP effect changes in the 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 favours neighbouring countries with strong trade relations with the EU, such as Turkey.

Figure 62: 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 63: 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.

4.3.4 Non-EU Ambition in GHG emission reduction

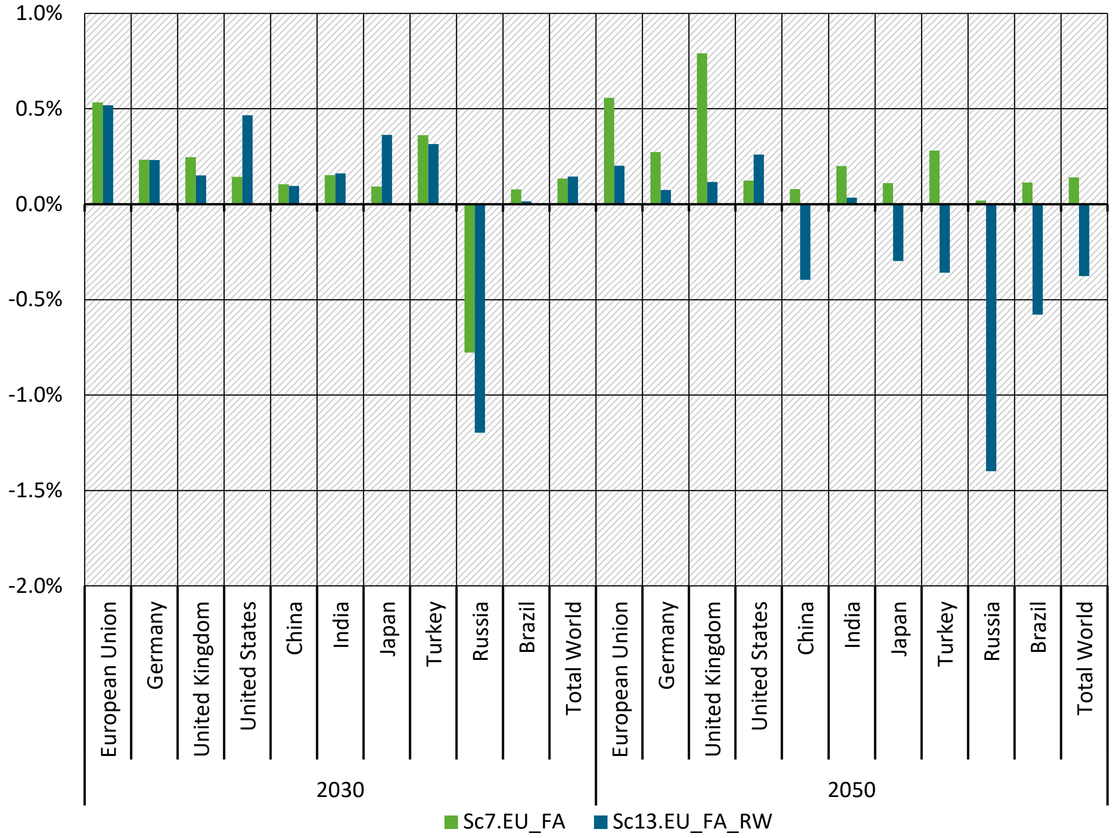
This final set of sensitivities (13-15, EU_FA_RW, EU_AU_RW, EU_ff55_RW) builds on scenarios 7 to 9. A higher level of ambition in climate protection is assumed for important countries outside the EU in the rest of the world. For China, it is assumed that a pathway is followed that will make the country climate neutral by 2060 (Table 9). 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).

Increasing the GHG mitigation targets has a small and mixed impact to the different countries. As for the EU increased investment in clean energy technologies are needed, which have a positive short-term effect but increase costs in the longer term. This will impact the international competitiveness of sectors and economies, in which structures adjust. The total economic effect is initially open and quite small. Fossil energy exporting countries suffer from lower exports.

Figure 64 shows the effects of increased climate protection measures once only in the EU (Scenario 7, EU_FA) and in the EU as well as in China and in advanced OECD countries (Scenario 13 EU_FA_RW) for the case of free allocation of emission allowances. In 2030, the overall economic effects in the EU, China, Turkey and India are remarkably similar in both scenarios. In the case of China, this is mainly due to the quite low carbon price in 2030. 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 13 (EU_FA_RW) than in scenario 7 (EU_FA). 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 13 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 close to zero in 2030, but positive in 2050.

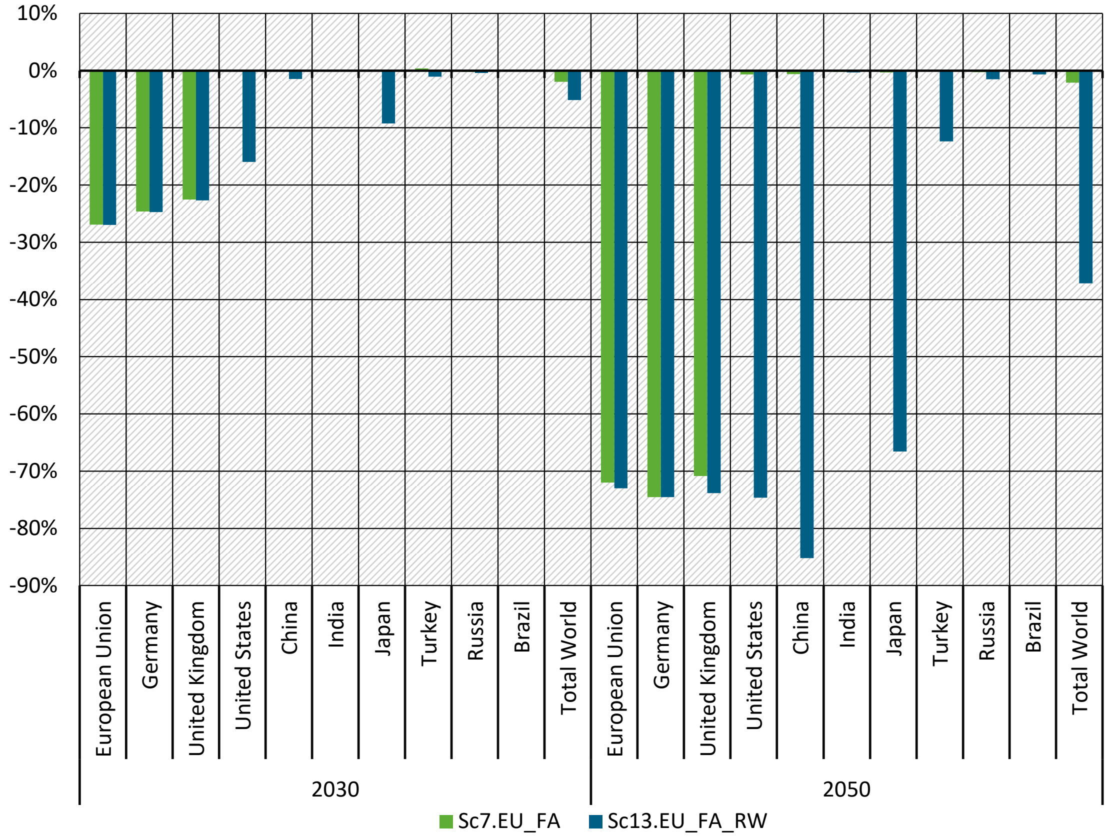
Figure 64: Deviations GDP – Sc13.EU_FA_RW and Sc7.EU_FA compared to Sc6.NDCs_Ref in 2030 and 2050



Source: GINFORS-E.

Of course, the climate protection scenario is still unbalanced when looking at the development of CO_2 emissions(Figure 65). While nothing happens in India and Brazil, emissions in China decrease very significantly. And in the EU, as well as in the USA and Japan, emissions are around 70% lower than in the reference.

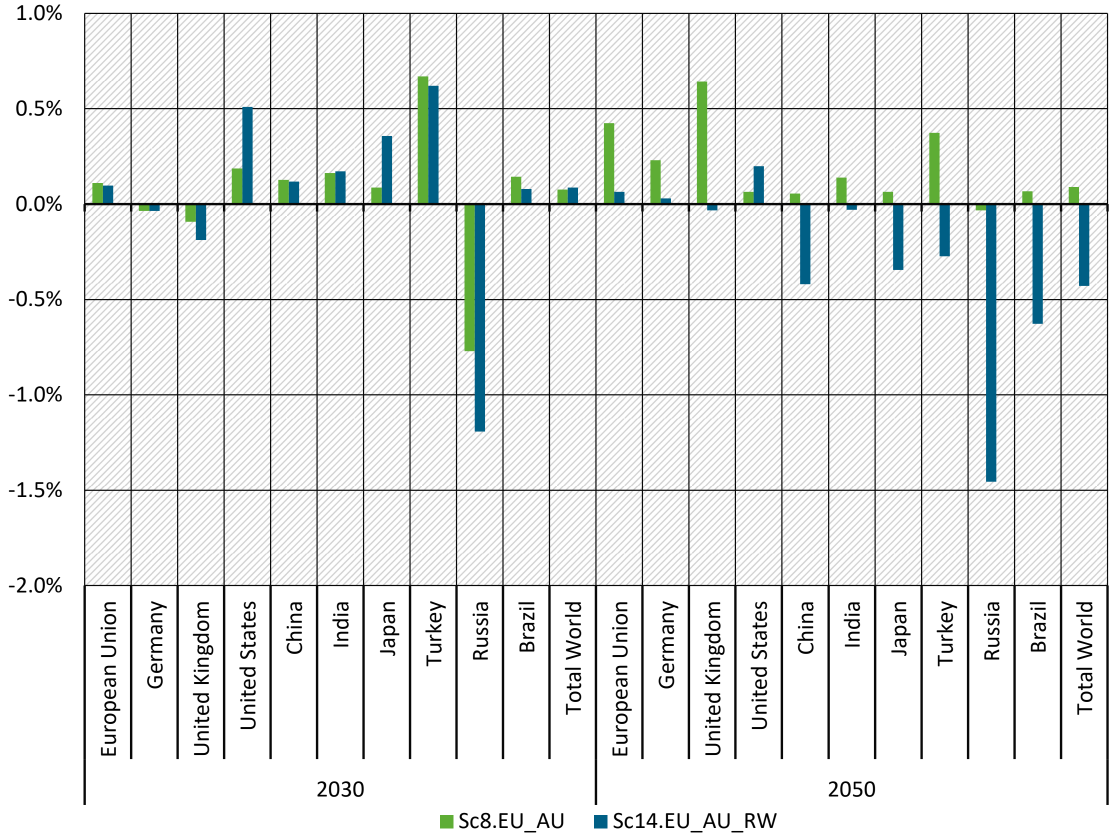
Figure 65: Deviations in carbon emissions per capita – Sc13.EU_FA_RW and Sc7.EU_FA compared to Sc6.NDCs_Ref in 2030 and 2050



Source: GINFORS-E.

