CLIMATE CHANGE
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Final report

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

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

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Abstract: Climate Protection Scenarios until 2050 Considering CO_2 Price Differences and Carbon Leakage - a Quantitative Model Comparison

Two models with different model philosophies are used to quantify the socio-economic effects of global GHG reduction scenarios. One model GEM-E3 is a general computable equilibrium model that follows neoclassical theory, the other model GINFORS-E is a macroeconometric model that follows a post-Keynesian approach. This technical report describes the methodical work to make both models largely consistent and subsequently apply four “exploratory” scenarios that do not refer to any particular policies but focus on different global ambition levels. First, a common harmonisation scenario assuming no substantial global climate protection is developed, which is used to calibrate the two models so that the model results correspond as closely as possible. For this purpose, the different databases and the model results for key results on population, economic growth, energy consumption and energy related GHG emissions are described. The subsequent exploratory scenarios cover a benchmark scenario and three global GHG reduction scenarios with global carbon prices with which the 2° and 1.5° targets can be achieved. In a further, modified 2° scenario, the EU achieves its climate targets from the “fit for 55” package in 2030 and 2050, while the rest of the world implements slightly less ambitious climate protection so that overall the global 2° target is reached. The results of the models are compared for important variables for selected countries and regions.

Kurzbeschreibung: Klimaschutzszenarien bis 2050 unter Berücksichtigung von CO_2-Preisdifferenzen und Carbon Leakage - ein quantitativer Modellvergleich

Zwei Modelle mit unterschiedlicher Modellphilosophie werden eingesetzt, um die sozio-ökonomischen Effekte von globalen THG-Minderungsszenarien zu quantifizieren. 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 Post-Keynesianischen Ansatz folgt. In diesem Technical Report wird die methodische Arbeit beschrieben, um beide Modelle weitgehend konsistent zu machen und sie anschließend auf vier "explorative" Szenarien" anzuwenden, die sich nicht auf bestimmte Politiken beziehen, sondern sich auf unterschiedliche globale Ambitionsniveaus konzentrieren. Zunächst wird ein gemeinsames Harmonisierungsszenario ohne substanziellen weltweiten Klimaschutz entwickelt. Es wird zur Kalibrierung der beiden Modelle so genutzt, dass die Modellergebnisse in diesem Szenario möglichst gut übereinstimmen. Dazu werden die unterschiedlichen Ausgangsdaten und die Modellergebnisse für zentrale Ergebnisgrößen zu Bevölkerung, Wirtschaftswachstum, Energieverbrauch und energiebedingten THG-Emissionen beschrieben. Die anschließenden explorativen Szenarien umfassen ein Benchmark-Szenario und drei globale THG-Reduktionsszenarien mit globalen Kohlenstoffpreisen, mit denen die 2°- und 1,5°-Ziele erreicht werden können. In einem weiteren, modifizierten 2°-Szenario erreicht die EU ihre Klimaziele aus dem "fit for 55"-Paket in den Jahren 2030 und 2050, während der Rest der Welt etwas weniger Klimaschutz betreibt, so dass insgesamt das globale 2°-Ziel erreicht wird. Die Ergebnisse der Modelle werden für wichtige Variablen für ausgewählte Länder und Regionen verglichen.

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List of abbreviations

AAGR	Average annual growth rates
boe	Barrel of oil equivalent
CO2	Carbon dioxide
CET	Clean energy technologies
EU	European Union
EU ETS	EU Emissions Trading Scheme
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
Mtoe	Million tonnes of oil equivalent
NDC	Nationally Determined Contributions (in Paris-Agreement)
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parities
RoW	Rest of world
Trn	trillion
UN	United Nations
USD	US Dollar
WEO	World Energy Outlook

Summary

Within the research project “Models for the analysis of international interrelations of the EU ETS and of a CBAM” (see Lutz et al. 2024a for the Summary Report and Lutz et al. 2024b for the Central Report), two models with different model philosophies have been applied to quantify the socio-economic effects of global GHG reduction scenarios. One model GEM-E3 is a general computable equilibrium model that follows neoclassical theory, the other model GINFORS-E is a macroeconometric model that follows a post-Keynesian approach. This technical report describes the methodical work to make both models largely consistent and subsequently apply four “exploratory” scenarios that do not refer to any particular policies but focus on different global ambition levels. First, a common harmonisation scenario assuming no substantial global climate protection is developed, which is used to calibrate the two models so that the model results in this scenario as well as central (predominantly) exogenous parameters correspond as closely as possible. For this purpose, the different databases and the model results for key results on population, economic growth, energy consumption and energy related GHG emissions are described. The subsequent exploratory scenarios cover a benchmark scenario and three global GHG reduction scenarios with global carbon prices with which the 2° and 1.5° targets can be achieved. In a further, modified 2° scenario, the EU achieves its climate targets from the “fit for 55” package in 2030 and 2050 (as proposed in July 2021), while the rest of the world implements slightly less ambitious climate protection so that overall the global 2° target is reached. The results of the models are compared for important variables for selected countries and regions. The carbon prices are mostly higher in GINFORS-E than in GEM-E3, but in the “EU moves ahead” scenario, converge in the EU by 2050. The macroeconomic effects in both models are similar on global level. However, they differ significantly in terms of regional structure. While the EU and Germany in GINFORS-E benefit slightly from global climate protection in all scenarios, the effects in GEM-E3 are slightly negative in the scenario in which the EU moves ahead and in the scenario that achieves the 1.5° target. Compared to the foreseeable costs of climate change, the effects are small.

Zusammenfassung

Im Rahmen des Forschungsprojektes “Modelle zur Analyse internationaler Wechselwirkungen des EU ETS und eines CBAM“ (siehe Lutz et al. 2024a für die Zusammenfassung und Lutz et al. 2024b für den Central Report) wurden zwei Modelle mit unterschiedlicher Modellphilosophie eingesetzt, um die sozio-ökonomischen Effekte von globalen THG-Minderungsszenarien zu quantifizieren. Das eine Modell GEM-E3 ist ein allgemeines berechenbares Gleichgewichtsmodell (CGE), das der neoklassischen Theorie folgt, das andere Modell GINFORS-E ist ein makroökonometrisches Modell, das einem Post-Keynesianischen Ansatz folgt. Im vorliegenden Technical Report wird die methodische Arbeit beschrieben, um beide Modelle weitgehend konsistent zu machen und sie anschließend auf vier "explorative" Szenarien" anzuwenden, die sich nicht auf bestimmte Politiken beziehen, sondern sich auf unterschiedliche globale Ambitionsniveaus konzentrieren. Zunächst wird ein gemeinsames Harmonisierungsszenario ohne substanziellen weltweiten Klimaschutz entwickelt. Es wird zur Kalibrierung der beiden Modelle so genutzt, dass die Modellergebnisse in diesem Szenario sowie die zentralen (überwiegend) exogenen Parameter möglichst gut übereinstimmen. Dazu werden die unterschiedlichen Ausgangsdaten und die Modellergebnisse für zentrale Ergebnisgrößen zu Bevölkerung, Wirtschaftswachstum, Energieverbrauch und energiebedingten THG-Emissionen beschrieben. Die anschließenden explorativen Szenarien umfassen ein Benchmark-Szenario und drei globale THG-Reduktionsszenarien mit globalen Kohlenstoffpreisen, mit denen die 2°- und 1,5°-Ziele erreicht werden können. In einem weiteren, modifizierten 2°-Szenario erreicht die EU ihre Klimaziele aus dem "fit for 55"-Paket in den Jahren 2030 und 2050, während der Rest der Welt etwas weniger Klimaschutz betreibt, so dass insgesamt das globale 2°-Ziel erreicht wird. Die Ergebnisse der Modelle werden für wichtige Variablen für ausgewählte Länder und Regionen verglichen. Die CO_2-Preise liegen in GINFORS-E meist höher als in GEM-E3, nähern sich aber im Szenario "EU geht voran" in der EU bis 2050 an. Die gesamtwirtschaftlichen Effekte in beiden Modellen sind global ähnlich. Sie unterscheiden sich in der regionalen Struktur aber deutlich. Während die EU und Deutschland in GINFORS-E in allen Szenarien leicht von globalem Klimaschutz profitieren, sind die Effekte in GEM-E3 in dem Szenario, in dem die EU voranschreitet, und in dem Szenario, in dem das 1,5°-Ziel erreicht wird, leicht negativ. Im Vergleich zu den absehbaren Kosten des Klimawandels sind die Auswirkungen gering.

1 Introduction

Within the research project “Models for the analysis of international interrelations of the EU ETS and of a CBAM” (see Lutz et al. 2024a for the Summary Report and Lutz et al. 2024b for the Central Report), two models with different model philosophies have been applied to quantify the socio-economic effects of global GHG reduction scenarios. One model GEM-E3 is a general computable equilibrium model that follows neoclassical theory, the other model GINFORS-E is a macroeconometric model that follows a post-Keynesian approach. In this report, the GINFORS-E and GEM-E3 models are harmonised and used for selected scenarios in which on the one hand the current climate policy is frozen and on the other hand harmonised climate protection is pursued with high ambition worldwide. In three scenarios, energy-related CO_2 emissions are reduced to such an extent by 2030 and 2050 that the 2° or the 1.5° target can be met. This technical report serves primarily as a basis for the more differentiated scenarios presented in the central report, which focuses on unilateral climate protection by the EU in connection with the design of the EU ETS.

A particular concern of the project is to work out the role of different models and model types for the socio-economic modelling of comprehensive climate protection measures. To this end, section 2 first discusses the respective databases of the two models and describes the reference data on which the two models were calibrated. Already the databases are different, and complete harmonisation is not possible. This is followed by a comparison of important results of both models for the harmonisation scenario.

This process was made more difficult by the fact that significant changes in climate protection targets occurred during the project. Germany and the EU as well as other countries have increased their climate ambition, most visible in the EU´s “Fit for 55” policy reform package. The Covid pandemic since the beginning of 2020 and the Ukraine war since February 2022, with consequences also for energy supply, world trade and expectations about long-term developments, have led to various adjustments during the project and also the way in which the models take up these developments. At the EU level for example, framework assumptions for the long-term development of population, economic growth, energy prices and emissions have been adjusted several times in this context. For 2030 and beyond, changes have been small, however.

Finally, both models have been updated and partly extended in this period. GEM-E3 now builds on the GTAP 10 database and has been applied in different impact assessments for the ”Fit for 55” package. GINFORS-E has been extended to 2050 and applied in impact assessments for the EU adaptation strategy (EU 2021a) 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).

In section 3, further scenarios with the intention to model global climate policy under different ambition levels are defined and selected results of both models are compared. These scenarios are intended to better understand how the two models address the policy related scenarios in the subsequent Central Report of this project, which distinguish among others different allocation rules or the introduction of a carbon border adjustment mechanism (see Lutz et al. 2024b). In particular, the influence of the models on the results is discussed. Thus, in addition to the “harmonisation” scenario used to harmonise the two models presented in section 2, four exploratory scenarios are defined for the two models. The NDCs-2020 scenario (2) is the benchmark for further scenarios with a global CO_2 price, the 2DEG scenario (3) and the 1.5DEG scenario (5), which efficiently achieves a target through a uniform global price. Another scenario (4), 2DEG_EU, is a variant of the 2° scenario, in which the EU achieves a 95% GHG reduction by 2050 and the rest of the world must achieve a correspondingly slightly lower reduction. Then, selected results of both models are compared. In particular, the influence of the models on the results is discussed.

In the following sections 4 and 5 the results for both models are presented in more detail. The sections show the effects of scenarios with different global climate ambition level in both models.

2 Harmonisation Scenario

2.1 Design and used data

The design and the purpose of the harmonisation scenario have been discussed and agreed on within the project during the year 2020. Based on the specifications for the data sets and expectations on major future developments at the end of 2021, policy scenarios were calculated in the further course of the project, which contain concrete design options for the EU ETS (see Lutz et al. 2024b). It is important to harmonise key parameters and results of the models for a specific scenario. Then differences in model results due to climate policy assumptions can be better traced back to the different model characteristics. This is obvious for key assumptions such as population development or international energy price projections, which are typically exogenous assumptions for global economic models. Harmonisation becomes more difficult if historical data bases are different as in the following. Deviations can come from differences in timeliness of the data, different base years, granularity concerning sectors or countries, or even different calculation methods and classifications.

Assumptions regarding population development stem from recent projections. They are quite stable over time. Assumptions about long-term economic growth are more driven by the current situation (business cycle, COVID-19 crisis, Ukraine war) and expectations. This could imply downward revisions of long-term GDP growth expectations due to the Covid19 crisis and the Ukraine war. Tendencies towards greater independence in important products such as energy sources, memory chips or health products could lead to world trade growing less strongly than previously expected and economic areas becoming less interconnected than expected. Less international competition in turn tends to lead to higher costs and prices and lower economic growth.

Long-term growth assumptions also depend on the method to harmonise national developments on international level. The methods make use of assumptions concerning prices, exchange rates and purchasing power parities to compare GDP developments in countries over time. A different base year can already have substantial influence on the global distribution of GDP and global growth rates.

Regarding energy and related carbon emissions, annual energy and energy-related carbon emission data from the IEA are the main direct or indirect data source. Annual World Energy Outlooks of the IEA are the key source for future global developments. However, they do not show any detail for EU countries. Their developments stem from recent EU reports.

For the EU-27, and for other countries that are part of the EU ETS, the carbon price of around 25 €/t CO_2 in constant prices in the EU ETS is kept constant until 2050. At the time of specification of this scenario in 2020, this was the “best guess” for the “starting year” of the projection; and its assumption of being kept constant until 2050 was deliberate for the idea of this Harmonisation scenario.[1] Allocation of allowances is modelled as in phase 3 of the EU ETS. Allowances for industry are assumed to be partly allocated for free (decreasing from 80 % in 2022 to 30 % in 2027), but in the utility sector all allowances are auctioned. Auctioning revenues go into the general household budget of each member state.

[1] Since the finalization of the harmonization scenario, CO2 prices have now increased to temporarily even around 100 Euro. They are around 70-80 Euro/t at the end of 2023.

Regarding energy efficiency and renewable energy, the scenario is following the trends of the EU Reference Scenario (EU 2021b). For energy efficiency this means that there are certain autonomous energy efficiency improvements over time, which follow historical trends.

For countries outside the EU, climate and energy policies are specified as follows: All carbon prices are set to zero. No carbon prices for other countries or additional climate policies are assumed in the future. Energy efficiency follows historical trends. For renewables, current and stated policies (deployment plans) are assumed.

Table 1: Energy and climate policies in the harmonisation scenario

Countries	ETS		Non-ETS		
	Carbon price	Allocation of allowances	Carbon price	Energy efficiency	Renewables
EU-28	25 €	as close as possible to phase 3 of the ETS/free allocation for industry, full auctioning for utilities	25 €	Following historical trends (as in EU Reference scenario)	Lower than in EU Reference scenario due to lower carbon price in ETS

Source: Own compilation.

Assumptions about energy prices stem from the EU reference scenario (EU 2021b, Table 2.). By the end of 2022, these expectations have not changed much in the case of low climate protection (IEA 2022). In the case of globally ambitious climate protection, however, the IEA expects a significant decline in the prices of fossil energy sources in real terms until 2050.

Table 2: International energy prices in €'15 per boe (harmonisation data)

	2015	2020	2025	2030	2040	2050
Oil	47.2	35.8	54.0	72.2	87.8	106.3
Gas (NCV)	38.7	17.8	27.0	36.2	46.6	51.2
Coal	11.6	8.4	12.0	15.6	18.0	18.7

Source: EU 2021b.

For population and GDP development, both models have been calibrated to meet the following projections. As population is an exogenous variable, implementation is straightforward, and differences should be zero or very small. For GDP, an exact match cannot be achieved in both models. The point here is that the order of magnitude is the same.

For EU countries, historical data of Eurostat is used for the years up to 2021 (Eurostat 2021). For the other years the Economic & Budgetary Projections for the 28 EU Member States (2018–2070) of the 2021 Ageing Report (EU 2021c) is used. Development of other countries including world totals stem from the UN World Population Prospects 2019 in Table 3 (UN 2019). For Germany, population according to the Ageing Report is about 1.5 million higher in 2030 compared to the UN projection.

Table 3: Population in million by country (harmonised data)

Country (aggregate)	2015	2020	2025	2030	2040	2050
EU-28	509	515	519	521	522	520
Germany	81	83	83	83	83	83
USA	321	331	340	350	367	379
China	1407	1439	1458	1464	1449	1402
India	1310	1380	1445	1504	1593	1639
Japan	128	126	124	121	113	106
Turkey	79	84	87	89	94	97
Russia	145	146	145	143	139	136
Brazil	204	213	219	224	229	229
World	7379	7795	8188	8555	9212	9756

Source: EU 2021c, UN 2019.

Note: As the UK has left the EU after decisions about the harmonisation scenario, numbers for the EU-28 are reported here. Starting with the following section, results are reported separately for the EU-27 and the UK.

For GDP we have exploited the projections from IEA (2020) world energy outlook for short-term and OECD (2018a) for long-term harmonisation. Table 4 provides the starting values to which we have adjusted both models as good as possible. As the models are complex systems that determine the GDP of the individual countries endogenously and the historical baseline data already differ slightly, neither model can achieve the targets exactly.

Table 4: GDP by country in PPP in trn $ 2014 (harmonisation data)

Country (aggregate)	2015	2020	2025	2030	2040	2050
EU-28	18.93	18.94	21.75	23.10	26.64	31.01
Germany	3.92	3.92	4.41	4.56	5.11	5.88
USA	17.87	18.74	21.09	23.39	28.06	34.09
China	11.06	14.58	19.68	24.46	31.05	36.15
India	2.20	2.53	3.69	5.01	7.88	11.35
Japan	4.65	4.57	4.88	5.21	5.90	6.60
Turkey	0.85	0.93	1.12	1.33	1.79	2.38
Russia	1.98	2.02	2.25	2.40	2.58	2.73
Brazil	2.33	2.20	2.47	2.75	3.30	3.85
World	80.47	85.92	102.32	117.92	150.92	190.08

Source: EU 2021b, IEA (2020), OECD (2018a).

Note: As the UK has left the EU after decisions about the harmonisation scenario, numbers for the EU-28 are reported here. Starting with the following section, results are reported separately for the EU-27 and the UK.

It must be highlighted in this context, that relations between countries change substantially due to changes in exchange rates. If national GDP is compared in market exchange rates, emerging economies show much lower absolute GDP values compared to industrialised countries such as the USA or Germany. On the contrary, emerging market economies such as India and China are larger when compared in purchasing power parities to industrialised countries (Table 4).

Table 5 gives an overview of the sources for historical data for the main indicators compared. GEM-E3 mainly builds on Eurostat and GTAP data, whereas GINFORS-E uses OECD and IEA data, which is the source for energy and emission data in the GTAP database. Global UN population data includes future estimates. For the EU countries, GEM-E3 uses historical data from Eurostat, while GINFORS-E again uses UN population data. In both models, exogenous future population development is taken from the Ageing report of DG ECFIN (EU 2021c) (in Table 3). For GEM-E3 the GTAP database has been used for the final energy consumption and Enerdata for energy-related CO_2 emissions. In GINFORS-E, IEA energy and emission data is used. In the electricity sector, it was assumed for the EU that no new nuclear power plants would be built beyond those planned and that CCS would not be used. For the future, all variables in the table and many other with the exception of population, carbon and energy prices, are calculated endogenously in both models.

Table 5: Comparison of data sources in GEM-E3 and GINFORS-E

		GEM-E3		GINFORS-E	
		For EU countries	For non-EU countries	for EU countries	for non-EU countries
Population		Eurostat (2021) and EU (2021c).	UN (2019)	Eurostat (2021) and Ageing report (2021)	UN (2019)
GDP		Eurostat (2021) and EU (2021c).	IEA (2020) and OECD (2018a)	EU (2021b)	OECD (2018b) and World Bank (2018)
Energy		GTAP 10 based on IEA, Agiuar et al. (2019)		IEA (2019a)	
(Energy-related) Emissions		Enerdata		IEA (2019b)	
Value added	Germany	Eurostat (2019)		OECD (2018c)	
	EU	Eurostat (2019)		OECD (2018c)	

Source: Own compilation

2.2 Comparison of GEM-E3 and GINFORS-E results

This section shows the deviations between the results of the two models in the harmonisation scenario. The differences between the GINFORS-E results and the GEM-E3 results are described in each case with GEM-E3 as the reference, which is set to 100%. **Population developments** in the two models are identical for all countries.

In the case of **GDP**, there are for certain countries significant differences (Table 6), as GDP is endogenous in both models. But even in the base year for the projections (2015), the historical values differ significantly in some cases, because in GINFORS-E the OECD values for 2015 are shown in USD2010, while the values in GEM-E3 are shown in USD2014. This means that exchange rate changes and different price developments between 2015 and 2020, which have prevented a better match, are reflected in the results. Additional differences until 2020 are due to the use of historical macroeconomic data in GINFORS-E until 2017.

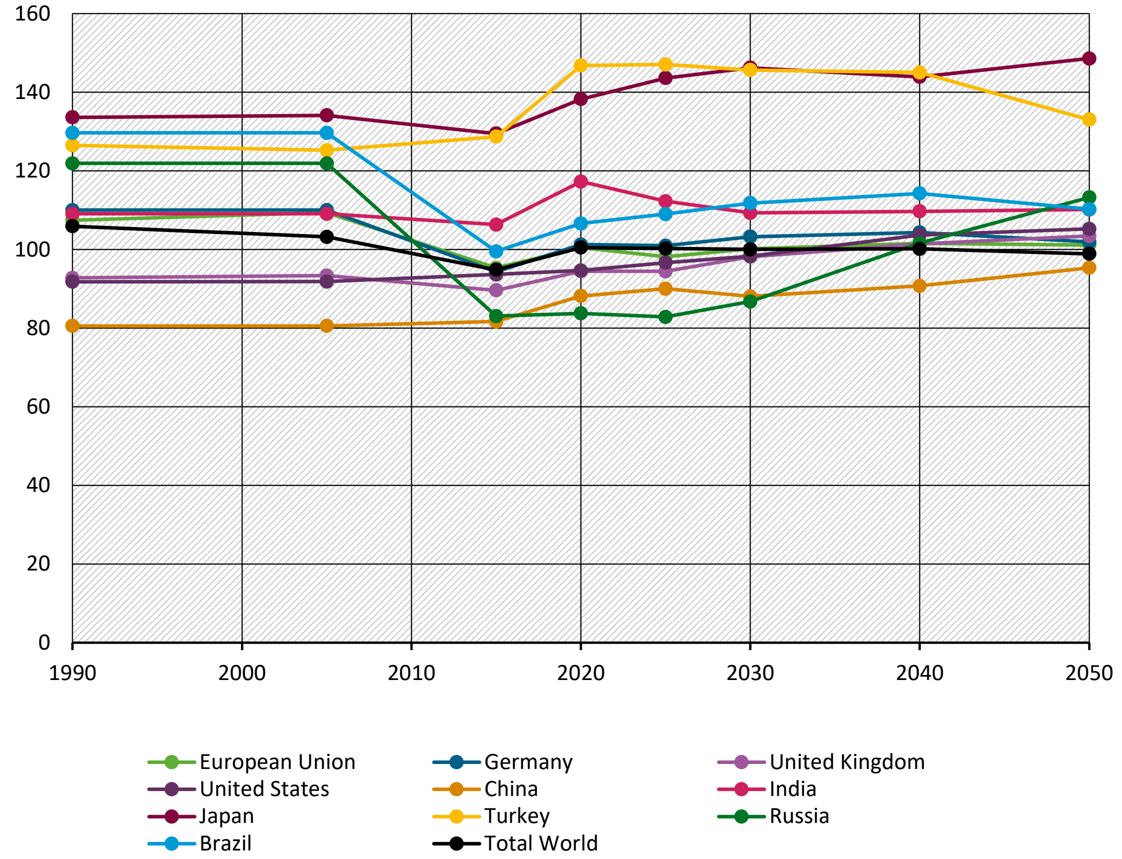
Table 6: Relative differences in GDP in constant prices of GINFORS-E compared to GEM-E3

Country (aggregate)	2015	2020	2025	2030	2040	2050
EU-27	-4.7%	0.5%	-1.9%	0.2%	1.6%	1.2%
Germany	-5.7%	1.3%	1.0%	3.3%	4.3%	1.9%
United Kingdom	-10.4%	-5.5%	-5.5%	-1.8%	1.4%	3.4%
USA	-6.3%	-5.3%	-3.3%	-1.7%	3.7%	5.2%
China	-18.3%	-11.8%	-10.0%	-11.9%	-9.2%	-4.6%
India	6.3%	17.3%	12.3%	9.3%	9.7%	10.2%
Japan	29.5%	38.3%	43.6%	46.2%	43.9%	48.6%
Turkey	28.7%	46.8%	47.1%	45.7%	45.0%	33.0%
Russia	-16.9%	-16.2%	-17.1%	-13.2%	1.6%	13.3%
Brazil	-0.5%	6.6%	9.0%	11.8%	14.3%	10.3%
World	-5.1%	0.5%	0.3%	0.0%	0.2%	-1.1%

Source: Own calculations.

Figure 1 illustrates the same information (differences in GDP between the two models over time) in a time series plot. As in Table 6, the depiction shows country specific deviations of GINFORS-E vs. GEM-E3 results (i.e., GEM-E3 results are assigned an index value of 100 for all countries). An index value of 100 in the graph corresponds to an exact match of results of both models. The following two figures also compare GDP development in the two models.

Figure 1: GDP (constant prices) comparison between GINFORS-E and GEM-E3 (GEM-E3 = 100)

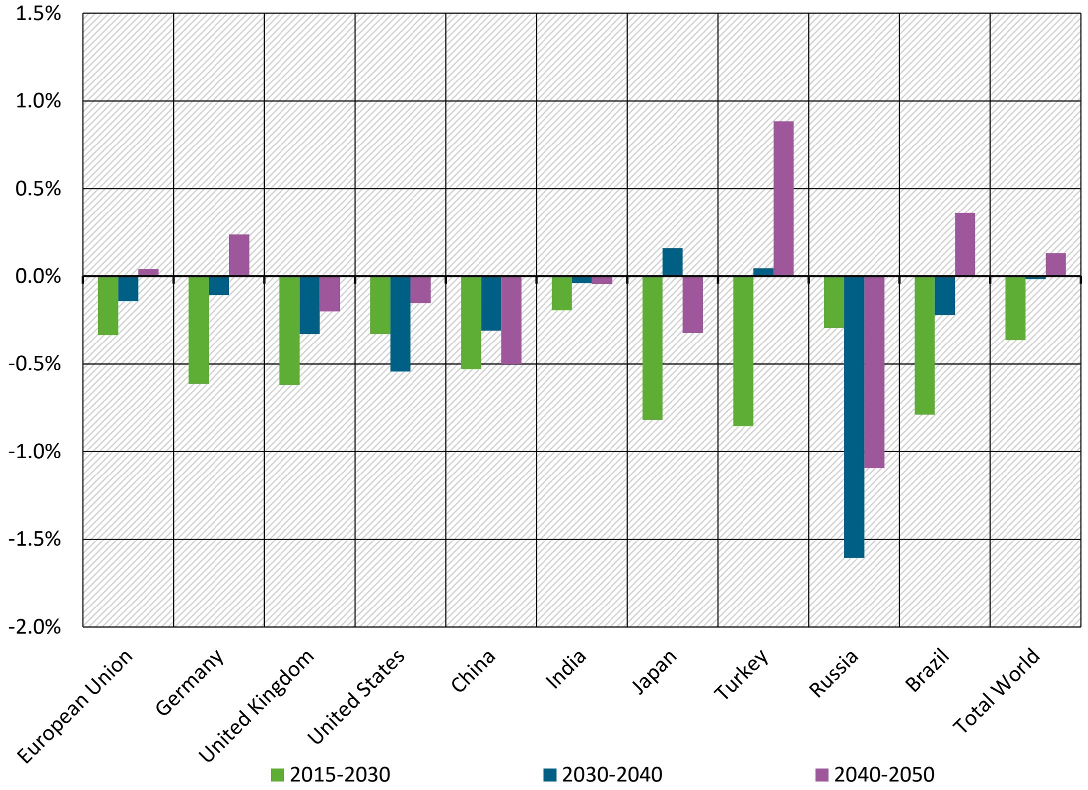


Source: GEM-E3, GINFORS-E.

For model harmonisation, an attempt was made to achieve similar GDP growth rates in the countries for the simulation period, from 2020 onwards in the following figures Figure 2 and Figure 3. For this purpose, components of final demand such as government consumption or investment were adjusted in GINFORS-E. However, this is only possible to a certain extent. A full match of GDP development in the two models is not possible, as GDP is endogenously modelled over time and the countries are interlinked by global trade. Given the endogeneity of the relationships, GINFORS-E cannot be calibrated exactly to the GEM-E3 results for all countries, years and various key variables such as GDP, energy consumption and emissions. It also has to be considered that for a country like India with current or recent annual growth rates of 6 to 7%, a difference of 1% or 2% in 2030 corresponds to GDP growth of a few months only.