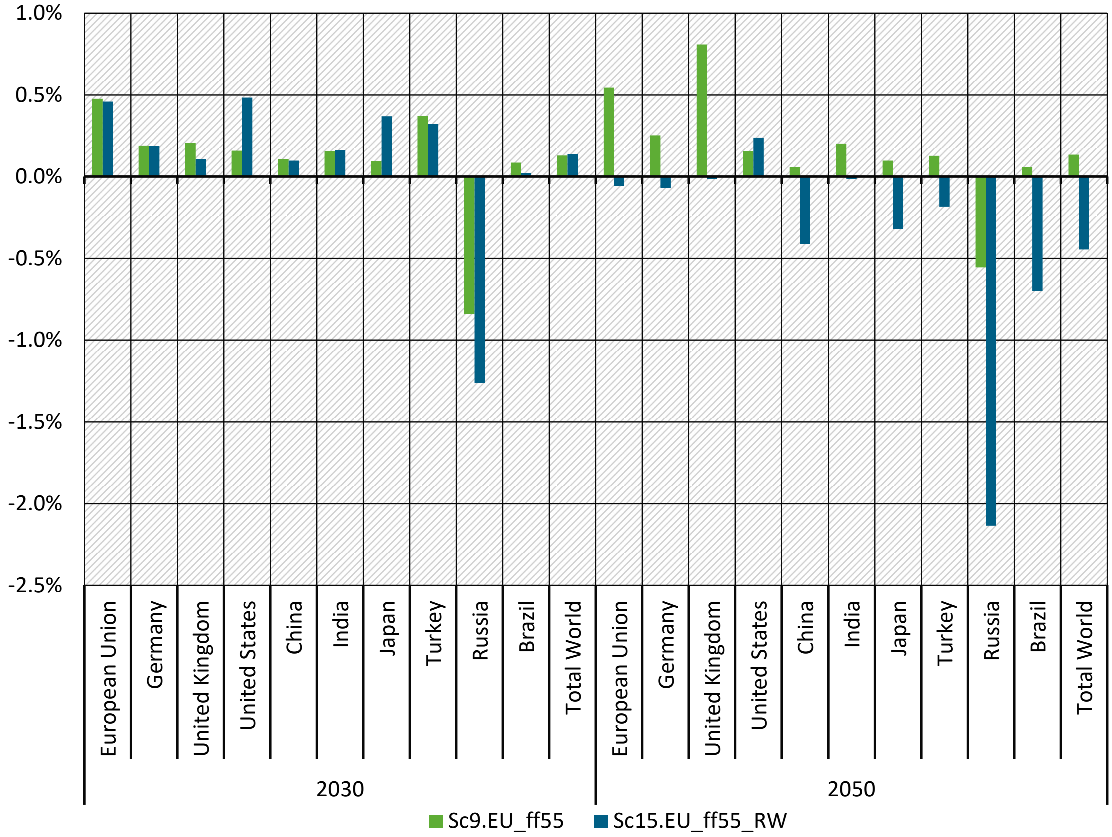
In the two variants with full auctioning (Scenario 14, Figure 66) and with the implementation of the fitfor55 package in the EU (Scenario 15, Figure 67), the effects on the overall economic effects and on CO_2 emissions are similar to those with free allocation. However, it is noticeable that the GDP effects in the EU are slightly worse in the case of full auctioning and the fitfor55 package with international participation.

Figure 66: Deviations in GDP – Sc14.EU_AU_RW and Sc8.EU_AU compared to Sc6.NDCs_Ref in 2030 and 2050



Source: GINFORS-E.

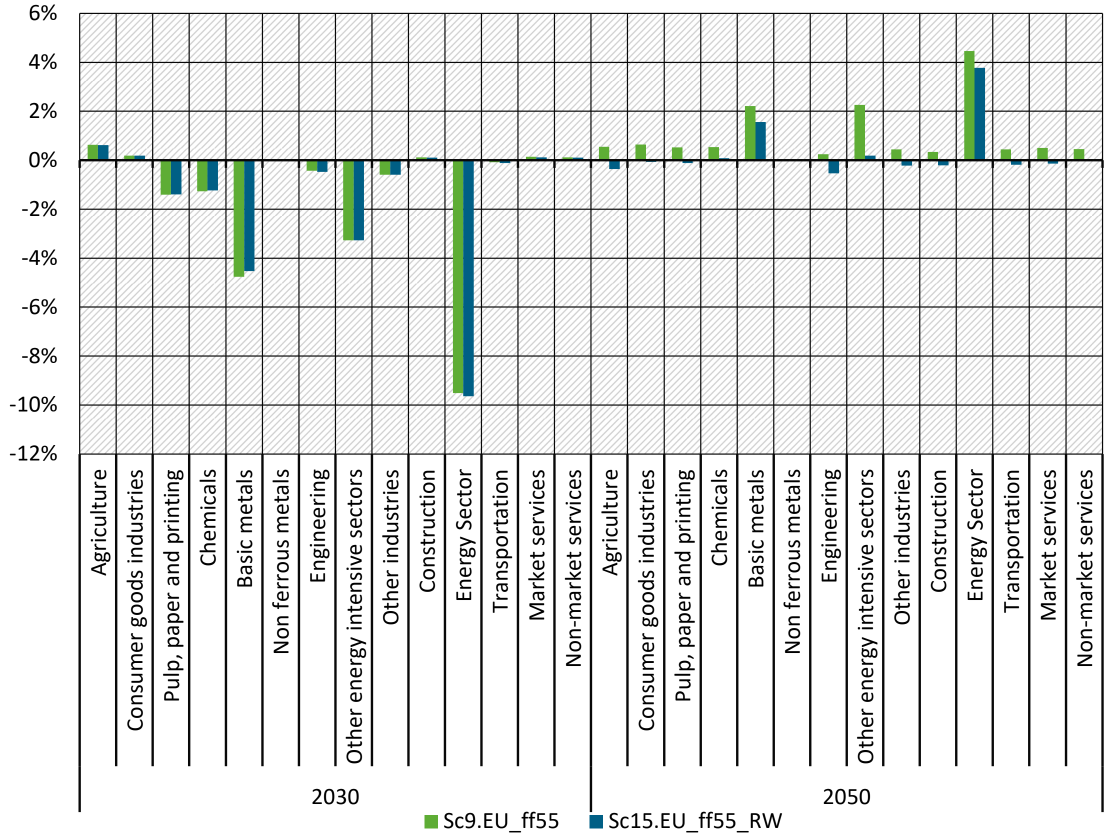
Figure 67: Deviations in GDP – Sc15.EU_ff55_RW and Sc9.EU_ff55 compared to Sc6.NDCs_Ref in 2030 and 2050



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 somewhat larger in 2050, but there is no structural change visible (Figure 68).

Figure 68: 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.

5 Comparison of GEM-E3 and GINFORS-E results

5.1 Results for scenario 6: NDCs_Ref

The two models have been harmonized via scenario 1, which is presented in more detail in the respective technical report. The following tables give an overview of the differences in Scenario 6, NDCs_Ref, which is the starting point for the comparison of the effects of unilateral ambitious climate policies of the EU. The differences between the GINFORS-E results and the GEM-E3 results are described in each case.

It can already be seen in the historical data for 2015 that there are partly significant differences in the baseline data. In the case of GDP in Purchasing Power Parities (PPP) (Table 27), this is mainly due to different base years with different exchange rates (2014 in GEM-E3 and 2010 in GINFORS-E). Here, an attempt has been made to align the future growth rates. However, there are also historical differences in energy consumption and energy-related emissions between the two models, which are discussed in more detail in the respective technical report.

Table 27: Relative differences in GDP between GINFORS-E (USD2014) and GEM-E3 (USD2010)

Country (aggregate)	2015	2020	2025	2030	2040	2050
European Union	-3.1%	2.1%	0.8%	3.0%	3.4%	1.7%
Germany	-5.3%	1.3%	0.8%	2.8%	2.3%	-1.0%
United Kingdom	-7.7%	-3.1%	-2.0%	1.4%	4.0%	5.8%
United States	-6.5%	-5.5%	-3.4%	-2.0%	3.4%	4.6%
China	-21.9%	-16.4%	-13.7%	-14.4%	-10.0%	-4.2%
India	-3.3%	-7.0%	-10.8%	-13.2%	-14.7%	-17.9%
Japan	27.4%	34.6%	40.9%	43.1%	38.8%	41.4%
Turkey	32.5%	52.6%	51.3%	50.4%	52.1%	40.9%
Russia	-14.8%	-9.2%	-10.2%	-9.0%	3.9%	12.9%
Brazil	2.4%	13.1%	11.6%	12.6%	11.6%	4.0%
Total World	**-5.7%**	**-0.4%**	**-0.7%**	**-0.8%**	**-0.3%**	**-1.5%**

Source: GEM-E3 and GINFORS-E.

Table 28: Relative differences in gross inland energy consumption in GINFORS-E and final energy consumption in GEM-E3

Country (aggregate)	2015	2020	2025	2030	2040	2050
European Union	-8.8%	-5.2%	-9.2%	-10.3%	-12.9%	-18.2%
Germany	4.0%	12.0%	10.7%	10.3%	6.8%	-2.7%
United Kingdom	-13.1%	-11.4%	-12.6%	-11.0%	-9.0%	-11.0%
United States	3.9%	5.1%	9.8%	9.9%	9.8%	6.4%
China	1.7%	6.0%	6.9%	2.5%	-7.9%	-18.3%

Country (aggregate)	2015	2020	2025	2030	2040	2050
India	-7.1%	0.0%	-7.3%	-11.3%	-16.4%	-20.3%
Japan	-2.8%	-1.2%	5.6%	7.7%	4.9%	0.2%
Turkey	-14.1%	-11.7%	-9.2%	-9.3%	-10.0%	-16.2%
Russia	0.0%	-0.3%	-2.4%	-4.6%	-6.9%	-10.6%
Brazil	-2.5%	-6.2%	1.6%	6.3%	11.4%	6.1%
Total World	**5.5%**	**9.1%**	**10.1%**	**8.1%**	**3.7%**	**-1.8%**

Source: GEM-E3 and GINFORS-E.

Table 29: Relative differences in energy-related[11] CO_2 emissions between GINFORS-E and GEM-E3

Country (aggregate)	2015	2020	2025	2030	2040	2050
European Union	-6.8%	-2.1%	-9.3%	-7.3%	-0.6%	-1.8%
Germany	-1.5%	4.5%	-0.9%	8.9%	25.4%	11.4%
United Kingdom	-8.5%	-3.2%	-3.6%	5.1%	19.7%	40.3%
United States	-3.3%	-2.0%	7.7%	8.7%	20.4%	17.1%
China	-0.9%	-0.2%	7.7%	4.8%	-0.1%	-4.6%
India	-3.8%	-8.9%	-17.0%	-14.9%	-8.9%	-3.2%
Japan	-0.3%	-3.0%	-1.4%	3.4%	2.2%	-0.9%
Turkey	-5.4%	-9.2%	-11.7%	-4.0%	2.1%	0.0%
Russia	-2.8%	-11.6%	-12.2%	-12.3%	-9.8%	-13.8%
Brazil	-5.5%	2.2%	4.2%	17.0%	22.7%	15.8%
World	**-0.3%**	**2.2%**	**5.7%**	**6.5%**	**9.3%**	**8.2%**

Source: GEM-E3 and GINFORS-E.

5.2 Scenario Comparison: Unilateral EU action (7, 8, 9 vs 6)

The two models share many common features but also have fundamental differences. Both models use similar datasets comprising of input-output tables, bilateral trade matrices, and energy balances. GEM-E3 is calibrated on a single base year. The GEM-E3 production and consumption functions are dynamically calibrated over time starting from their base year values following normative assumptions. GINFORS-E is calibrated on a time series of historical data. The factor demand and consumption functions in GINFORS-E are empirically estimated on long time series data. The price elasticities in GINFORS-E are generally lower than those assumed in GEM-E3. Consistent with this, lower Armington elasticities for international trade are also applied in GINFORS-E. This is based on the model philosophy that adjustment processes take longer than in the CGE model, which reflects faster adjustment processes.

[11] Energy-related emissions are emissions from fuel combustion.

The key model differences, which are presented in the table below, explain some of the differences in results. Optimisation and full utilisation rate mean that the economy in the reference is at an optimum. Climate policy through higher CO_2 prices usually leads to slightly negative macroeconomic effects unless specific assumptions are made about additional financing. Investment is more constrained in GEM-E3 than in GINFORS-E. In contrast, the empirically estimated behavioural equations, together with the assumption that capacity is not fully utilised, allow for additional climate change investments to be taken in GINFORS-E, which can have a positive effect in the more demand-driven modelling. Elasticities of substitution tend to be lower in GINFORS-E, which, together with assumptions about mark-up pricing, investment and financing, make the GINFORS-E model more responsive to climate policy in general. Impacts in terms of GDP or production changes in non-carbon intensive sectors and not directly affected countries tend to be higher than in GEM-E3.

Table 30: Key model features

Feature	GEM-E3	GINFORS-E
Economic agents' behaviour	Optimisation	Non-Optimisation – empirically estimated
Price formation	Cost minimization, market clearing	Mark-up pricing
Growth / Dynamics	Technical progress, capital accumulation, Output Multiplier	Demand driven through increasing investments and or consumption, output multiplier, price increases on markets reduce growth
Macroeconomic closure	Savings equal investment on national or regional level	Investments can surpass savings on national level
Labour Market	Involuntary unemployment through a labour supply curve. Endogenous unemployment though labour supply function.	Endogenous unemployment
Elasticities	Nested CES, CET Armington function, LES Consumption functions	Factor demand functions, international trade adjusted to reproduce an Armington function: lower elasticities in GINFORS-E (especially for non-energy inputs and trade elasticities)
Investment	Based on Tobins Q (firms profitability compared to cost of capital replacement)	Follows past relations (no optimisation, capital partly substitutes energy)
Financing	Additional to the reference scenario financing has to become available from agent's savings or cancelling of investment projects	Indefinite financing is available at a given capital cost
Capital Stock / Capacity utilisation rate	Full utilisation rate	Less than 1 utilisation rate

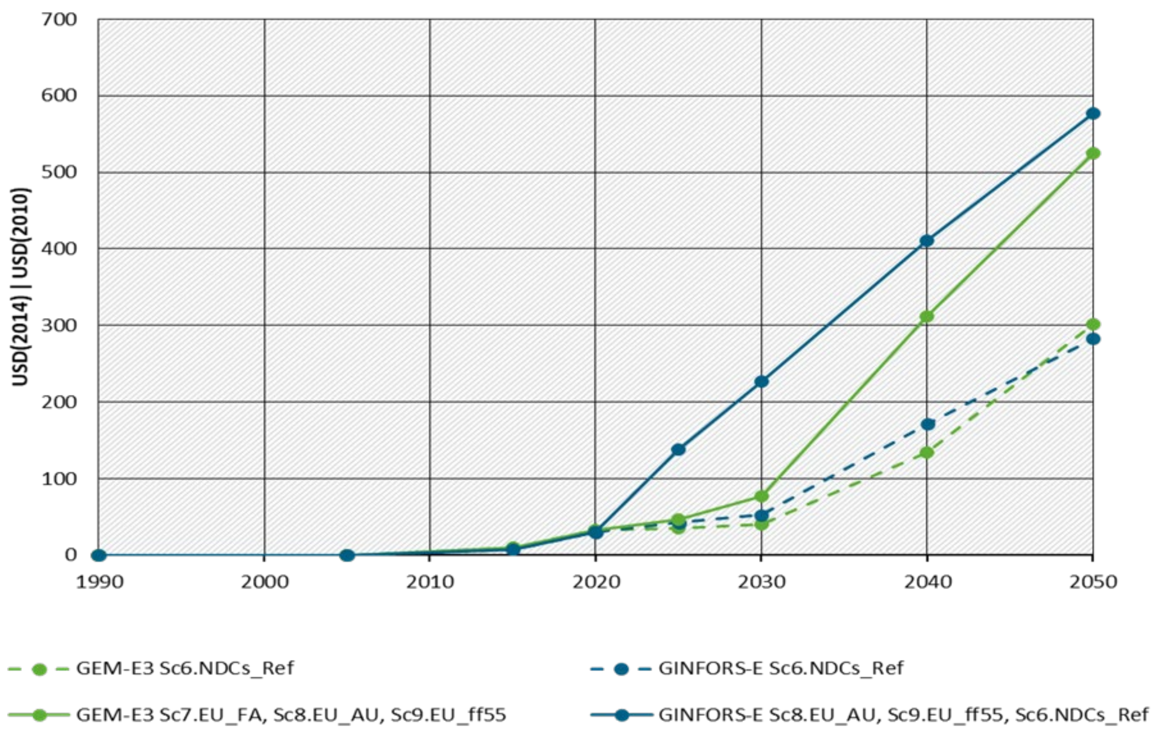
Source: Own compilation.

In reference scenario 6 (NDCs_Ref), the carbon prices in both models are similar. In 2030, quite low prices of 52.6 USD2010/t CO_2 in GINFORS-E and 39.9 USD2014/t CO_2 in GEM-E3 are sufficient to achieve the target of a 40% GHG reduction compared to 1990. In the following years, prices rise sharply in both models and reach a level of about 300 USD to achieve a GHG reduction of 80% compared to 1990. In the target scenarios 7 to 9, the differences in CO_2 prices are significantly larger. While GINFORS-E requires a price of 226 USD/t in 2030, GEM-E3 requires a much lower price of around 76 USD to reach a GHG reduction of 55%. By 2050, the prices then converge again strongly and are at 524 USD2014 in GEM-E3 and 577 USD2010 in GINFORS-E. This difference in carbon prices indicates the following:

1. In the short term the GEM-E3 is more flexible regarding the representation of abatement options (hence the lower carbon price).
2. In the long-term remaining GHG emissions are harder to abate and both models have a similar and steeper "implied" marginal abatement cost curve.

An important aspect must always be considered when interpreting the following results: Already in the reference, high carbon prices are necessary in 2050 and emissions decrease strongly after 2030. The scenario comparison only measures the delta between a 95% to an 80% GHG reduction in 2050. The following results do not describe the overall effects of climate protection in Germany and the EU, but only the effects of this difference.

Figure 69: EU carbon prices in scenarios 6 to 9



Source: GEM-E3 and GINFORS-E.

Both models find positive carbon leakage rates for carbon-intensive sectors with GEM-E3 having significantly larger rates in the case of free allocation and full auctioning (despite the lower carbon prices that the CGE model produces). This result is partly driven by the higher trade (Armington) elasticities in GEM-E3 allowing for easier substitution between domestic and imported products. Other elasticities of substitution are also higher in GEM-E3 than in GINFORS-

E, which increases substitution processes away from the carbon-intensive sectors and also increases carbon leakage. In GEM-E3 the introduction of a CBAM is quite effective, hence in scenario 9 the carbon leakage rate even goes to negative.

At a sectoral level, the leakage takes place in the carbon intensive and trade exposed sectors. According to both models, basic metals is the most vulnerable sector regarding carbon leakage. GEM-E3 considers chemicals together with non-metallic minerals as sectors also quite exposed. Both models present the highest carbon leakage rates in Scenario 8. Full auctioning increases the risk of carbon leakage considerably according to both models. At the same time, the differences for scenarios 7 and 8 between the two models are high. In GEM-E3, the leakage effects in the designated ETS sectors are between three- to ten-times higher than in GINFORS-E. In scenario 9 with the CBAM, GEM-E3 reports negative leakage rates, i.e. an additional emission reduction in non-EU countries takes place. A reason is, that carbon prices for imports from non-EU countries to the EU increase more due to the CBAM in scenario 9 than the carbon prices in the EU between scenario 6 and scenario 9, as there already is a substantial carbon price in the reference scenario 6 in the EU. In GINFORS-E, leakage rates are lower in scenario 9 than in the case of free allocation in scenario 7, with the exception of paper products and printing. But they remain positive. The figures for the ETS sectors also include power generation with extremely low leakage rates.

Table 31: Carbon leakage rates by sector for 2020 to 2050 – each in comparison to Sc6.NDCs_Ref

	GINFORS-E			**GEM-E3**		
	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55
Paper products and printing	1.59%	1.91%	1.72%	11.25%	14.22%	-15.21%
Chemicals and pharmaceutical products	5.60%	7.84%	1.29%	34.57%	75.41%	-98.17%
Other non-metallic minerals	5.65%	6.57%	6.19%	18.92%	47.77%	-103.40%
Basic metals	17.10%	22.44%	11.91%	69.04%	144.15%	-436.69%
ETS Sectors	9.8%	13.6%	5.4%	11.6%	24.4%	-36.2%

Source: GEM-E3 and GINFORS-E.

In the short term until 2030 the EU escalating carbon prices increase production costs for EU located firms deteriorating competitiveness on the internal and international markets. However, changes in costs are relatively low and both models report relatively low leakage rates below 37% with the exception of full auctioning in GEM-E3.

Table 32: Carbon leakage rates by sector for 2030 – each in comparison to Sc6.NDCs_Ref

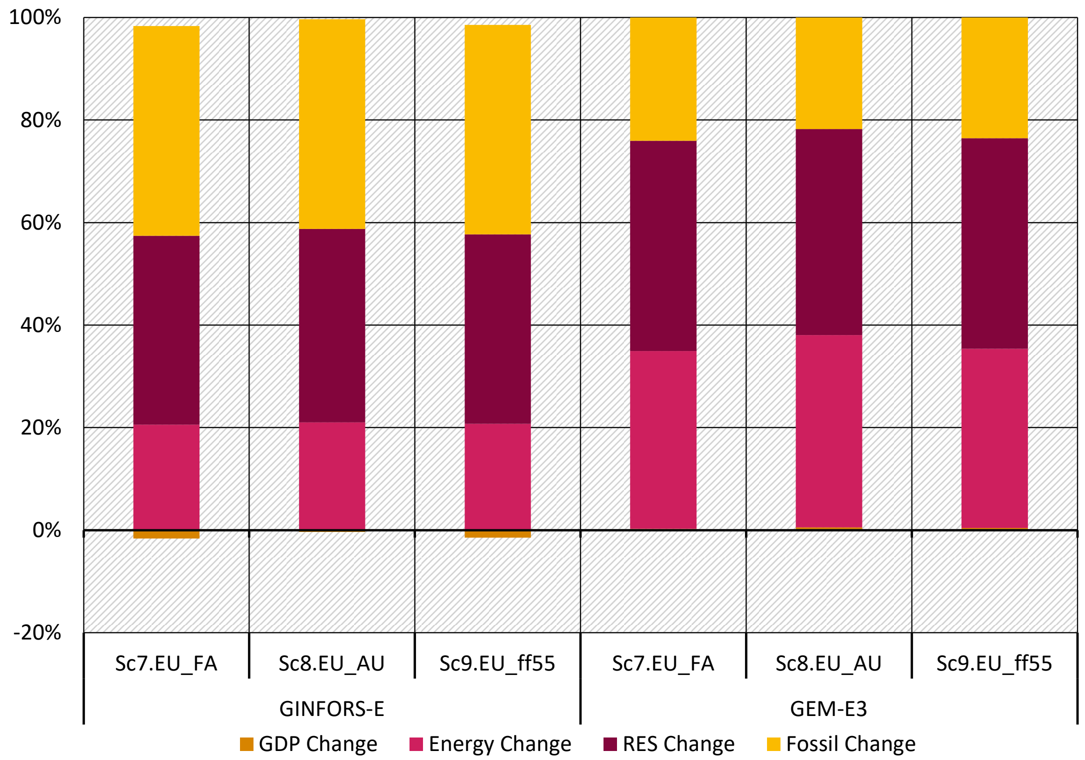
	GINFORS-E			**GEM-E3**		
	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55
Paper products and printing	1.10%	2.09%	1.35%	0.9%	9.2%	-2.2%
Chemicals and pharmaceutical products	5.87%	10.40%	5.63%	37.2%	88.7%	6.6%
Other non-metallic minerals	10.07%	19.52%	9.26%	1.8%	33.9%	-23.7%
Basic metals	18.34%	26.97%	17.99%	10.5%	95.8%	-124.8%

	GINFORS-E			GEM-E3		
	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55	Sc7.EU_FA	Sc8.EU_AU	Sc9.ff55
ETS Sectors	10.5%	17.2%	10.1%	2.2%	16.2%	-8.0%

Source: GEM-E3 and GINFORS-E.