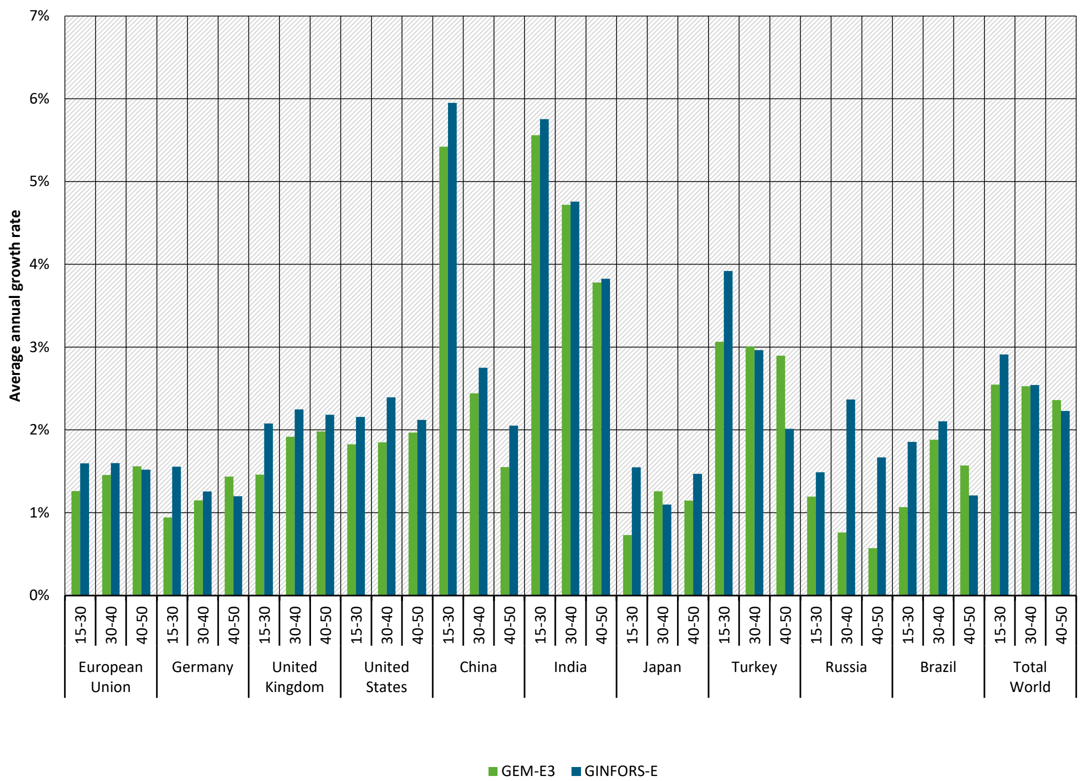
Differences in the average annual growth rates (AAGR) are particularly apparent for the period up to 2030 (Figure 2), which can be explained by different assumptions about the development in the pandemic and assumptions about global recovery, but which only play a minor role for scenario and model comparison in section 3.2 and in the central report. Here, further synchronisation would have been time consuming and difficult because the developments in 2020 for individual components of GDP and countries have been very different and the models were calibrated to them at different points in time. Larger deviations are seen for Turkey and Russia.

Figure 2: Differences in AAGR of GDP between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

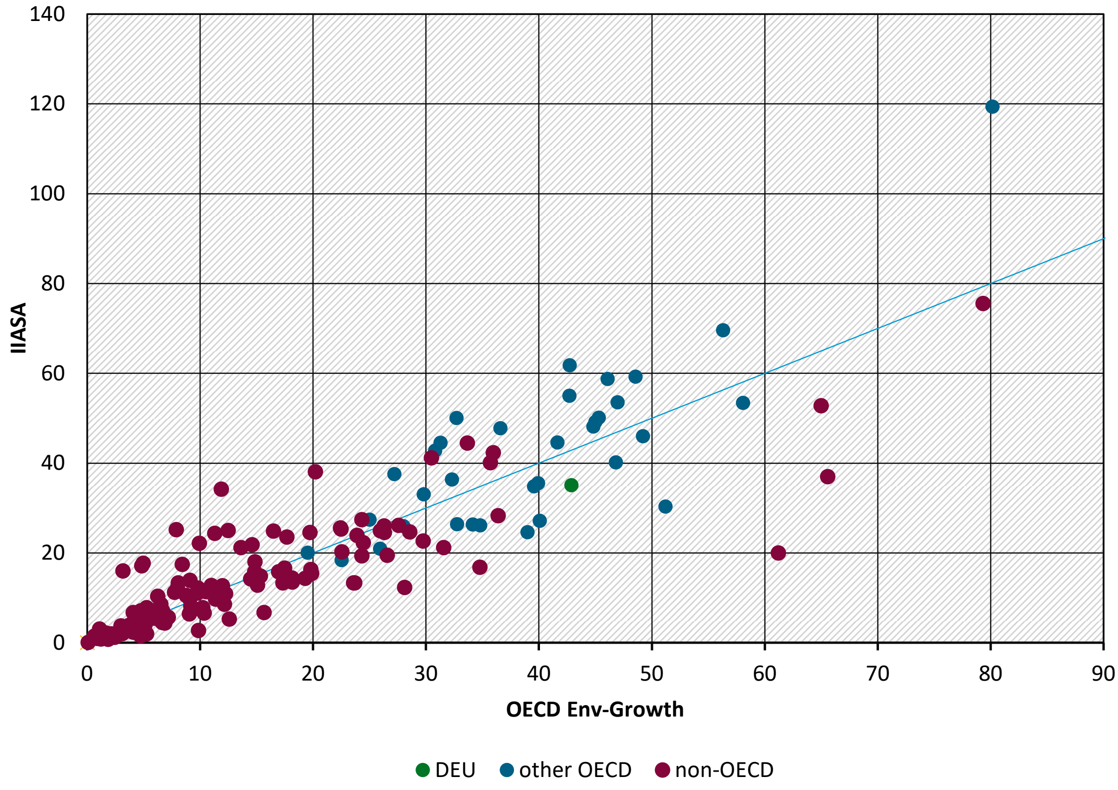
Figure 3: Comparison of AAGR of GDP in GEM-E3 and GINFORS-E



Source: GEM-E3, GINFORS-E.

To illustrate our degree of harmonisation, below we present it in comparison to two quantifications of SSP2 scenarios by the IIASA model and the OECD Env-Growth model for 2030 (IIASA 2016). For Germany (DEU), the OECD calculates a GDP per capita of 42.870 USD PPP, whereas the IIASA model reports 35.113 USD PPP. The numbers have been controlled for slightly different starting values in 2005. SSP scenarios are the socioeconomic pathways used for international modelling for the IPCC. The GDP values for countries are quantified in this context using various models. The example shows that major deviations between central results of socio-economic models are not unusual.

Figure 4: Differences in GDP per capita between SSP2 quantifications of IIASA and OECD Env-Growth models (2030)



Source: IIASA (2016).

For energy consumption, there are already larger differences between the two models in 2015. Annual average growth rates, however, are similar in the two models (Table 7). It should be noted that in GINFORS-E gross domestic energy consumption is reported according to the IEA energy balances, while GEM-E3 reports final energy consumption according to Eurostat. In both models, energy consumption is endogenously modelled as a result of economic development, relative prices and technical progress. The indicators are similar, but not identical[2].

As can be seen from Figure 5, differences across countries remain quite constant for most countries in the projected period. Countries for which positive deviations at the beginning of the period turn to negative deviations remain an exception. However, this is the case for China.

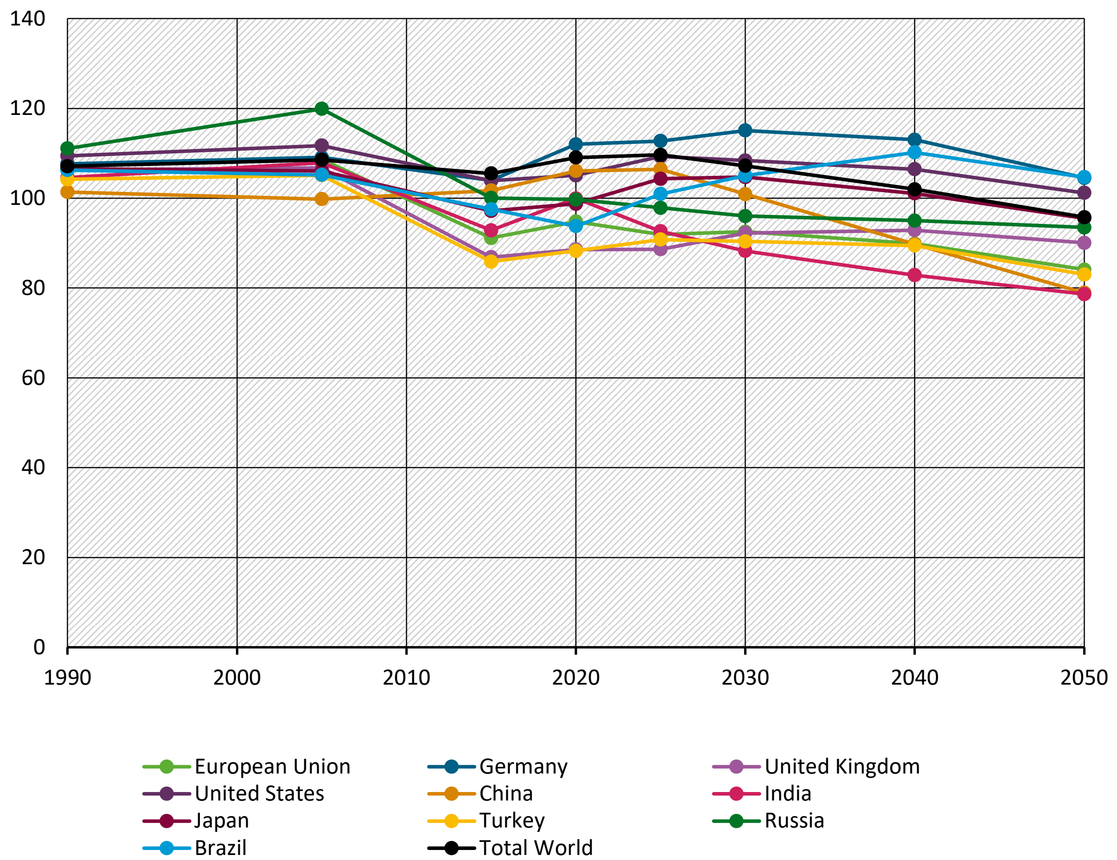
[2] The differences result from conceptual differences in the databases. In both models, the figures shown are the total final energy consumption.

Table 7: 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
EU-27	-8.8%	-5.2%	-8.1%	-7.5%	-10.1%	-15.9%
Germany	4.0%	12.0%	12.7%	15.1%	13.0%	4.5%
United Kingdom	-13.1%	-11.4%	-11.3%	-7.8%	-7.1%	-9.9%
USA	3.9%	5.1%	9.3%	8.4%	6.5%	1.2%
China	1.7%	6.1%	6.5%	0.9%	-10.3%	-21.1%
India	-7.1%	0.0%	-7.4%	-11.8%	-17.1%	-21.3%
Japan	-2.8%	-1.2%	4.3%	4.7%	1.1%	-4.4%
Turkey	-14.1%	-11.7%	-9.2%	-9.6%	-10.5%	-17.0%
Russia	0.0%	-0.3%	-2.1%	-4.0%	-5.0%	-6.5%
Brazil	-2.5%	-6.2%	0.9%	5.0%	10.2%	4.7%
World	5.5%	9.1%	9.7%	7.2%	2.0%	-4.2%

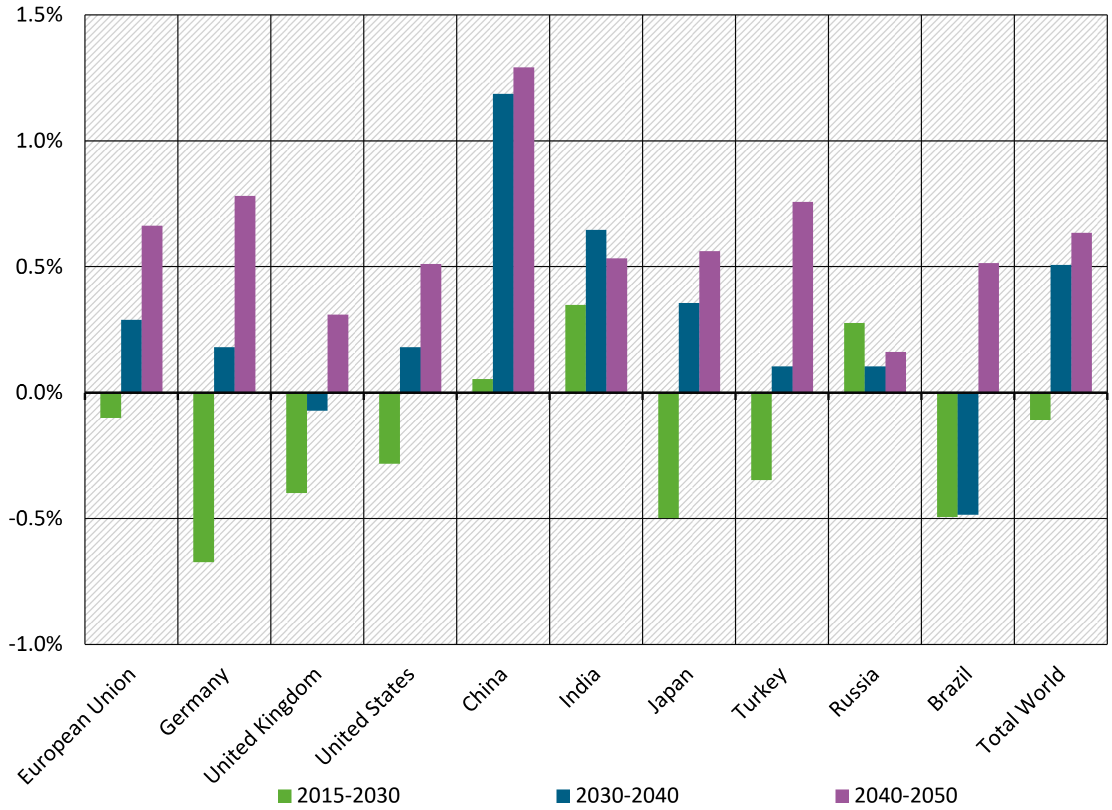
Source: Own calculations.