The two models show different adoptions of the technological choices to reduce GHG emissions. GINFORS-E decarbonises the energy system mainly by substituting fossil fuels (fossil change) and RES deployment (energy change). GEM-E3 ranks first RES deployment (RES change) and energy efficiency improvements. Changes in activity (GDP change) are marginal in both models (Figure 70).

Figure 70: EU emission reduction Kaya decomposition for 2030 – compared to Sc6.NDCs_Ref in 2030 (left – GINFORS-E, right – GEM-E3)



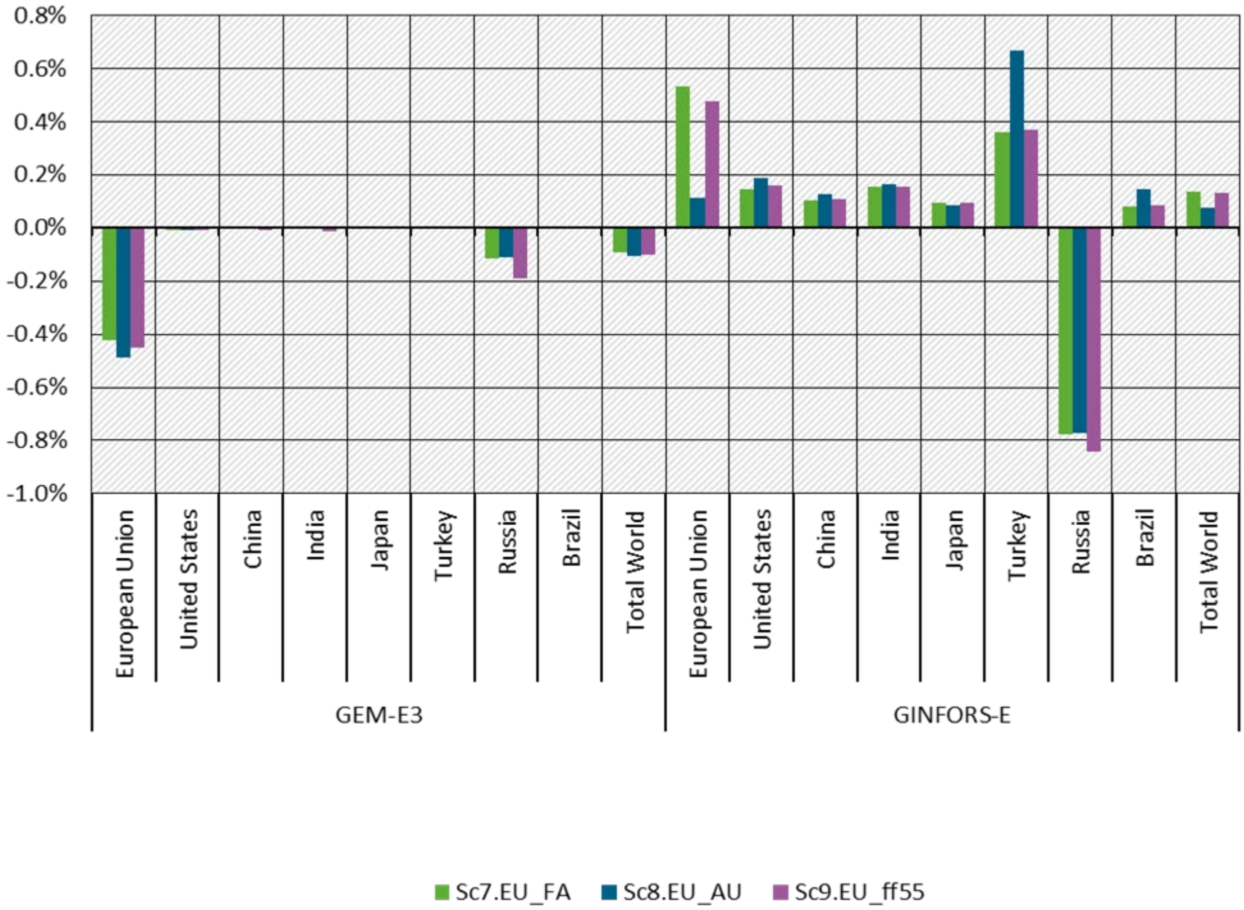
Source: GEM-E3 and GINFORS-E.

In scenarios 7 to 9, the country GDP effects are predominantly slightly negative in GEM-E3, and positive in GINFORS-E, except for Russia where the negative effects are much more pronounced in GINFORS-E than in GEM-E3 (Figure 71). It is also interesting to note that the more positive GDP results in GINFORS-E apply both for countries with ambitious climate goals in scenarios 7-9 (EU as a whole, Germany, UK) and in general also for countries without such goals (such as USA, India, Japan and Turkey). The difference in GDP in both models is driven by the crowding out effect and lower constraints in GINFORS-E as briefly described above. In GEM-E3 additional investments in clean energy have to be financed by cancelling investments of equal value elsewhere in the economy whereas in GINFORS-E the additional investments are financed from idle financial deposits. Additional investment has positive short-term demand effects but will increase capital costs in the long-term. So GINFORS-E allows for some temporal shift of investments. In addition, the GEM-E3 model assumes full (100% utilisation rate) operation of equipment (factories), hence additional demand for goods may create inflationary effects (which lessen in the long term once investments increase the production capacity of the economy). On the other hand, GINFORS-E assumes utilisation rates of below 1, i.e. availability of idle production capital, and it is possible for factories to meet the additional demand without the (full) inflationary effects.

As noted above, for the EU, the two models show different signs for the effects in 2030. In GEM-E3, the negative effects for the EU-28, Germany and the United Kingdom are between 0.3 and 0.6% compared to the reference. In the CGE model, higher CO_2 prices without any type of carbon revenues recycling lead to a deceleration of the growth rate in GDP. The effects are in a small range between 0.4% and 0.5% for the EU, strongest with full auctioning and smallest with free allocation of emission allowances. Other countries are hardly affected in GEM-E3. One exception is Russia, which can export less fossil fuels to the EU.

In GINFORS-E, on the other hand, the GDP effects in 2030 are positive for the EU, with the design of the EU ETS playing a significantly larger role. In the macroeconometric model, the direction of the macroeconomic effects due to the structural changes induced by the carbon price increase is basically open, as the economy has unused resources in the reference. The increased CO_2 reduction in the “target” scenarios 7, 8 and 9 is associated with certain changes in production and consumption structures towards sectors with low carbon emissions and lower fossil fuel imports. Energy efficiency increases and clean energy technology costs are lower. While industrial production is slightly lower than in the reference, as prices increase, production in the construction and service sectors increases a bit. As these sectors account for most of the European production and value added, this change is sufficient for the slightly positive EU GDP effect.

Figure 71: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030



Source: GEM-E3 and GINFORS-E.

In this respect, sectoral production impacts in Figure 72 should be interpreted with caution, because the effects are relatively large in sectors with low shares in total production, while they are hardly visible in the bigger sectors. For GINFORS-E, the design of the EU ETS plays a significantly larger role for the EU. However, the order of the different design options in scenarios 7 to 9 are the same as in GEM-E3. Results show that the measures of free allocation of allowances and CBAM are the more beneficial options for the EU economies when compared to full auctioning in 2030.

Russia is also negatively affected in GINFORS-E because less energy can be exported to Europe. This effect is stronger than in GEM-E3. The (slightly) largest effect is in scenario 9 with a CBAM in the EU, which might be partly explained by a relatively high share of exports to the EU in the reference scenario 6-- not least in the basic metals industry. Other countries benefit from the somewhat stronger economic growth in the EU. On the one hand, as in the case of Turkey, they are more competitive in carbon-intensive sectors in all three scenarios 7-9, but also benefit overall from the higher GDP in the EU.

For the average annual growth rates, however, this means only very small differences between the results of the two models. When considering the differences in the sign of the GDP effects, it should always be considered that the long-term growth dynamics in both models are hardly changed by the climate protection measures.

The scenarios do not include the costs of climate change. According to numerous studies (Feyen et al. 2020), the effects of climate change on the long-term growth path can be significant, so that the costs of climate protection will in any case be much lower than the costs of climate change.

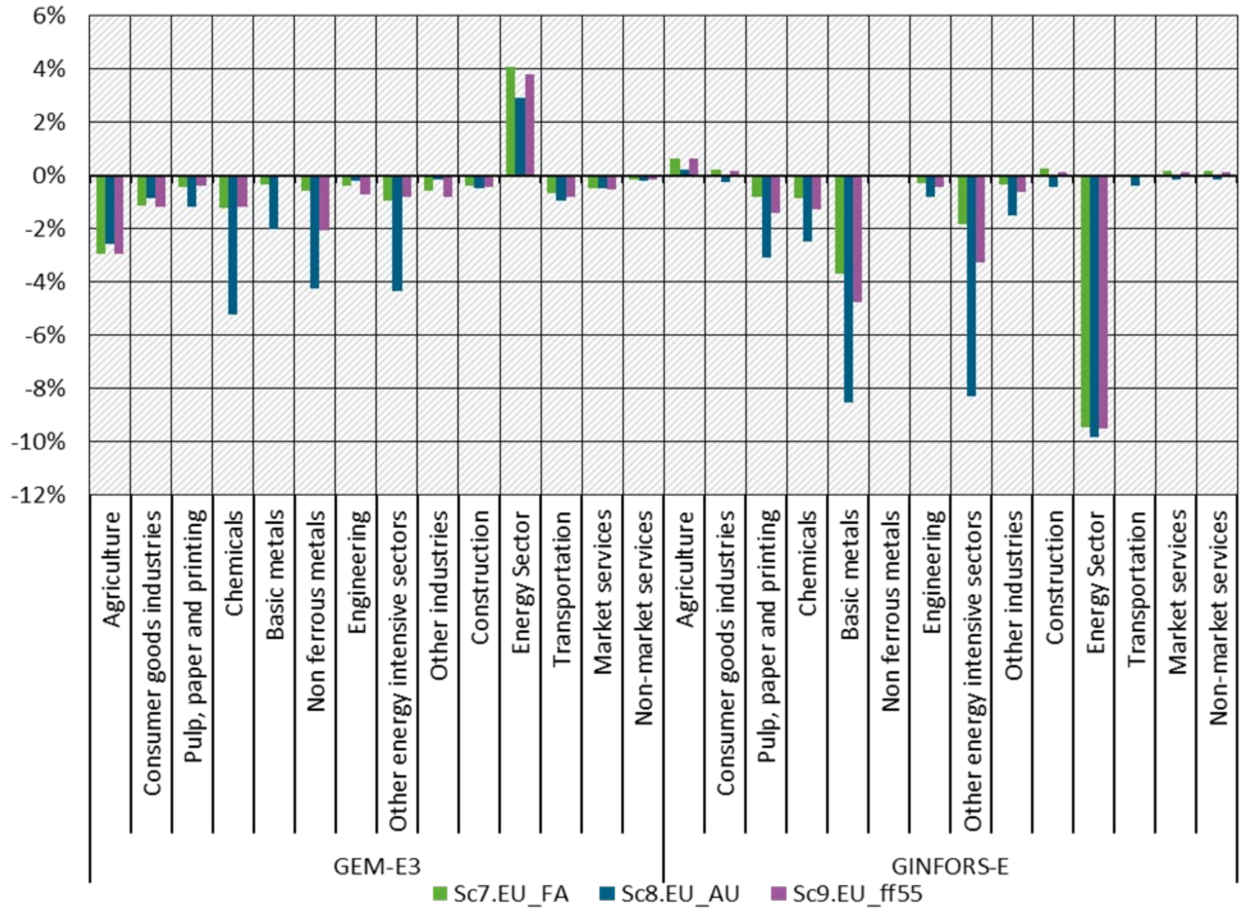
The following Figure 72 figure shows the sectoral production effects in the carbon-intensive sectors. As can be seen, the predicted impacts of more ambitious climate policy in the EU are, by and large, negative in both models (apart from CBAM for the directly affected sectors in GEM-E3, see below). The degree of the production drop in the Basic metals and the "Other energy intensive sectors" (mainly non-metallic minerals such as cement) is somewhat larger in GINFORS-E, whereas for Chemicals the cross-model differences are diverging; in GEM-E3 the drop for the auctioning scenario it is larger while the effect for CBAM is shown to be more positive than in GINFORS-E. In the other sectors, the overall effects also diverge (see below specifically for the Energy Sector).

In GEM-E3 and in GINFORS-E, in line with our expectations the introduction of the CBAM leads to positive effects compared to auctioning in all three energy-intensive sectors where it is applied – chemicals, basic metals, and other energy intensive sectors. Remarkably, in GEM-E3, the CBAM even leads to positive production effects for these three sectors compared to the reference with less ambitious climate policy, whereas free allocation, and even more the auctioning case, have negative production impacts in these sectors. This is remarkable because – as explained below – the assumed CBAM does not cover exports, nor "downstream" industry production that uses the ETS-covered products as inputs. At the same time, the assumed free allocation in Scenario 7 covers 80% of the sectors' emissions (in line with an estimation on free allocation shares in Germany where such estimates are available from DEHSt (e.g., 2023)). This might explain a part of the more positive effect of Scenario 9 versus Scenario 7. In contrast, in GINFORS-E, the CBAM scenario leads to slightly larger drops in production than free allocation.

The effects on the energy sector go in different directions. In GINFORS-E, declines in gas use up to 2030 are not offset by higher electricity production, whereas energy production increases in GEM-E3.[12] In GEM-E3 and in GINFORS-E the CBAM protects the energy intensive industries in the domestic market, which leads to the reduction in imports. However, CBAM increases the production costs of downstream sectors (that are now purchasing more expensive imported materials). These downstream sectors include e.g. engineering, construction and agriculture, but also sectors covered by ETS, as they use their own products as inputs due to the broader sector coverage as well. This increase is having a negative impact on competitiveness and production. In non-energy-intensive sectors as services, the effects in GINFORS-E are slightly more positive.

[12] In GEM-E3 the clean energy technologies manufacturers are represented separately allowing for a better capture of value chains and import/export dependence. The effects on the energy sector go in different directions

Figure 72: EU sectoral production – deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030

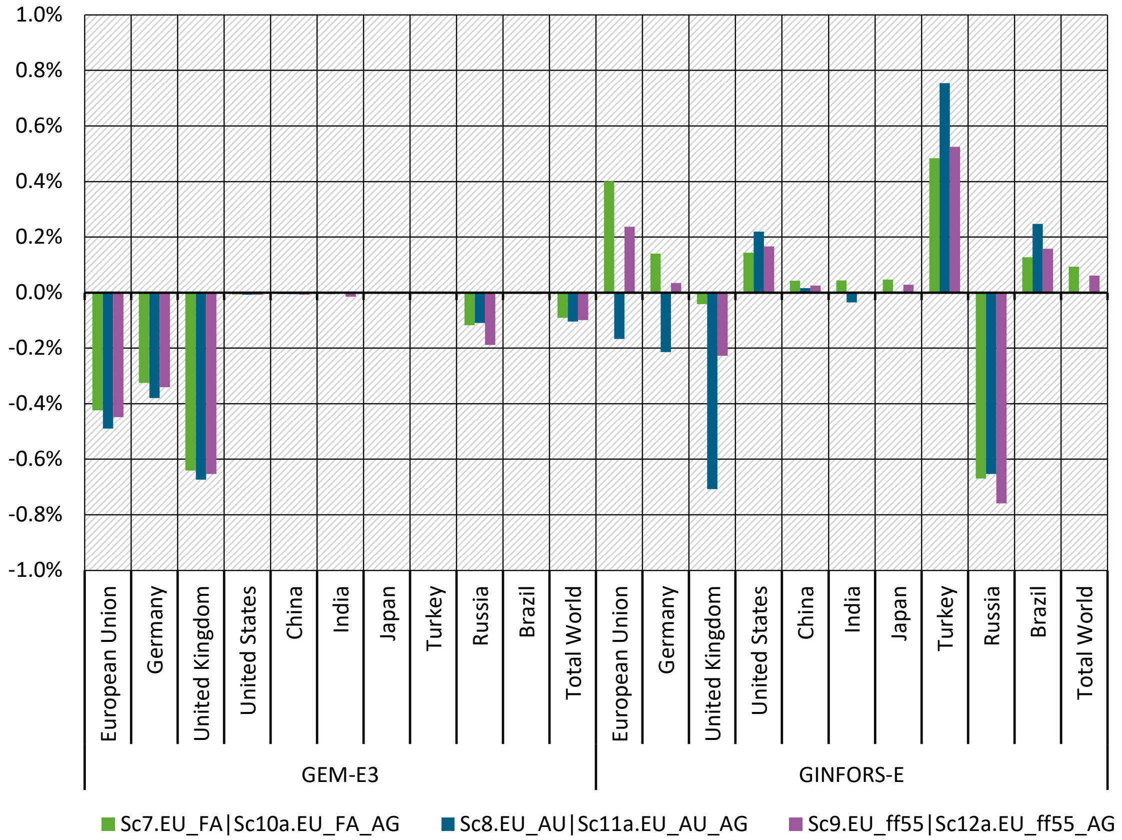


Source: GEM-E3 and GINFORS-E..Brief comparison with identical Armington elasticities: Unilateral EU action against respective reference

In the following, we compile how the EU's unilateral action in scenarios 7 to 9 relative to the reference (NDCs_Ref) plays out in the two models when identical Armington elasticities are assumed. This means that for GEM-E3, as in section 5.2, scenarios 7 to 9 are compared with 6. For GINFORS-E, scenarios 10a to 12a are compared with the modified reference 6G.

As can be seen in Figure 73 major differences in GDP effects for EU remain with identical Armington elasticities in both models, but they are significantly reduced compared to the comparison in section 5.2. Positive GDP effects in GINFORS-E are reduced and get even negative for scenario 8 with full auctioning.

Figure 73: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and from Sc6a.NDCs_Ref_AG for GINFORS-E in 2030



Source: GEM-E3 and GINFORS-E.

In GEM-E3, the Armington elasticities are originally more than 50% higher, with the exception of the other non-metallic minerals sector (slightly lower, see Table 7). The effects of higher Armington elasticities on carbon leakage in GINFORS-E in Table 33 are not clear. Some leakage rates increase compared to scenarios 7 to 9, others are reduced. For chemicals, the leakage gets negative in the case of CBAM in scenario 12. They remain low compared to the rates in GEM-E3. Small relative changes in production in the rest of the world, which is not further decarbonizing, have a strong effect on leakage rates, which should be interpreted with caution.

Leakage rates of over (-)100% may come as a surprise, but they are possible in a global model because, unlike in a partial model with a fixed global production volume, e.g. for the steel industry, equilibrium or induced effects can lead to further effects in the total model, which in principle can lead to higher positive or negative effects globally on production and related emissions than in the EU itself. More detailed information is presented in the textbox before Table 15.

For the sectoral production effects, the higher Armington elasticities in GINFORS-E result in significantly higher negative effects in the carbon-intensive sectors when comparing Figure 74 to Figure 72. As a result, the macroeconomic effects also turn out to be somewhat more negative. Even with identical elasticities, the differences between sectors tend to be higher in GINFORS-E than in GEM-E3 and the dispersion is larger. In both models, the full auctioning variant remains by far the worst for carbon-intensive industries.

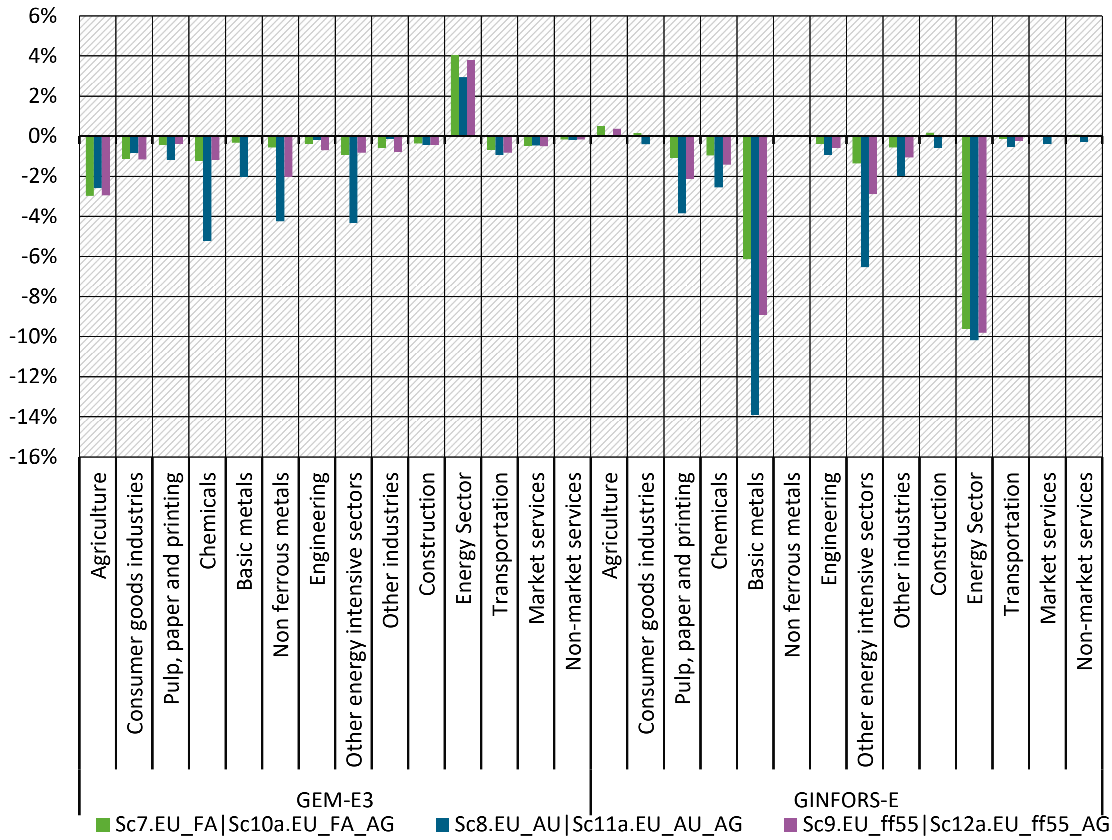
The foreign trade effects are partly determined by the Armington elasticities. Higher elasticities lead to stronger effects in the carbon-intensive sectors. GINFORS-E reacts more strongly to changes in the Armington elasticities than GEM-E3. Aligning the assumptions on the Armington elasticities leads to a convergence of the macroeconomic effects between the two models, but differences remain.