Figure 5: Gross inland energy consumption comparison between GINFORS-E and final energy consumption in GEM-E3 (GEM-E3 = 100)



Source: GEM-E3, GINFORS-E.

Figure 6: Differences in AAGR of final energy consumption in GEM-E3 and gross inland energy consumption in GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

Table 8: Relative differences in energy-related CO_2 emissions between GINFORS-E and GEM-E3

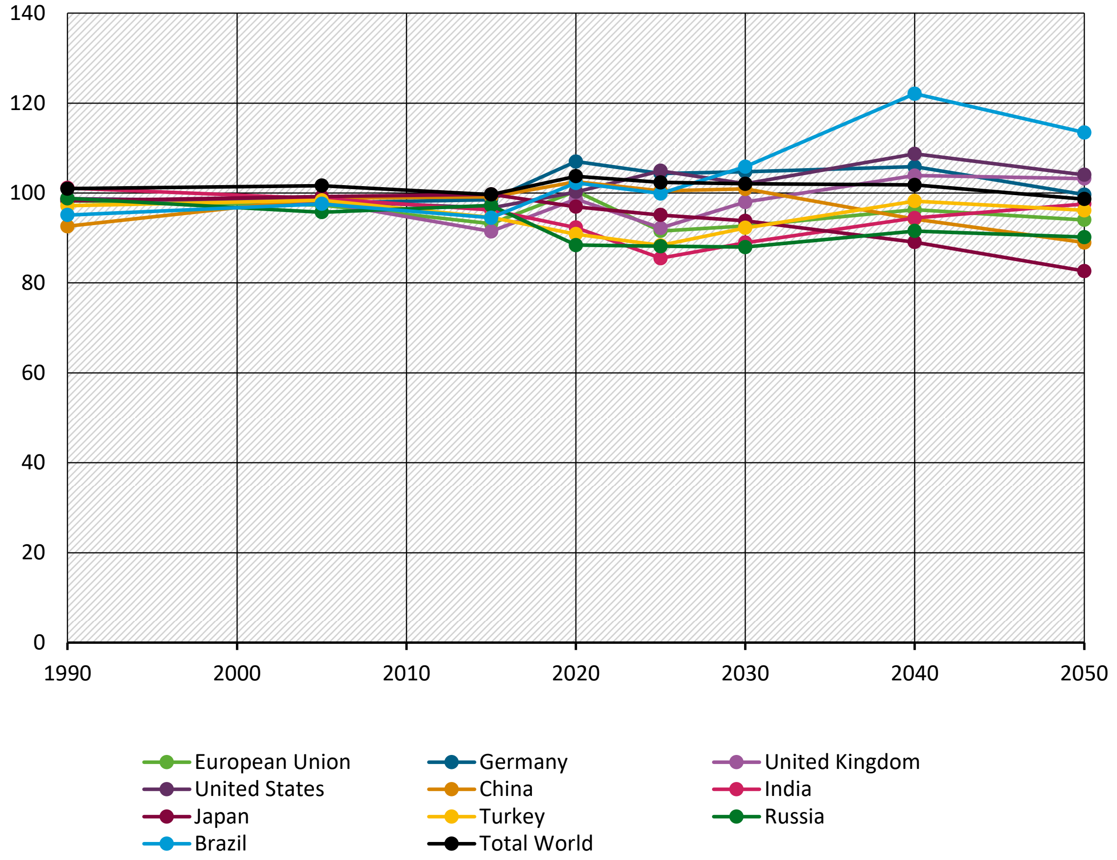
Country (aggregate)	2015	2020	2025	2030	2040	2050
EU-27	-6.8%	0.4%	-8.4%	-7.3%	-3.7%	-6.0%
Germany	-1.5%	7.0%	4.4%	4.8%	5.9%	-0.3%
United Kingdom	-8.5%	-1.4%	-7.8%	-2.0%	3.9%	3.2%
USA	-3.3%	0.2%	4.9%	2.1%	8.7%	4.0%
China	-0.9%	2.5%	0.5%	0.9%	-5.8%	-11.0%
India	-3.8%	-7.7%	-14.5%	-11.0%	-5.6%	-2.4%
Japan	-0.3%	-3.0%	-4.9%	-6.2%	-10.9%	-17.3%
Turkey	-5.4%	-9.1%	-11.7%	-7.8%	-1.8%	-3.9%
Russia	-2.8%	-11.6%	-11.8%	-12.0%	-8.4%	-9.8%
Brazil	-5.5%	2.2%	-0.1%	5.9%	22.1%	13.5%
World	-0.3%	3.7%	2.4%	2.0%	1.8%	-1.3%

Source: Own calculations.

In comparison to energy consumption, **energy-related CO_2 emissions** differ less in 2015 (Table 8). For most countries and years, differences in energy-related CO_2 emissions are below 10% with a few exceptions.

Figure 7 visualizes this observation in form of a line diagram. Brazil is the notable exception as the deviation between the two models is quite pronounced in 2040 – although this deviation is again decreasing until the end of the projection period.

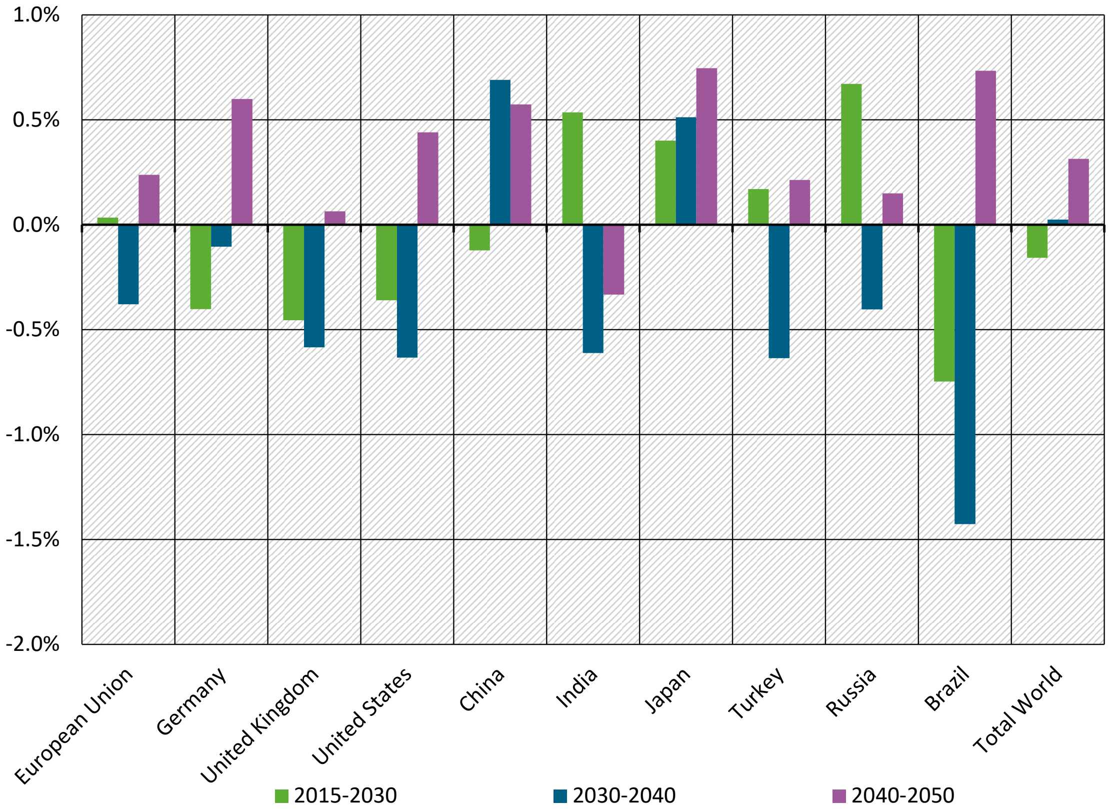
Figure 7: CO_2 emissions comparison between GINFORS-E and GEM-E3 (GEM-E3 = 100)



Source: GEM-E3, GINFORS-E.

Annual average growth rates of emission development are quite similar in the countries. As can be seen from Figure 8, development of CO_2 emissions tends to be faster in GEM-E3 in the period from 2030 to 2040 and faster in GINFORS-E between the years 2040 and 2050.

Figure 8: Differences in AAGR of CO_2 emissions between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

Differences in economic structures between the two models for Germany, the EU and probably also for the other countries are higher compared to GDP (Table 9, Table 10). This is partly due to differences in historical data for 2015 with different base years and exchange rates (USD2010 in GINFORS-E, USD2014 in GEM-E3). The two models make use of different datasets with different sector classifications. In the OECD database that is used in GINFORS-E, the energy sector, which consists of electricity production and electricity and gas distribution, includes water supply. This is one reason why the level of production is much higher in GINFORS-E compared to GEM-E3. GEM-E3 reports iron and steel and non-ferrous metals industries separately, while GINFORS-E summarises both into basic metals. Industries are partly assigned differently to sectors, but the granularity of the data is not sufficient to fully match the two databases.

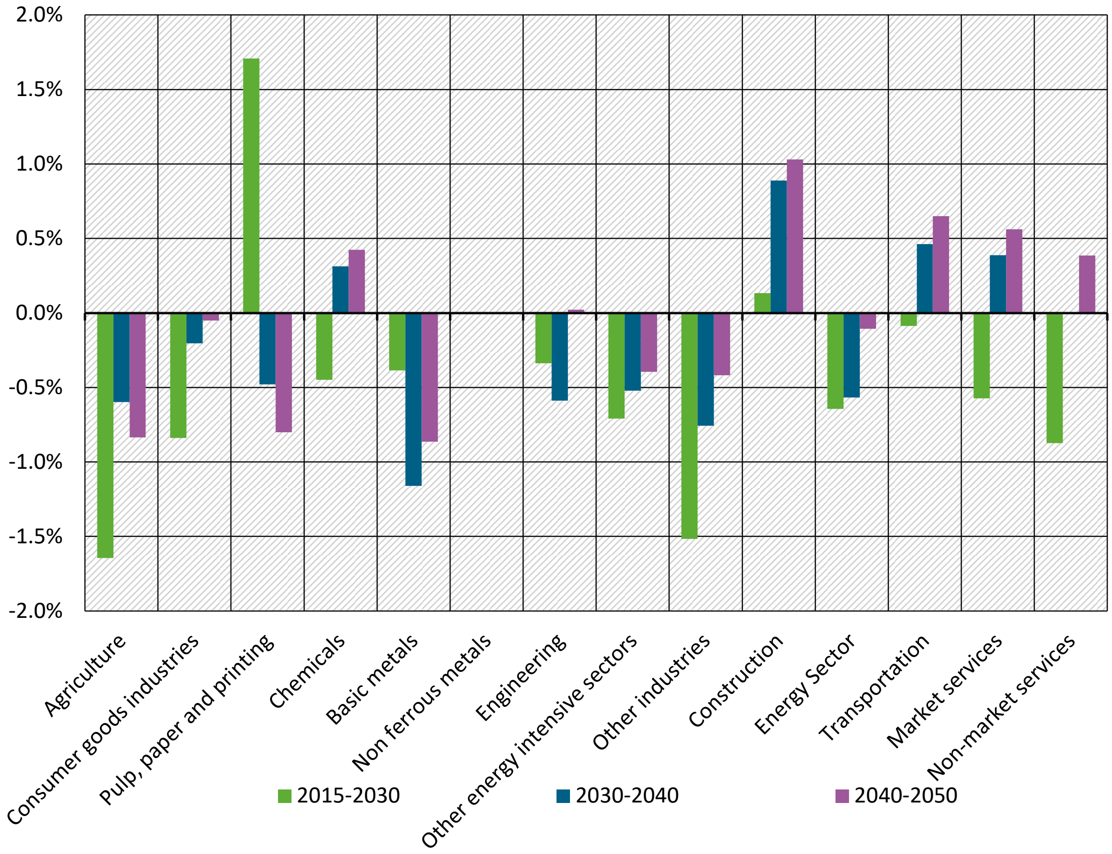
Regarding developments over time, German production of agriculture, basic metals, other energy intensive (industry) sectors, other industries, and the energy sector develop faster in GINFORS-E compared to GEM-E3. This means in Table 9 that the relative difference of production in absolute terms is higher (more positive) in 2050 compared to 2015. This is also the case for the EU (Table 10). In contrast, the chemical industry, construction, transportation, and services (after 2030) grow a bit faster in GEM-E3.

Table 9: Relative differences in German sectoral production between GINFORS-E and GEM-E3

Sector	2015	2020	2025	2030	2040	2050
Agriculture	-25.6%	-21.8%	-10.7%	-4.9%	0.9%	9.6%
Consumer goods industries	-44.3%	-41.9%	-39.8%	-37.0%	-35.7%	-35.3%
Pulp, paper, and printing	-24.5%	-43.6%	-42.4%	-41.6%	-38.8%	-33.7%
Chemicals	-15.5%	-3.6%	-8.1%	-9.6%	-12.4%	-16.0%
Basic metals	-65.2%	-64.5%	-65.3%	-63.1%	-58.6%	-54.9%
Non-ferrous metals*						
Engineering	-5.0%	-4.9%	-6.0%	-0.1%	5.9%	5.6%
Other energy intensive sectors	-45.6%	-41.3%	-41.2%	-39.6%	-36.3%	-33.8%
Other industries	-66.9%	-62.3%	-61.5%	-58.6%	-55.3%	-53.4%
Construction	-46.9%	-48.6%	-47.1%	-47.9%	-52.3%	-56.9%
Energy Sector	11.2%	17.1%	15.4%	22.6%	29.7%	31.1%
Transportation	8.7%	16.1%	11.2%	10.1%	5.2%	-1.3%
Market services	-31.3%	-24.3%	-24.9%	-25.2%	-28.0%	-31.9%
Non-market services	-40.8%	-36.0%	-34.4%	-32.6%	-32.6%	-35.1%

Source: Own calculations. * Part of basic metals in GINFORS-E.

Figure 9: Differences in AAGR of production in Germany between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

For the EU, development of production over time is very similar for service sectors, which account for about 80% of EU production. In some manufacturing industries such as chemicals, but also in agriculture, production in GINFORS-E develops a bit faster than in GEM-E3 (Table 10). In terms of average annual growth rates, this means lower values for GEM-E3 in Figure 10.