Table 33: Carbon leakage rates by sector for 2020 to 2050 – in comparison to Sc6a.NDCs_Ref_AG (GINFORS-E) and Sc6.NDCs_Ref (GEM-E3)

	GINFORS-E			GEM-E3		
	Sc10a.EU_FA compared to Sc6a	Sc11a.EU_AU compared to Sc6a	Sc12a.ff55 compared to Sc6a	Sc10a.EU_FA compared to Sc6	Sc11a.EU_AU compared to Sc6	Sc12a.ff55 compared to Sc6
Paper products and printing	1.07%	2.04%	1.52%	7.90%	10.31%	-8.86%
Chemicals and pharmaceutical products	4.13%	6.10%	-1.44%	23.69%	47.85%	-70.03%
Other non-metallic minerals	11,12%	16,45%	4,47%	7.62%	22.75%	-73.51%
Basic metals	15.49%	25.06%	9.36%	40.21%	82.59%	-314.14%

Source: GEM-E3 and GINFORS-E.

Figure 74: EU Sectoral Production – deviations from Sc6.NDCs_Ref for GEM-E3 and from Sc6a.NDCs_Ref_AG for GINFORS-E in 2030

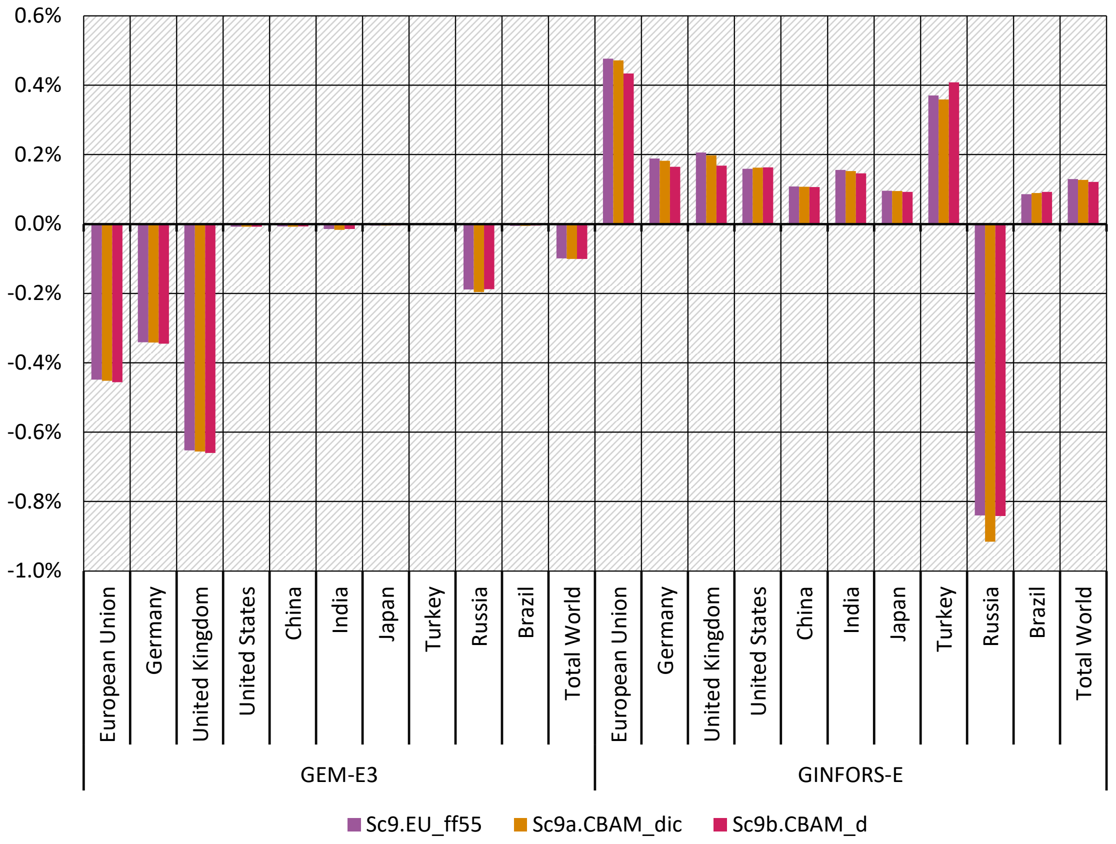


Source: GEM-E3 and GINFORS-E.

5.3 Other scenarios and sensitivities

The design of the CBAM – either only on direct in scenario 9b or on direct and indirect emissions in scenario 9a, and whether reimbursements for the higher electricity costs or not (as in scenario 9a) – has minor impact on the results in both models (Figure 75).

Figure 75: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030



Source: GEM-E3 and GINFORS-E.

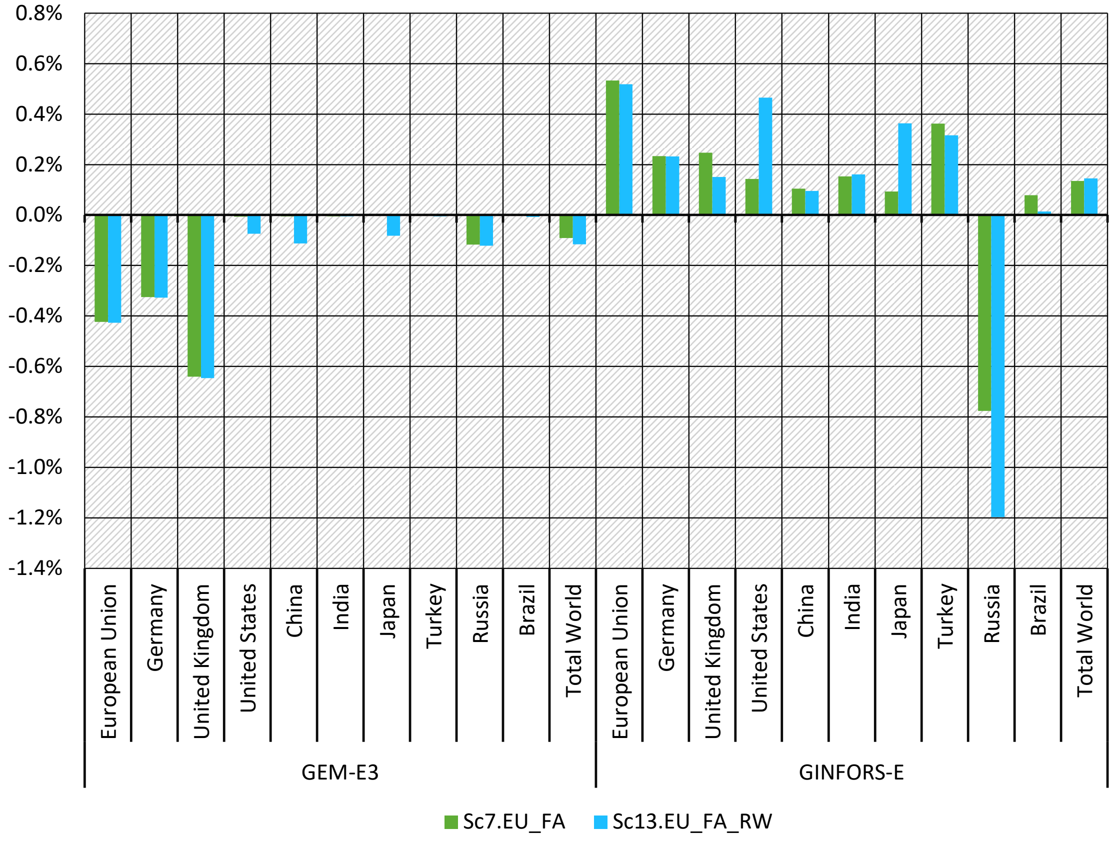
Revenue recycling in section 3.3.3 (scenario 9r) shows for the GEM-E3 model, that revenue recycling can improve the macroeconomic impacts of unilateral EU climate action. High carbon prices generate high revenues. Their use can have an important impact on sectoral and macroeconomic effects. In this sense, recycling via the EU's Innovation Fund and Modernization Fund or carbon contracts for difference, for example, should be seen as essential elements of a successful climate mitigation policy.

Increasing non-EU ambition in climate mitigation in scenarios 13, 14 and 15 shows small negative impacts in GEM-E3 and small and mixed effects in GINFORS-E (Figure 76, Figure 77, Figure 78). In 2050, unilateral action is slightly less economically beneficial for the EU than the participation of advanced OECD countries and China in climate mitigation in both models. But at least in GINFORS-E, climate mitigation with participation of other countries is still more beneficial than no additional climate action, at least in the cases of free allocation and full auctioning, and close to zero in the CBAM case.

There are several reasons for these diverging developments. On the one hand, increasing climate protection in other parts of the world supports the competitiveness of carbon-intensive industries in the EU. At the same time, the costs for the goods produced in these sectors are rising globally, which means that they lose competitiveness in comparison to other products. On the other hand, EU industries may realize fewer benefits from switching to carbon-neutral production, if other countries follow. Finally, exporters of fossil fuels are burdened due to lower demand. Overall, this leads to a slightly negative effect on GDP in the long term due to increasing climate protection in many countries.