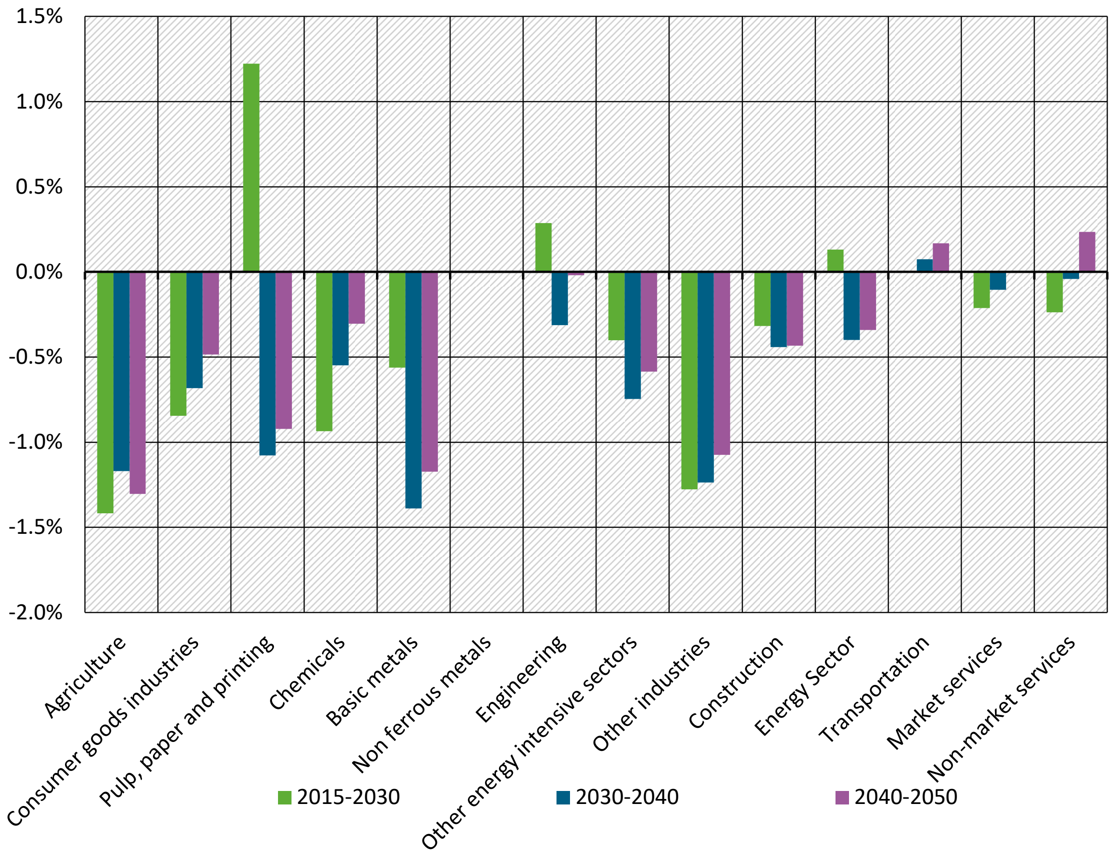
Table 10: Relative differences in production for the EU between GEM-E3 and GINFORS-E

Sector	2015	2020	2025	2030	2040	2050
Agriculture	4.4%	10.1%	19.2%	28.8%	44.5%	64.3%
Consumer goods industries	-37.5%	-34.6%	-33.4%	-29.2%	-24.2%	-20.5%
Pulp, paper, and printing	-15.4%	-36.7%	-33.7%	-29.6%	-21.7%	-14.2%
Chemicals	-1.2%	7.2%	9.4%	13.6%	19.9%	23.5%
Basic metals	-65.4%	-64.7%	-65.0%	-62.4%	-56.9%	-51.6%
Non-ferrous metals*						
Engineering	-6.0%	-7.4%	-12.5%	-9.9%	-7.1%	-6.9%
Other energy intensive sectors	-49.5%	-46.1%	-48.0%	-46.4%	-42.3%	-38.9%
Other industries	-55.7%	-51.0%	-50.7%	-46.5%	-39.5%	-32.7%

Sector	2015	2020	2025	2030	2040	2050
Construction	-32.0%	-28.7%	-30.8%	-28.8%	-25.6%	-22.4%
Energy Sector	19.0%	22.3%	13.0%	16.7%	21.4%	25.6%
Transportation	-1.9%	6.0%	-2.3%	-1.9%	-2.6%	-4.2%
Market services	-19.4%	-14.4%	-18.0%	-16.9%	-16.0%	-16.1%
Non-market services	-29.6%	-26.4%	-28.4%	-27.1%	-26.8%	-28.4%

Source: Own calculations. * Part of basic metals in GINFORS-E.

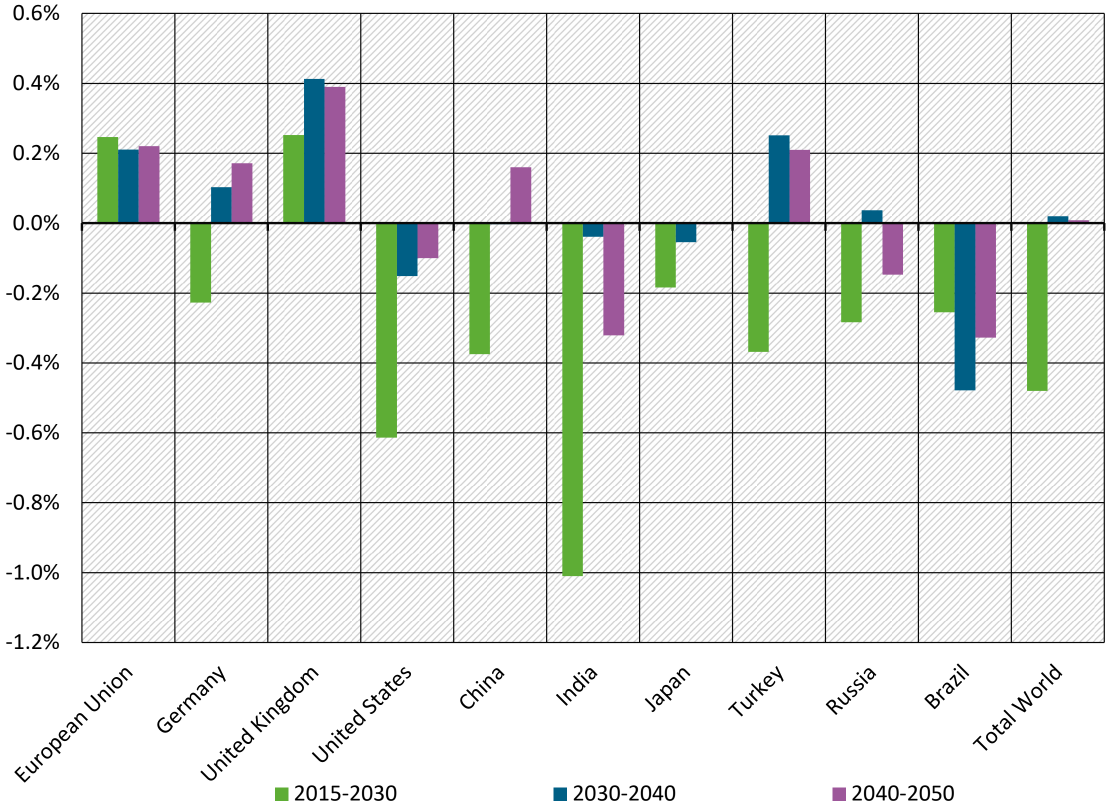
Figure 10: Differences in AAGR of production in the EU between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

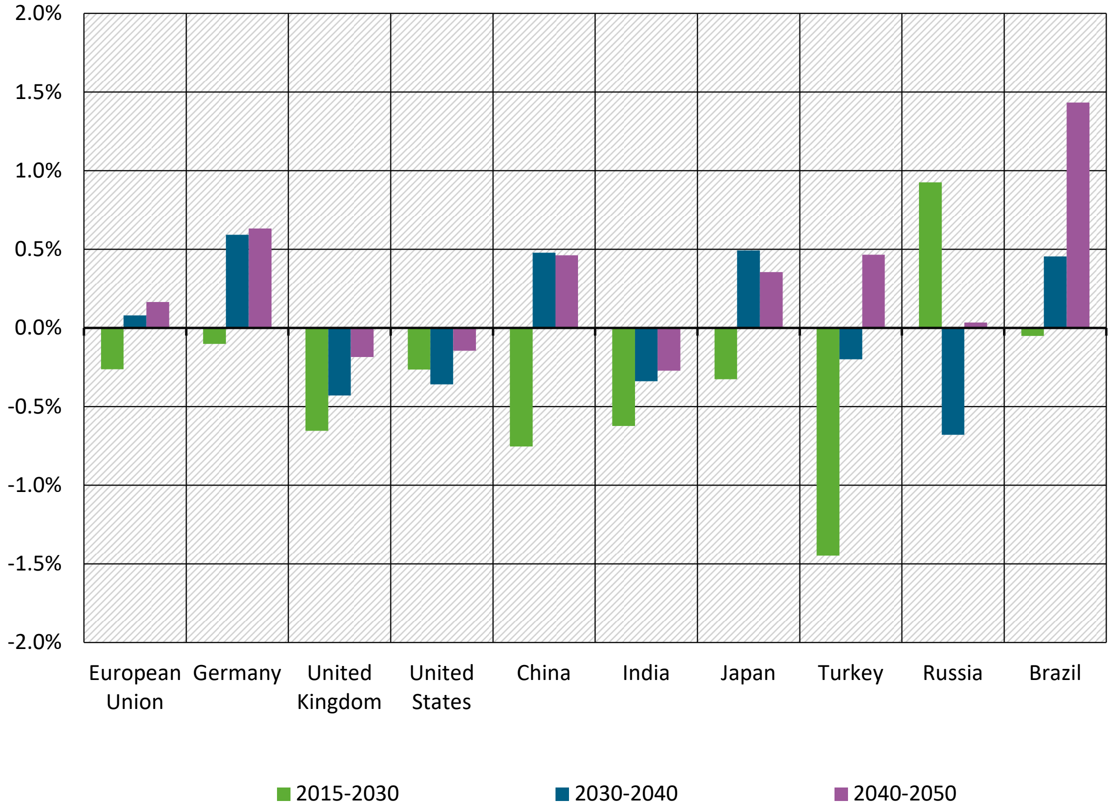
Private consumption and employment are model variables that correlate strongly with GDP, but nevertheless depend on other variables and specific modelling approaches. They are shown for information in the following Figure 11 and Figure 12.

Figure 11: Differences in AAGR of employment between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

Figure 12: Differences in AAGR of private consumption between GEM-E3 and GINFORS-E (percentage points)



Source: GEM-E3, GINFORS-E.

Concluding on the degree of model harmonisation in this project, we note that to achieve even greater harmonisation of the models than already obtained, further, and very detailed intervention in the modelling of the economic structure would be required in one of the models. This would probably be very time consuming. For this reason, too, this was not pursued further in the project.

3 Explorative global climate policy ambition scenarios

3.1 Scenario Design

In addition to the harmonisation scenario, four other scenarios have been specified in the two models, which are briefly described below in terms of their differences from the reference scenario (Table 11). These differences relate to exogenous carbon prices as a proxy for climate policies.

Table 11: Scenarios

Number	Abbreviation	Brief description
1	Harmonisation	Climate mitigation as in 2020
2	NDCs_2020_30	2030 NDCs as in 2020; after 2030 CO_2 prices increase with the rate of GDP growth. Full auctioning in all sectors in EU and RoW.
3	2DEG	2° scenario, global carbon price (for all energy-related emissions)
4	2DEG_EU	2° scenario, EU goes ahead (55%/95%) -> EU carbon price, global carbon price for rest of world
5	1.5DEG	1.5° scenario, global carbon price

Source: Own compilation

Table 12: NDC targets of major emitting countries in Mt CO_2 for 2030

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	4400	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

Benchmark scenario 2 is a scenario in which all countries achieve their NDCs for 2030 as they were in summer 2020 (NDCs-2020_30, Table 12). The ambition level for many countries is so low that no or small specific climate protection policy in the form of a CO_2 price is necessary to achieve the respective targets. There is no sector differentiation between ETS and non-ETS. i.e. there is a single carbon price per country. It is assumed that emission allowances are fully auctioned. After 2030, CO_2 prices increase with annual GDP growth rates until 2050. For the EU, this implies a 40% reduction in GHG emissions by 2030 compared to 1990.

Scenario 3 is a 2° consistent scenario that assumes a globally uniform CO_2 price (2DEG). The emission pathway is shown in Table 13. As in scenario 2, all emission allowances are auctioned. This is a cost-efficient scenario, which is unlikely from the perspective of a common but different responsibility of country groups, given the different ambition levels for GHG neutrality and historical responsibility of country groups. While industrialised countries and Brazil pledged for climate neutrality in 2050, China foresees climate neutrality for 2060, and India for 2070.

Scenario 4 builds on scenario 3. However, the EU goes one step further and achieves its Green Deal targets (2DEG_EU). This means a 55% reduction in GHG emissions by 2030 compared to 1990. In 2050, EU emissions are then 95% lower than in 1990. To achieve the target, the CO_2 price in the EU is higher than in Scenario 3. All other countries, however, are slightly relieved, so that the global reduction path is as in Scenario 3.

Finally, scenario 5 is consistent with the 1.5° target ("revised 1.5 Scenario" in Table 13), and a globally uniform CO_2 price is assumed as in scenario 3 (1.5DEG). All emission allowances are again auctioned.

Pathways are derived from the available model runs made in the EC funded CD-Links project. The 2.0 C CDLinks scenario leads to slightly lower energy-related CO_2 emissions in the long term than the Announced Pledges Scenario (APS) scenario in the current WEO of the IEA (2022, p.64), which may lead to a 1.7° increase in global median temperature in 2100, also depending on assumptions about negative emission technologies in the second half of the century. The ambition of the revised 1.5 Scenario is between the Net Zero Emissions (NZE) scenario of the WEO 2022 with a temperature increase of 1.4° in 2100 and the APS, so i.e. in line with a 1.5° path.

Table 13: Annual global energy related GHG emissions in Gt

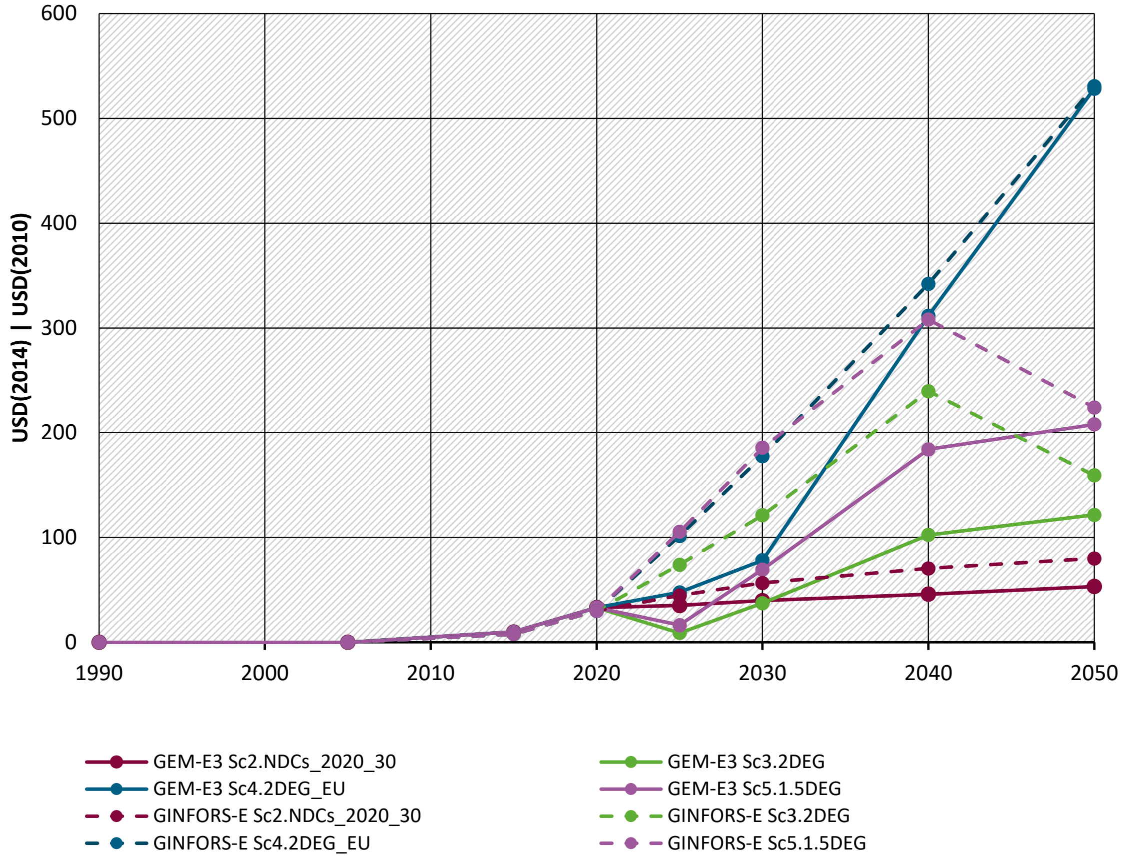
Sector	2020	2025	2030	2035	2040	2045	2050
2.0 C CDLinks/2DEG scenario	33	30	25	21	17	15	15
1.5 C CDLinks	33	28	21	14	9	6	4
Revised 1.5 Scenario / 1.5DEG scenario	33	28	21	14	11	10	9

Source: https://data.ene.iiasa.ac.at/cd-links/#/login?redirect=%2Fworkspaces

3.2 Short comparison for the two models

In scenarios 3 to 5 for achieving the 2° and 1.5° target, GINFORS-E shows higher carbon prices for the EU in 2030 than GEM-E3 in all scenarios (Figure 13). According to GINFORS-E, short-term CO_2 reduction is more expensive than according to GEM-E3. In the years thereafter until 2050, CO_2 prices in GINFORS-E continue to be significantly higher in Scenario Sc3.2DEG than in GEM-E3 but decline significantly between 2040 and 2050. In scenario Sc4.2DEG_EU, where the EU is more ambitious than the rest of world, CO_2 prices in GINFORS-E are consistently higher, but the difference becomes small in 2050. For Scenario Sc5.1.5DEG to achieve the 1.5-degree target, CO_2 prices in both models increase strongly until 2050 and are at comparable levels in 2040 and 2050.

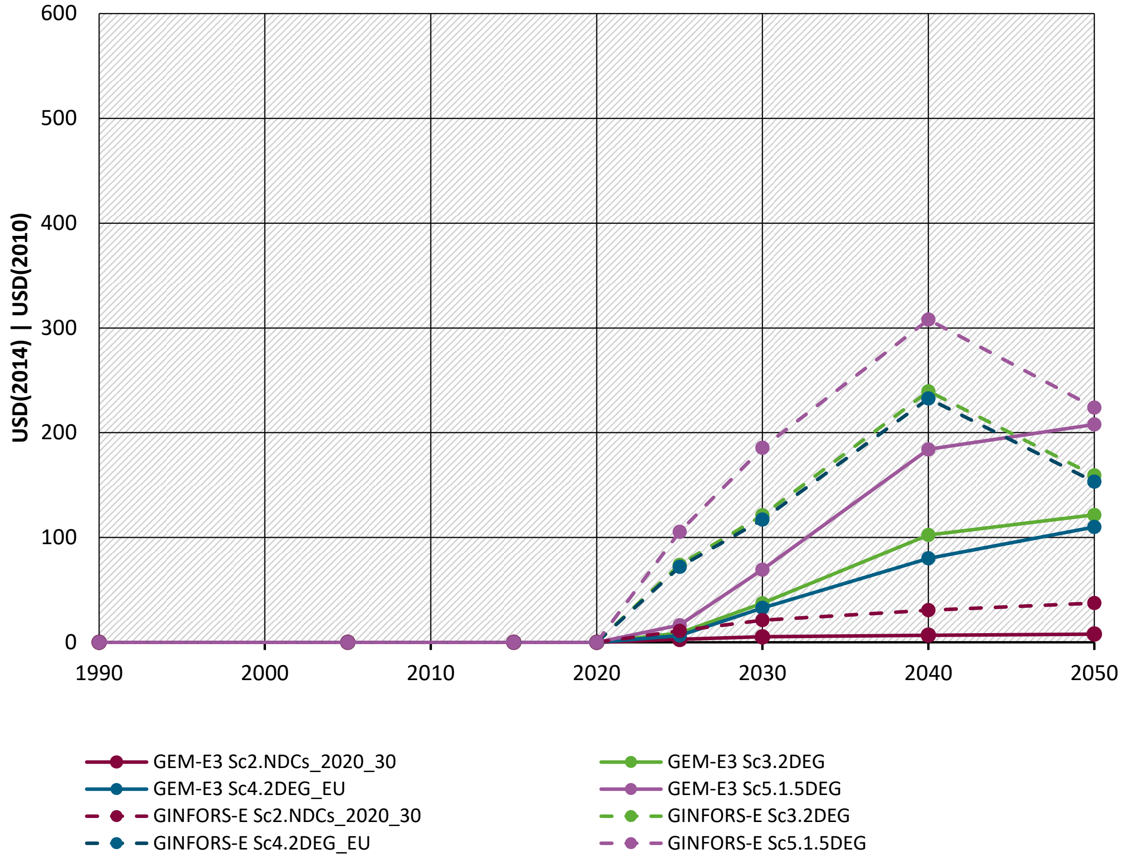
Figure 13: Model comparison - EU CO_2 prices in scenarios 2 to 5



Source: GEM-E3, GINFORS-E.

For carbon prices in the rest of the world, the differences between the models in scenarios Sc3.2DEG and Sc4.2DEG_EU are very small. In scenario Sc2.NDCs_2020_30, CO_2 prices in GINFORS-E are significantly higher than in GEM-E3, but overall, at a low level until 2050. A larger difference is seen for scenario Sc5.1.5DEG, where CO_2 prices in GINFORS-E are significantly higher in 2025, 2030 and 2040. In 2050, the differences in both models are again small (Figure 14).

Figure 14: Model comparison – Global* CO_2 prices in scenarios 2 to 5

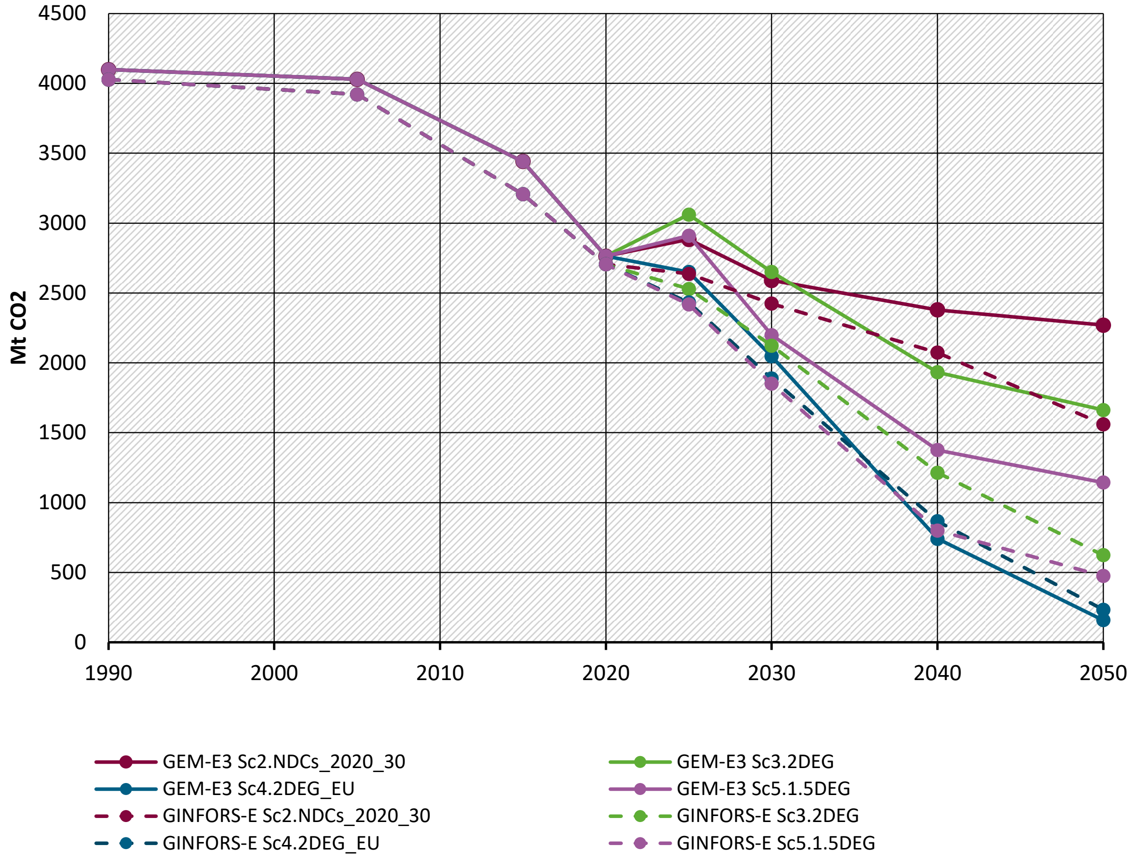


Source: GEM-E3, GINFORS-E. * China for scenario 2

EU energy-related CO_2 emissions develop in part significantly differently in both models in scenarios 2 to 5. Already in scenario Sc2.NDCs_2020_30, the emissions in GEM-E3 are slightly higher in the reference compared to GINFORS-E. For the years up to 2050, CO_2 prices grow with GDP by assumption. Obviously, this increase in GINFORS-E on a higher-level leads to a further significant decrease in EU emissions to 1560 Mt in 2050, while emissions in GEM-E3 only decrease slightly by 2050 (2270 Mt).

In scenario Sc3.2DEG for achieving the 2° target with a uniform global carbon price, emissions in GINFORS-E decrease to 623 Mt in 2050, while in GEM-E3 they decrease only to a limited extent to 1662 Mt. Reduction in the rest of world is higher in GEM-E3. Obviously, the costs of reducing GHG emissions in the rest of the world compared to reduction in Europe are lower in GEM-E3 than in GINFORS-E. For this reason, also in scenario Sc5.1.5DEG, emissions in the EU are significantly lower in GINFORS-E than in GEM-E3. The differences between the emissions calculated by the models in scenario Sc4.2DEG_EU, achieving the EU reduction targets, are only small.

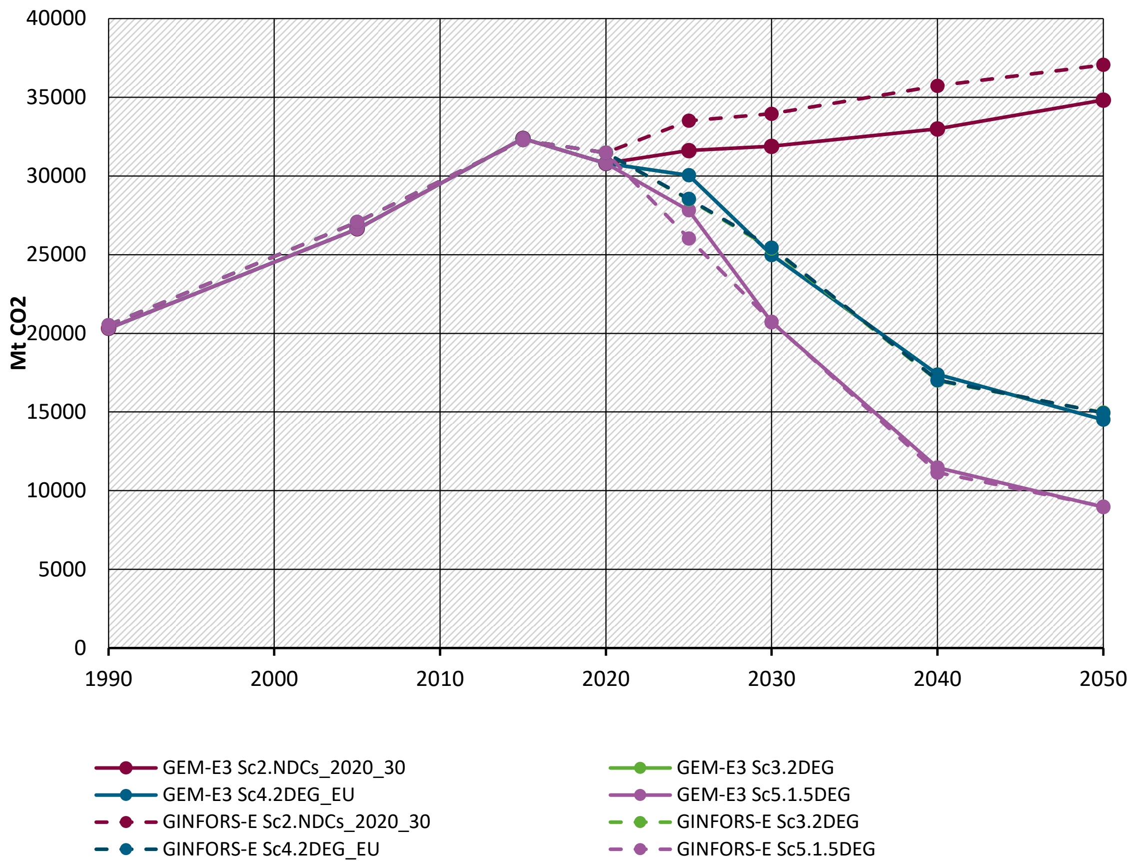
Figure 15: Model comparison – EU energy related CO_2 emissions in scenarios 2 to 5



Source: GEM-E3, GINFORS-E.