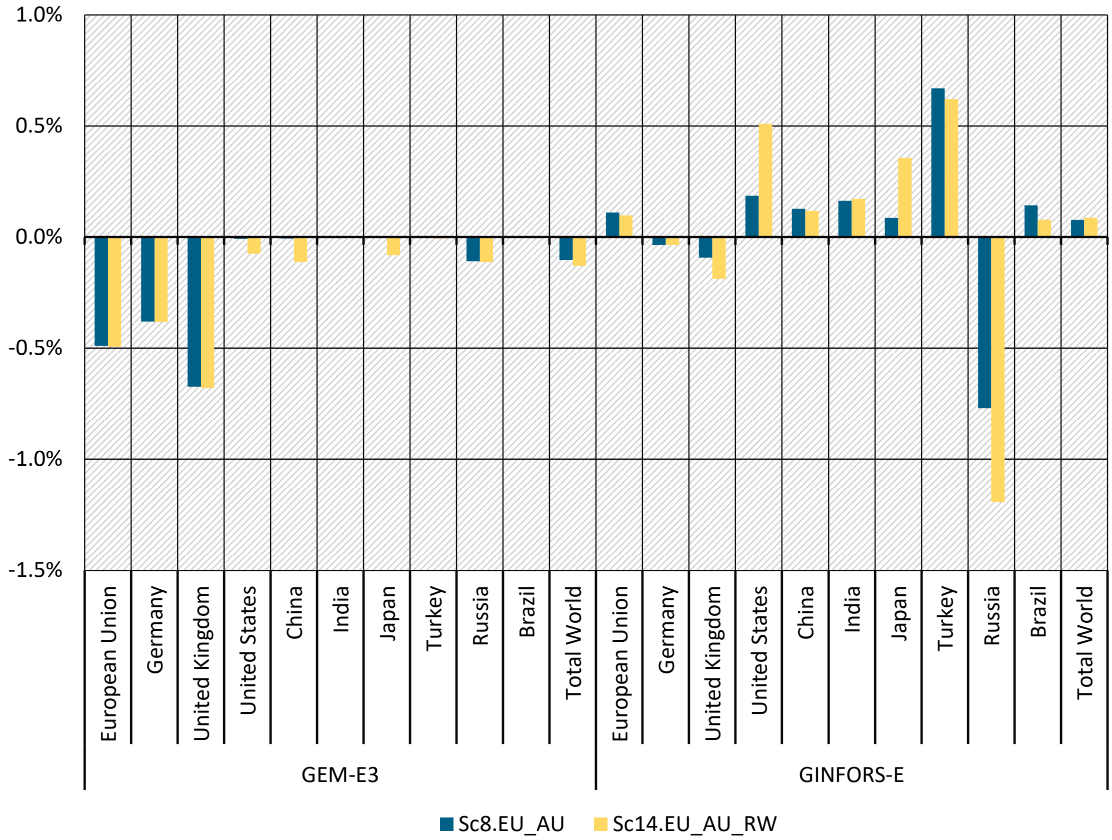
In general, the macroeconomic effects of additional international climate mitigation efforts are small, while the carbon emissions are reduced strongly. Again, it is important to note that the economic benefits of global climate protection in the form of lower losses and damages are not included in the scenarios. They are expected to be several times higher than the reported macroeconomic effects of ambitious climate mitigation.

Figure 76: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030 - Sc7.EU_FA and Sc13.EU_FA_RW



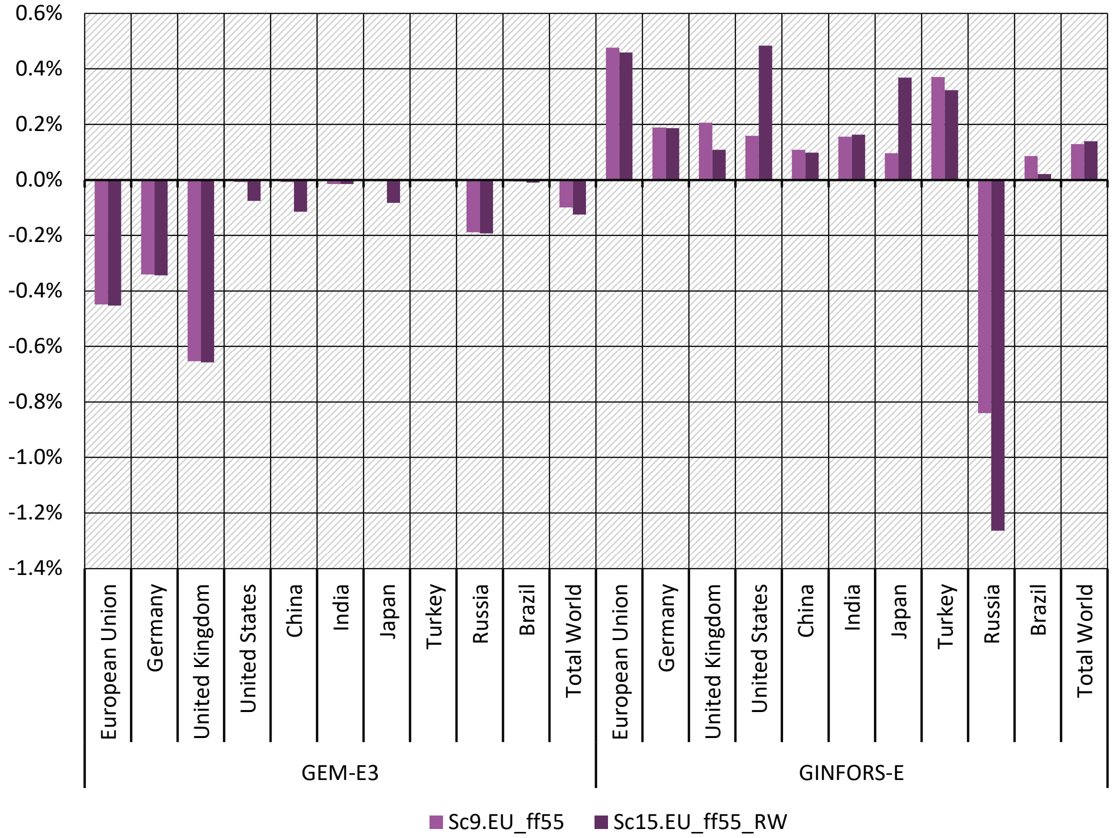
Source: GEM-E3 and GINFORS-E.

Figure 77: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030 – Sc8.EU_AU and Sc14.EU_AU_RW



Source: GEM-E3 and GINFORS-E.

Figure 78: GDP deviations from Sc6.NDCs_Ref for GEM-E3 and GINFORS-E in 2030 – Sc9.EU_ff55 and Sc15.EU_ff55_RW



Source: GEM-E3 and GINFORS-E.

6 Conclusions and outlook

Two models which build on different methodologies are used to quantify the socio-economic effects of unilateral EU climate action, assuming either free allocation as currently practiced in the EU ETS, or alternatively, a) full auctioning or b) the gradual introduction of a CBAM with phasing in of surrender obligations. 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.

This report discusses the mechanisms through which these two models provide different insights to the same policy question. The study focusses on the structural differences of the two approaches, as they are reflected in the applied economic models. The focus is on the different insights the two models provide when they are used in assessing the impact of GHG mitigation policies. In many studies macroeconometric, Keynesian-type models present positive impacts on GDP as the ambition to reduce emissions increases, whereas neoclassical models present negative effects. This study assesses the mechanisms through which these materialise, using a set of policy-relevant scenarios for the EU ETS and a Carbon Border Adjustment Mechanism (CBAM). The key factors driving the differences of the model results are the source of financing of the additional investments, the rate of resource utilization, and trade and substitution elasticities.

The policy scenarios regard the EU increasing its GHG emission reduction target from 40% in 2030 to 55% and from 80% in 2050 to 95%, whereas the non-EU countries follow their (unconditional) NDC targets (partly converted to 2030 emissions) and afterwards do not change their policies. We examine different industrial competitiveness measures and designs of the EU ETS including free allowances, full auctioning, and a carbon border adjustment mechanism. The scenario setup allows the measurement of carbon leakage (by country/region and sector) and the overall effectiveness of different measures to mitigate it – next to carbon leakage, also in terms of affected sector production.

The key insights can be summarised as follows: There is a risk of carbon leakage in the case of unilateral EU climate action. Carbon-intensive sectors lose international competitiveness and reduce production compared to a scenario without additional climate mitigation in both models. The macroeconomic costs in form of GDP losses are limited in the GEM-E3 model. GINFORS-E even reports small GDP increases for the EU in the case of unilateral action. Negative macroeconomic and sectoral effects can be further reduced by appropriate design of the EU ETS including CBAM. Both models show that the carbon leakage risk is no argument against EU climate action, especially if the small impacts on GDP are compared to GDP losses due to climate change.

The two models (in particular when in GEM-E3 and GINFORS-E the option of “crowding out” is selected as above) show different impacts on GDP, sectoral production, and carbon leakage. In GEM-E3, the GDP effect in 2030 is slightly negative whereas GINFORS-E shows a positive GDP effect in all countries except Russia. Employment follows the GDP effect for both models. A Kaya decomposition analysis show that in GEM-E3 the deployment of RES technologies drives the GHG emission reduction in EU, followed by energy efficiency measures, while GINFORS-E shows that RES technologies and the substitution within fossil fuels are the main contributors. Changes in activity are marginal in both models.

The carbon leakage is calculated over the 2020-2050 period by sector and country or region. The GEM-E3 model found the highest leakage rate in the ferrous metals sector followed by non-ferrous metals and chemicals with an overall leakage rate of 11.6% in ETS sectors, the leakage rate is almost doubled when full auctioning is assumed. In GINFORS-E it is found that basic metals have the highest leakage rate followed by non-metallic minerals, chemicals and rubber and plastic products. Leakage rates are significantly lower than in GEM-E3, as trade (Armington) elasticities and other elasticities of substitution are also lower. Full auctioning increases leakage rates. On a macro level, there is no carbon leakage in GINFORS-E, as emission reductions outside the EU are higher in absolute terms than emission increases in ETS sectors outside the EU. This is driven by reductions in zero carbon technologies due to additional EU climate action.

It can be inferred from the results obtained by GEM-E3 when assuming that the CBAM is introduced (scenario 9) that this policy instrument is effective, since emissions in foreign countries / regions decrease in comparison to the reference scenario (negative carbon leakage). The rationale here is that prices of imported goods exhibit a greater difference to the reference scenario (from zero to the elevated carbon price) than the CO_2 prices in the EU ETS (from the lower carbon price in the reference scenario to the elevated carbon price). In contrast, the leakage rates in GINFORS-E decrease only slightly more with the introduction of CBAM in scenario 9 than in scenario 7 with free allocation. Carbon leakage rates in GINFORS-E respond less strongly to CBAM introduction. The picture is less pronounced for the sectoral production effects: here, neither policy option (free allocation or a gradually introduced CBAM) leads clearly to higher sectoral EU production values.

At a sectoral level, the leakage takes place in the carbon intensive and trade exposed sectors. According to both models, basic metals is the most vulnerable sector regarding carbon leakage. GEM-E3 considers chemicals together with non-metallic minerals as sectors also quite exposed. In GINFORS-E non-metallic minerals are also vulnerable. Both models present the highest carbon leakage rates in the scenario will full auctioning (scenario 8), a policy option which proves to increase the risk of carbon leakage considerably according to both models. At the same time, the differences between the two models are high in the scenarios with free allocation and full auctioning (scenarios 7 and 8). In GEM-E3, the effects in the designated ETS sectors are between three to ten times higher than in GINFORS-E. In scenario 9 with the CBAM, GEM-E3 reports negative leakage rates, i.e. an additional emission reduction in non-EU countries takes place.

In scenarios 7 to 9, the country GDP effects are predominantly slightly negative (when compared to scenario 6) in GEM-E3, and positive in GINFORS-E, except for Russia where the negative effects are much more pronounced in GINFORS-E than in GEM-E3. The difference in GDP in both models is driven by the crowding out effect and lower constraints in GINFORS-E as briefly described above. In GEM-E3 additional investments in clean energy have to be financed by cancelling investments of equal value elsewhere in the economy whereas in GINFORS-E the additional investments are financed from idle financial deposits. Additional investment has positive short-term demand effects but will increase capital costs in the long-term. So GINFORS-E allows for some temporal shift of investments. In addition, the GEM-E3 model assumes full (100% utilisation rate) operation of equipment (factories), hence additional demand for goods may create inflationary effects (which lessen in the long term once investments increase the production capacity of the economy). On the other hand, GINFORS-E assumes utilization rates of below 1, i.e. availability of idle production capital, and it is possible for factories to meet the additional demand without the (full) inflationary effects.