In contrast, the differences in global emissions between the models are small. Only the reference scenarios Sc2.NDCs_2020_30 show larger differences. In the other scenarios, the development of global emissions is almost identical (Figure 16).

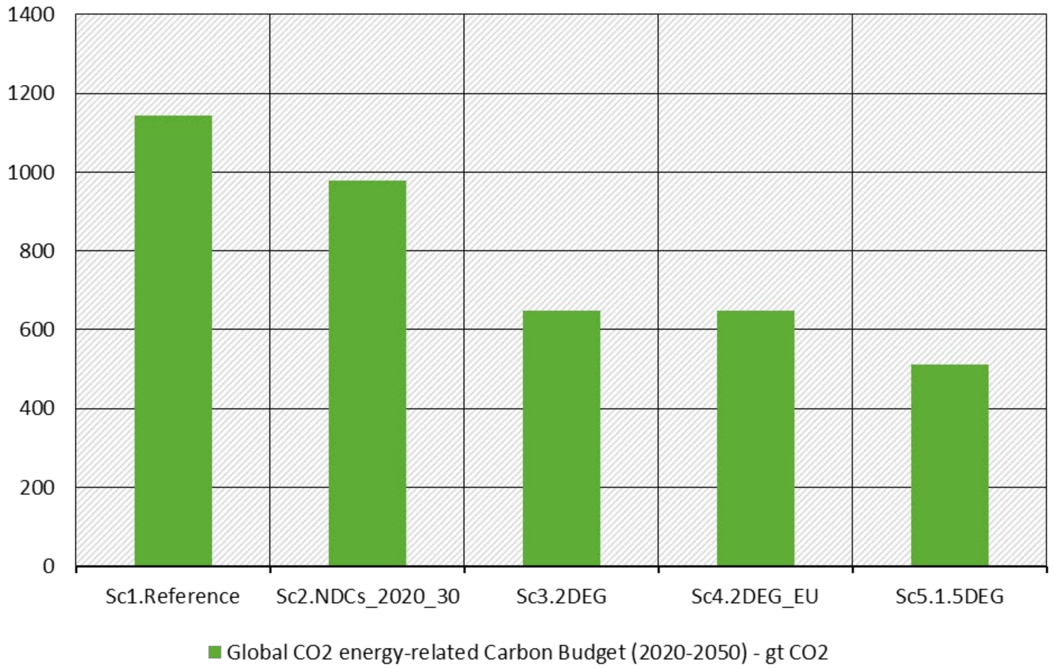
Figure 16: Model comparison – Global energy related emissions in scenarios 2 to 5



Source: GEM-E3, GINFORS-E.

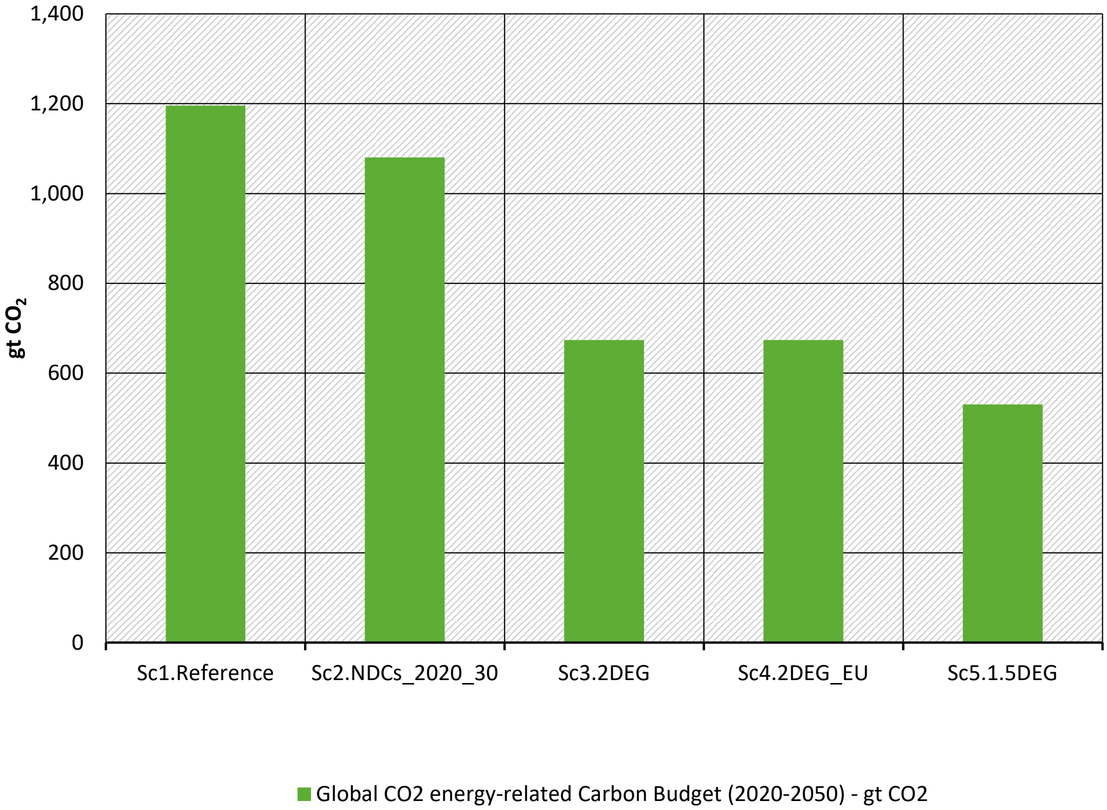
For this reason, the global carbon budgets, i.e., cumulated CO_2 emissions from 2020 to 2050, up are also very similar in the target scenarios. Due to the higher emissions in GINFORS-E until 2030, these carbon budgets are higher in scenarios 1 and 2. Figure 17 shows the cumulative carbon budget (2020-2050) of the scenarios of GEM-E3, Figure 18 the same for GINFORS-E. As expected, the Sc5.1.5DEG scenario achieves the biggest reduction in cumulative global CO_2 energy-related emissions – in GEM-E3 48% lower than scenario Sc2.NDCs_2020_30.

Figure 17: Global CO_2 energy-related emissions budget (2020-2050)- GEM-E3.



Source: GEM-E3

Figure 18: Global CO_2 energy-related emissions budget (2020-2050) – GINFORS-E.

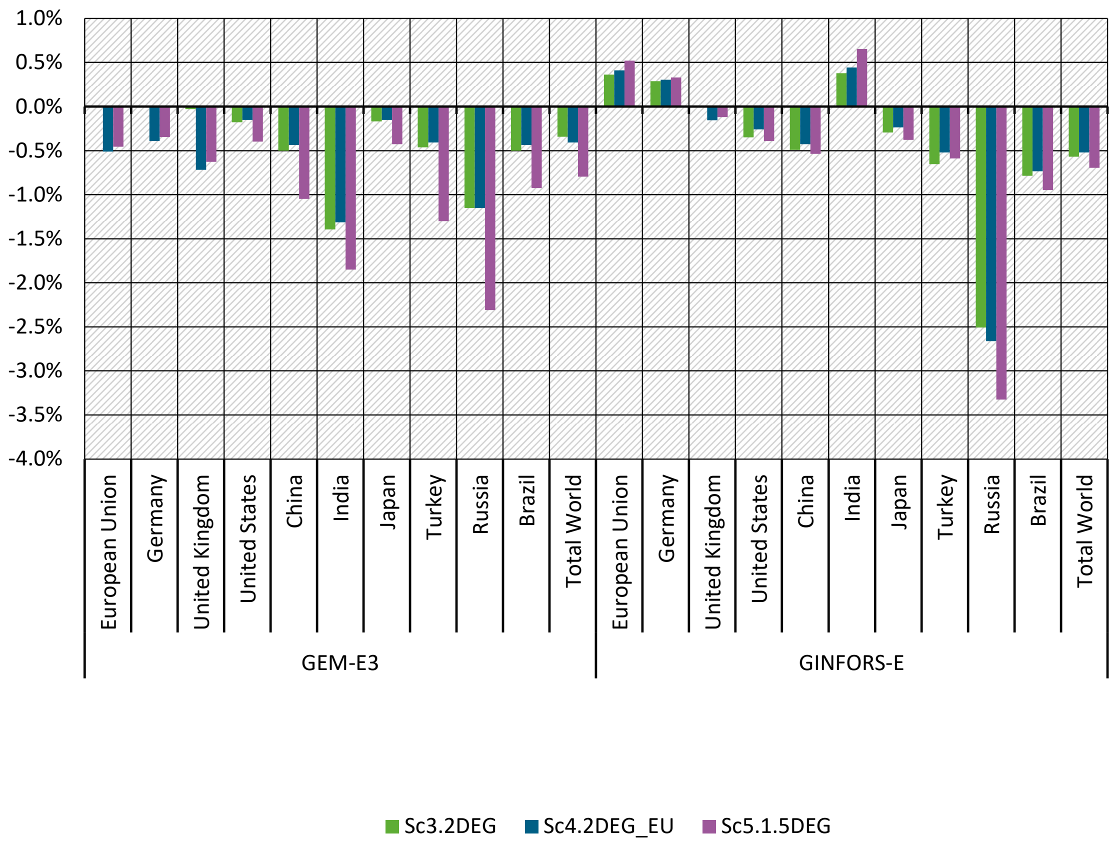


Source: GINFORS-E

The macroeconomic effects of the mitigation scenarios Sc3.2DEG to Sc5.1.5DEG in comparison to scenario Sc2.NDCs_2020_30 show clear differences in the regional distribution for both models, while the global effects on GDP in 2030 are similar with around -0.5%. For GEM-E3, the difference between the 2° and the 1.5-degree scenario(s) is more pronounced than in GINFORS-E. In GEM-E3, the effects are negative for all countries and regions shown, with India and Russia being negatively affected above average. For the EU, there are no visible effects in Sc3.2DEG.

In GINFORS-E, there are slightly positive GDP effects in the EU, Germany and India for 2030, while the effects in the other countries are negative. The losses are more pronounced in Russia. However, the differences should not be overinterpreted. In terms of average annual growth rates, the effects in both models are below 0.1% for most countries. It also has to be mentioned that (avoided) negative impacts of climate change are not considered.

Figure 19: Deviations in GDP in Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30 in 2030 – comparison between GEM-E3 and GINFORS-E

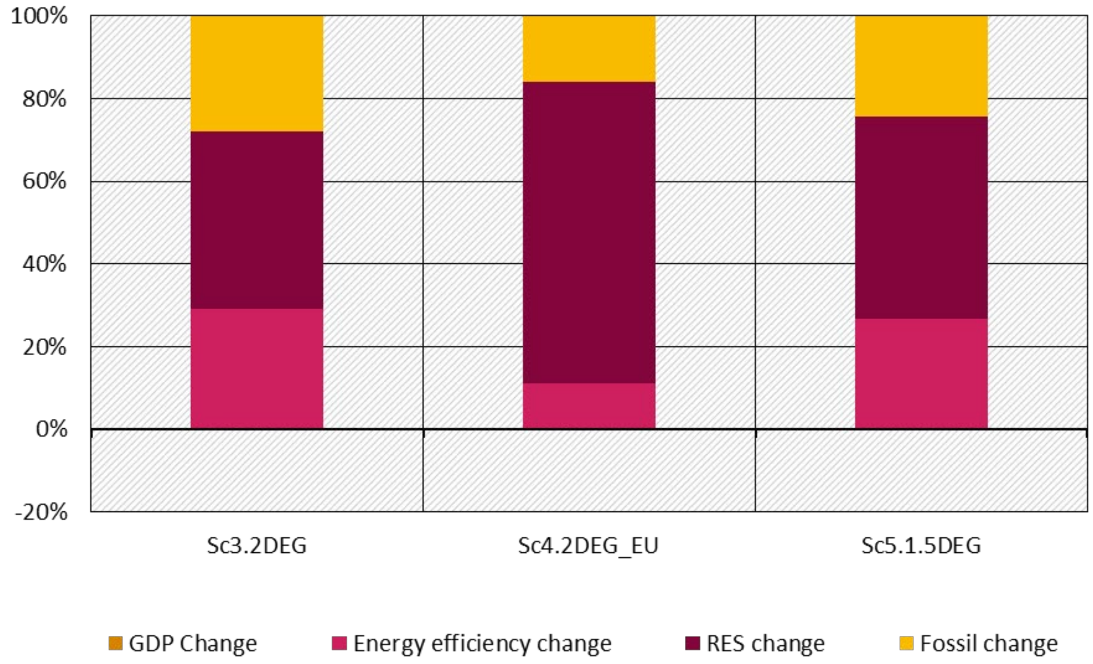


Source: GEM-E3, GINFORS-E.

Figure 20 shows the decomposition of CO_2 emissions reduction due to changes of in GDP, energy efficiency, RES technologies and substitution of fossil fuels in scenarios Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30 for Germany in 2050. RES deployment is the key driving factor for emissions reductions whereas GDP changes have virtually zero impacts.