The CBAM is associated with higher GDP than full auctioning at least until 2030 in both models, but lower than the reference for GEM-E3. CBAM cannot completely avoid carbon leakage in the GINFORS-E model because prices in the EU rise and thus international competitiveness decreases on the export side (recall that export rebates have not been assumed). The design of the CBAM has minor impact on the results in both models with respect to the reference scenario – thus, the results indicate that the CBAM is effectively mitigating leakage potentially resulting from higher climate protection ambition. For the future, it makes sense to examine further design options for the CBAM and the EU ETS as a whole. This could include policy instruments which are (or could be) combined with carbon prices. The EU and its member states, for example, apply relevant support measures for carbon-intensive industries, including the innovation funds of the EU or carbon contracts for differences, which have so far only been reflected to a limited extent in models.

Revenue recycling of the increased public budget revenues improve the macroeconomic impacts of unilateral EU climate action. In this sense, the EU's Innovation Fund and Modernisation Fund for example, which recycle revenues back to carbon-intensive industries, should be seen as essential elements of a successful climate mitigation policy. More research is needed to better understand the impact of different recycling mechanisms in the future.

Assumptions on trade (Armington) elasticities are important for the impacts on carbon-intensive sectors and the macroeconomic effects of unilateral climate mitigation of the EU. Empirically robust results for the elasticities would be important in this regard, and the time aspect of potential reallocation and transformation also plays a key role, which should be investigated in more detail. Other model parameters such as elasticities of substitution for energy intensive sectors, different types of revenue recycling or assumptions for international energy prices could also be evaluated more thoroughly for their potential impact.

Finally, the question of international participation in climate mitigation measures is important – even though the informative value of the modelled increased carbon prices in major EU trading partners in our sensitivity analysis (scenarios 13-15) is limited by the fact that countries such as the USA (with the Inflation Reduction Act) do not implement pure carbon price solutions but rather a subsidy-oriented policy framework. Further research is also needed in this direction to model implemented and planned policies more realistically.

As such, increasing non-EU ambition in climate mitigation in scenarios 13 to 15 shows small negative GDP impacts in GEM-E3 and small and mixed effects in GINFORS-E. In 2050, unilateral action is slightly less economically beneficial for the EU than the participation of advanced OECD countries and China in climate mitigation in both models. But at least in GINFORS-E, climate mitigation with participation of other countries is still more beneficial than no additional climate action, at least in the cases of free allocation and full auctioning and close to zero in the CBAM case. The reason for this is that the carbon intensive industries only play a minor role in the overall economy. While they are protected by the intensified international climate protection efforts, the question of how the rest of the world develops economically plays a major role for the rest of the economy. Only slight declines in GDP more than compensate for the effects in the carbon-intensive sector.

In general, the macroeconomic effects of additional international climate mitigation efforts are small, while the carbon emissions are reduced strongly. It is important to note that the economic benefits of global climate protection in the form of lower losses and damages are not included in the scenarios. They are expected to be several times higher than the reported macroeconomic effects of ambitious climate mitigation (Feyen et al. 2020). The message of the study is positive: far-reaching climate protection worldwide is possible and leads only to marginal macroeconomic effects. CBAM is the most suitable of the analysed design options of the EU ETS with regard to carbon leakage. The economic effects (GDP and sectoral industry production), in contrast, for the year 2030 are slightly more positive with free allocation. The results for full auctioning without a CBAM are clearly the worst.

Future modelling could be improved in different directions in particular to better inform policy: Climate policy in the EU treats technologies and process routes partly differently within individual industry sectors, which should also be better reflected in modelling. 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. For policies as the CBAM the current sector differentiation in the models is not adequate. In this regard, specific datasets such as EXIOBASE, GLORIA or GTAP could be explored to what extent more differentiated data is available and respective modelling is possible. The GLORIA database separates for example 2 types of fertilizers, 5 (types of) chemicals, 5 non-metallic minerals and 8 metals (see report on WP 3 for more details).

Distinguishing between parts of an industry that have already been transformed to climate neutrality and those that are still carbon-intensive would also be valuable for modelling. With regard to the industry sectors, it could also be considered and analysed in more detail how different behaviours and time horizons concerning low-carbon investment, which are also influenced by the political framework, can be depicted.

Model coupling could be another option. Energy system or industry sector models have higher subsector differentiation and may also include technology differentiation, e.g., the separation between primary and secondary steel. In this respect, global modelling quickly reaches its limits. For example, there are global energy system models and detailed surveys of the steel market. However, no differentiated data are available on the economic links with upstream and downstream industries in input-output tables for most countries, including EU members. The technical requirements for global modelling also increase sharply with increasing sector differentiation.

In addition, there is a need to further refine the modelling of climate policy design options with a view to the sectors particularly affected and to better understand the impact channels. At the same time, the focus should also be on the newly emerging industries, which have played only a minor role in previous statistics and model data sets. They are at least as decisive for the socio-economic success of climate policy as the carbon-intensive industries. In political practice, policy measures often go beyond pure price instruments. These realities must also be included in climate policy modelling. In any case, it is important to understand what drives economic agents and how their behaviour can be targeted cost-effectively towards climate neutrality. To this end, data availability and computing capacities for modelling socio-economic impacts of climate mitigation policies are improving. Models should be deepened in the future on the one hand and focused on central policy issues and product differentiations on the other.

7 GEM-E3 and GINFORS-E

In this section a brief overview of the two models (GEM-E3 and GINFORS-E) is provided focusing on the key mechanisms regarding carbon pricing the economic/energy system adjustments. Detailed description of the two models is available at Fragkos et al. (2021)[13] and EC - JRC (2021)[14], brief descriptions of the models are provided in the following excerpts.

7.1 GEM-E3 – Short model description

GEM-E3 is a large scale multi-sectoral CGE model that since the 1990s is extensively used by governments and public institutions to assess the socio-economic implications of policies, mostly in the domains of energy and the environment. The development of GEM-E3 involved a series of modelling innovations that enabled its departure from the constraining framework of standard / textbook CGE models (where all resources are assumed to be fully used) to a modelling system that features a more realistic representation of the complex economic system. The key innovations of the model relate to the explicit representation of the financial sector, semi-endogenous dynamics based on R&D induced technical progress and knowledge spillovers, the representation of multiple households (the model represents 460 households distinguished by income group), un-employment in the labour market and endogenous formation of labour skills. The model has detailed sectoral and geographical coverage, with 67 products and 46 countries/regions (global coverage) and it is calibrated to a wide range of datasets comprising of IO tables, financial accounting matrices, institutional transactions, energy balances, GHG inventories, bilateral trade matrices, investment matrices and household budget surveys. All countries in the model are linked through endogenous bilateral trade trans-actions identifying origin and destination. Particular focus is placed on the representation of the energy system where specialized bottom-up modules of the power generation, buildings and transport sectors have been developed. The model is recursive dynamic coupled with a forward-looking expectations mechanism and produces projections of the economic and energy systems until 2100 in increasing time steps: annual from 2015 to 2030 and then five-year period until 2100. The substitution elasticities of the model are not derived from the general literature but are estimated according to its dimensions and functional forms using the latest available datasets. The model is founded on rigorous and sound micro-economic theory allowing it to study in a consistent framework the inter-linkages of the economic sectors and to decompose the impacts of policies to their key driving factors. It is acknowledged that the model simulations are sensitive to several input parameters and modelling assumptions including capital costs of power producing technologies and associated learning rates, cost of capital and financing availability, easiness to substitute production factors, preferences over domestic and imported goods etc. To address the uncertainty within, the model provides the option to make all its parameters stochastic according to user defined probability distributions and perform ex-tensive sensitivity analysis.

The most important results, provided by GEM-E3 are: Full Input-Output tables for each country/region identified in the model, dynamic projections in constant values and deflators of national accounts by country, employment by economic activity and by skill and unemployment rates, capital, interest rates and investment by country and sector, private and public consumption, bilateral trade flows, consumption matrices by product and in-vestment matrix by ownership branch, GHG emissions by country, sector and fuel and detailed energy system

[13] Available at https://www.mdpi.com/1996-1073/14/1/236

[14] Available at https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-ginfors-e/

projections (energy demand by sector and fuel, power generation mix, deployment of transport technologies, energy efficiency improvements).

7.2 GINFORS-E – Short model description

GINFORS-E (global inter-industry forecasting system - energy) is a global model with country and sector details for 64 countries and one region of the rest of the world, based mainly on OECD and IEA data. It is designed for the assessment of economic, energy, climate, and environmental policies up to the year 2050. The model can be used to analyse 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.

The core of the GINFORS-E model is a bilateral world trade model based on OECD data that consistently and coherently models exports and imports of 25 commodity groups for 64 countries and a "rest of the world" region. It includes a macro model for each country consisting of exports and imports, other core components of final demand (private and public consumption and investment), goods markets, and the labour market, based on TINFORGE (Mönnig, Wolter 2020). The models are also divided into 36 categories of goods, corresponding to the latest OECD internationally harmonized input-output (IO) tables. For each country, OECD bilateral trade data at the industry level are linked to the IO tables. The use of domestic and imported inputs, labour demand, and foreign trade depend on relative prices.

The model is solved simultaneously year by year. Almost all model variables are deter-mined endogenously via identity or behavioural equations. The behavioural variables are estimated econometrically as much as possible. Only a few variables, such as population trends and international energy prices, are exogenously specified or held constant based on international projections, such as tax rates. Data for 64 countries plus one region for rest of world include:

- Macroeconomic data as GDP and components (consumption, investment, exports, imports), in constant and current prices plus deflators
- Bilateral trade by 33 product groups
- Population, employment, unemployment, wages
- Input-Output tables (https://www.oecd.org/sti/ind/input-outputtables.htm)
- Sector data for 36 industries: output in constant and current prices, value added, employment, and final demand
- Energy balances
- CO_2 emissions by sector and fuel, other GHG emissions
- Energy prices by user and fuel, including tax rates (VAT, energy)
- Carbon prices

Each national model is linked to an energy model that determines energy transformation, energy production, and final energy demand for 18 energy sources broken down by eco-nomic sector. The model accounts for technological trends and price dependencies.

Industry production prices are determined by unit costs in the countries. For example, if electricity prices rise in the steel industry, producer prices will rise in line with their share of the electricity price. Higher producer prices affect the global competitiveness of the industry in question and other downstream production sectors (e.g. in the automotive industry).

GINFORS-E can be used to analyse the macroeconomic effects of a variety of price changes and policies in individual countries. It flexibly models trade structures, labour markets, energy intensities, and energy carrier structures, considering price dependencies and the situation in individual countries. The use of domestic and imported intermediate inputs, labour demand and foreign trade are modelled as price dependent. Price changes due to tax adjustments are considered. The parameters used in the model equations are estimated econometrically (OLS) based on time series data.

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 (Grave et al. 2015, 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 (Flaute et al. 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. 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).

Another strand of research has focused on resource use and developed a model version GINFORS3 based on WIOD data (Meyer 2011). It has been further developed and extensively applied in various EU FP 7 research projects (Aaheim et al. 2015, Ahlert et al. 2018, Distelkamp, Meyer 2017).

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