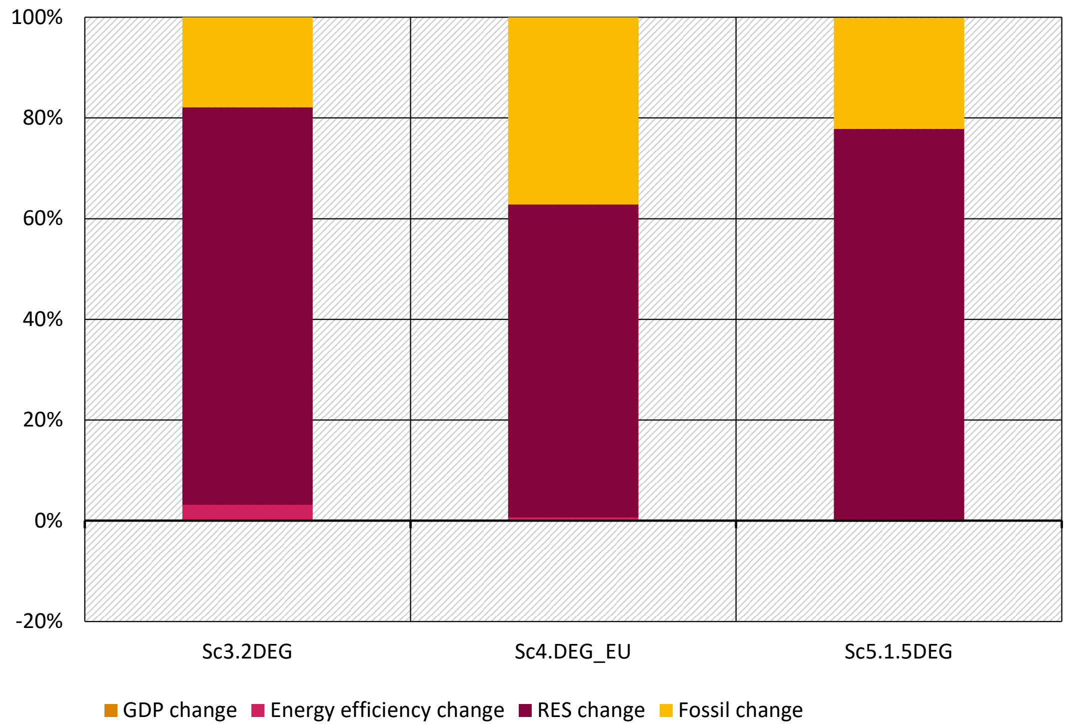
In GINFORS-E, RES deployment is also the most important driver of GHG reduction, while the shift between fossil fuels (Fossil change) is the other important factor. Energy efficiency change only plays a minor role in the Sc3.2DEG in the year 2050, when the energy transition will be implemented successfully (Figure 21).

Figure 20: Germany Kaya decomposition for GEM-E3 in 2050 for scenario 3, 4, 5 compared to scenario 2 for the reduction of CO_2 energy-related emissions (stacked up to 100%).



Source: GEM-E3

Figure 21: Germany Kaya decomposition for GINFORS-E in 2050 for scenario 3, 4, 5 compared to scenario 2 for the reduction of CO_2 energy-related emissions (stacked up to 100%).



Source: GINFORS-E.

4 GEM-E3 – Scenario results

The simulation of the different GHG emission reduction targets, carbon prices and options to allocate emission allowances affect the energy and economic systems in several ways. Increasing the price of carbon brings about the substitutions of fuels and the adoption of less carbon intensive production and consumption technologies. Countries and sectors that contribute to emission reduction and energy savings benefit, whereas sectors that are carbon-intensive suffer a drop in their output. According to the simulation, achieving the 2- or 1.5-degree climate target is feasible at a cost that ranges from 0.7 to 1.2% of GDP over the 2020-2050 period. In terms of annual growth rate this equals a marginal reduction of 0.02%. The results of Scenario 5 (1.5DEG) show that getting to 1.5 degrees would require a larger effort (in terms of GHG abatement) from non-EU countries indicating the low-cost reduction potential that is available in many non-EU countries. The EU has already adopted significant GHG mitigation measures already in the reference. These impacts on GDP are low compared to the expected cost of climate change. Mitigation to climate change will bring macroeconomic benefits by reducing these costs of climate change.

Table 14: Changes in GDP and CO_2 emissions from the respective reference scenario (Sc2.NDCs_2020_30)

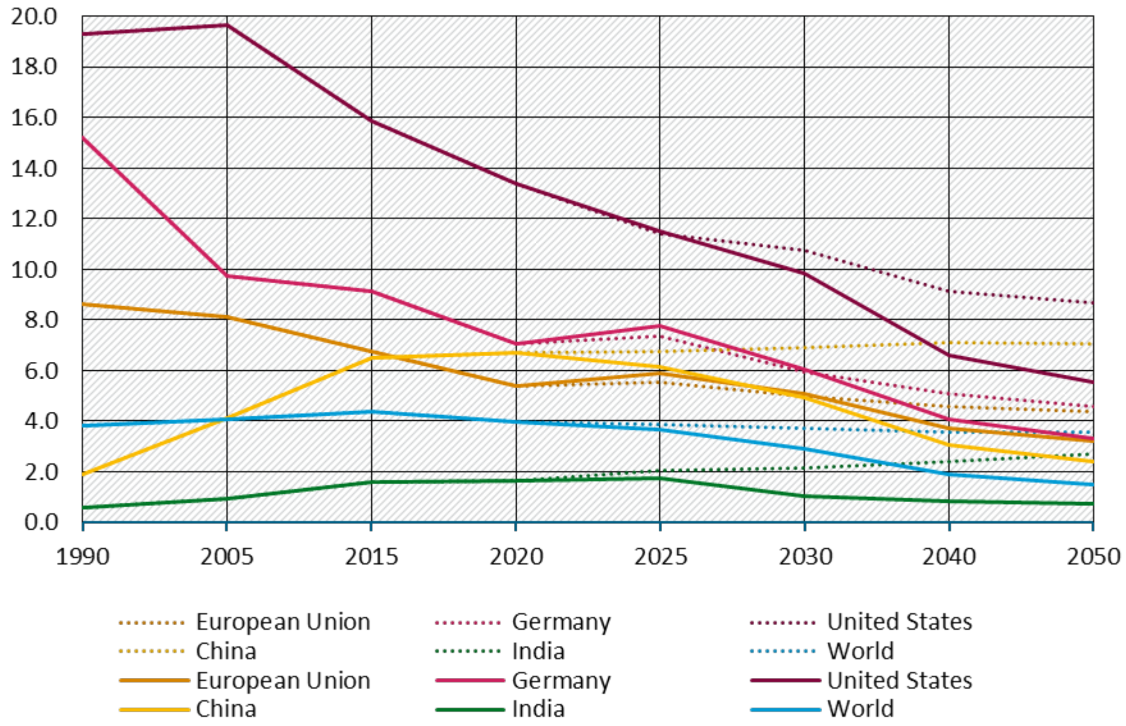
		GDP in 2050 vs. 2020		CO_2 in 2050 vs. 2020		Implied Cost (\$) per Tn CO_2 (absolute difference in GDP divided by absolute difference in CO_2 emissions)		Cumulative CO_2 emissions (2020-2050)
		World	EU	World	EU	World	EU	World
%Change from Sc2.NDCs_2020_30	2DEG	-0,7%	-0,2%	-33,8%	-9,1%	83	169	647414
	2DEG_EU	-0,8%	-0,8%	-33,8%	-44,3%	94	183	647414
	1.5DEG	-1,2%	-0,5%	-47,7%	-26,1%	105	202	511543

Source: GEM-E3

Scenarios 3, 4 and 5 examine how the energy and economic systems will adjust to escalating GHG emission reduction objectives. Scenario 3 is an optimal cost global 2 C degree case, whereas scenario 5 is a cost optimal 1.5 C degree case. When comparing with 3 and 5, under scenario 4 the EU has the lowest emissions (by constraint). The performance of scenarios 3, 4 and 5 is evaluated against the reference scenario (Sc2.NDC_2020_30).

All scenarios lead to improvements in carbon intensity and emissions per capita (as indicated in figure below). Carbon emissions per capita in Scenario 3 improve more (compared to Scenario 2) in China, USA and India, considering the low ambition of their NDCs (Sc2), and less in the EU where significant GHG emission reductions take place already in the reference scenario Sc2.

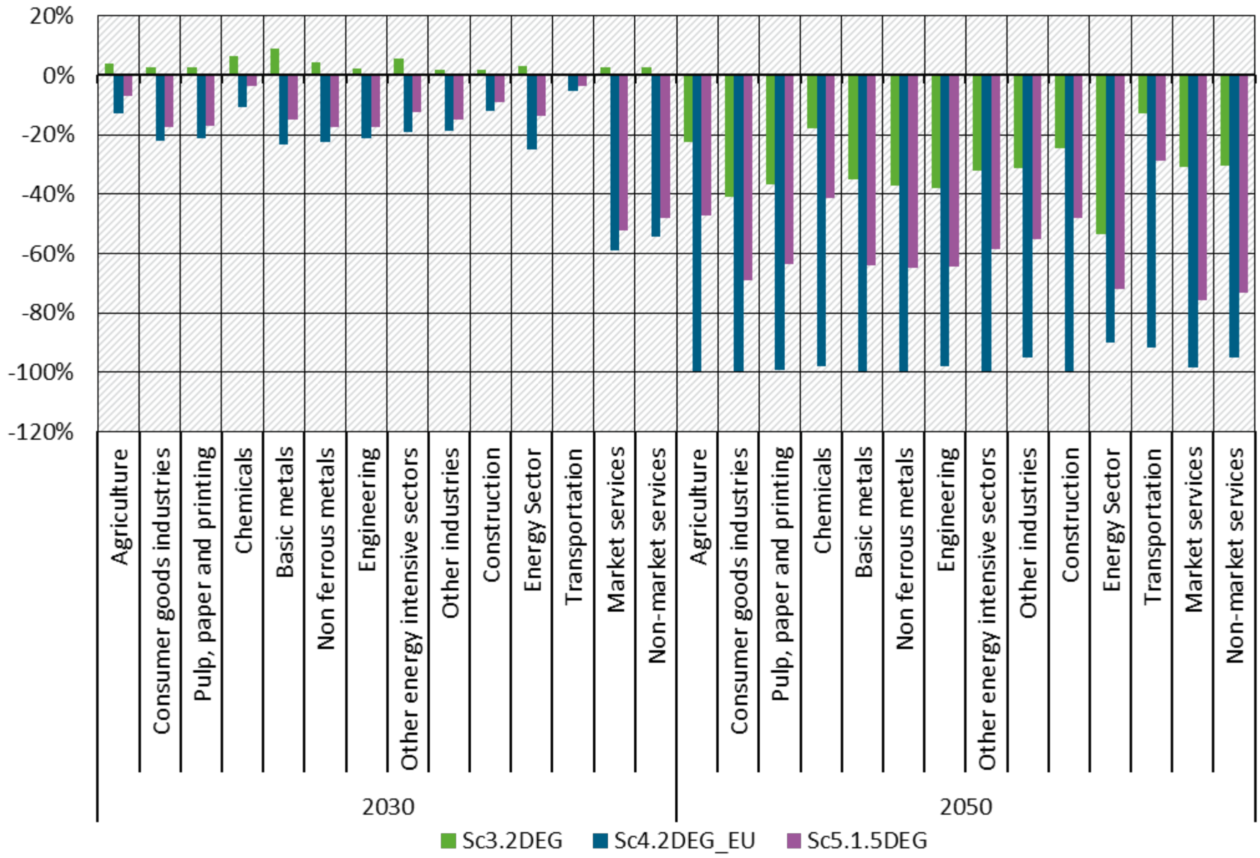
Figure 22: CO_2 per capita - Scenario 3 (continuous) compared to Scenario 2 (dotted line) [CO_2 /c]



Source: GEM-E3

The highest abatement potential is identified in the energy sector and the energy intensive industries. Both sectors account for more than 50% of total reductions in the EU. What needs to be noted is that in 2030 the carbon price that is required to achieve the EU NDC target in scenario 2 is higher than the global carbon price of Scenario 3 (global concerted GHG emission reduction). Thus in 2030 GHG emissions are higher in the EU than in scenario 2.

Figure 23: Deviations in EU sectoral energy-related CO_2 emissions, scenarios 3, 4, and 5 compared to scenario 2



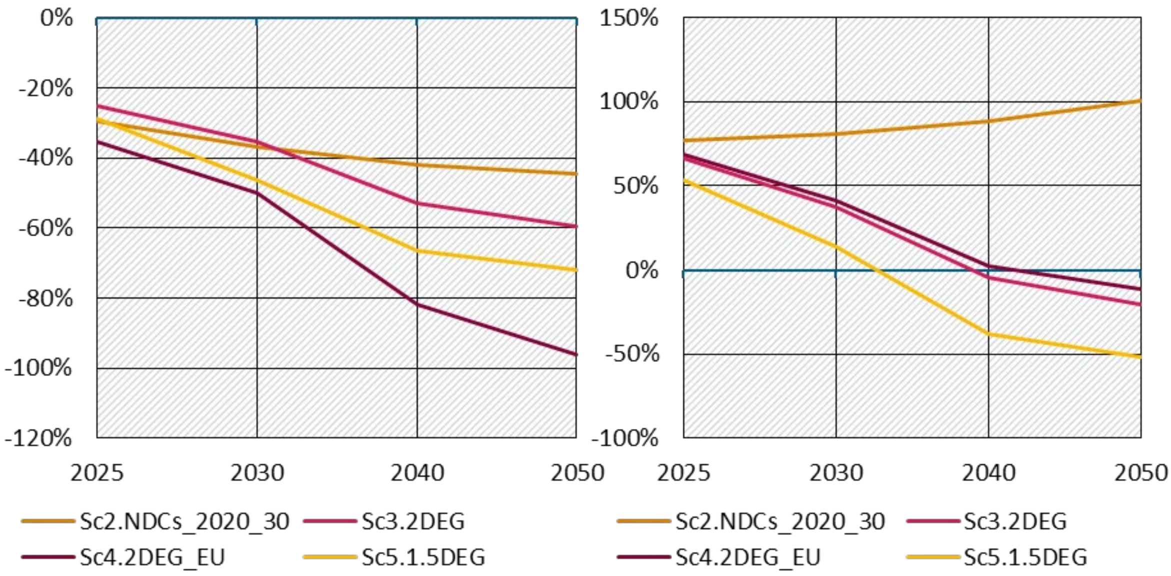
Source: GEM-E3

Note: Other energy intensive sectors refer to non-metallic mineral sector.

In scenario 4 (Sc4.2DEG_EU) the EU is forced to reduce emissions more compared to scenario 5 (Sc5.1.5DEG)[3]. This is attributed to the low-cost abatement options that are available to non-EU countries. The gap between the pink (scenario3) and purple (scenario4) line in Figure 24 shows the lower mitigation effort required from non-EU countries to reach the 2-degree target when the EU increases its effort (as the global carbon budget remains the same).

[3] The 95% target of the EU in 2050 implemented in scenario 4 is higher than the abatement that EU performs under a global least cost abatement scenario.

Figure 24: Deviations in EU (left) and non-EU (right) CO_2 energy-related emissions from 1990 for scenarios 2, 3, 4, and 5.



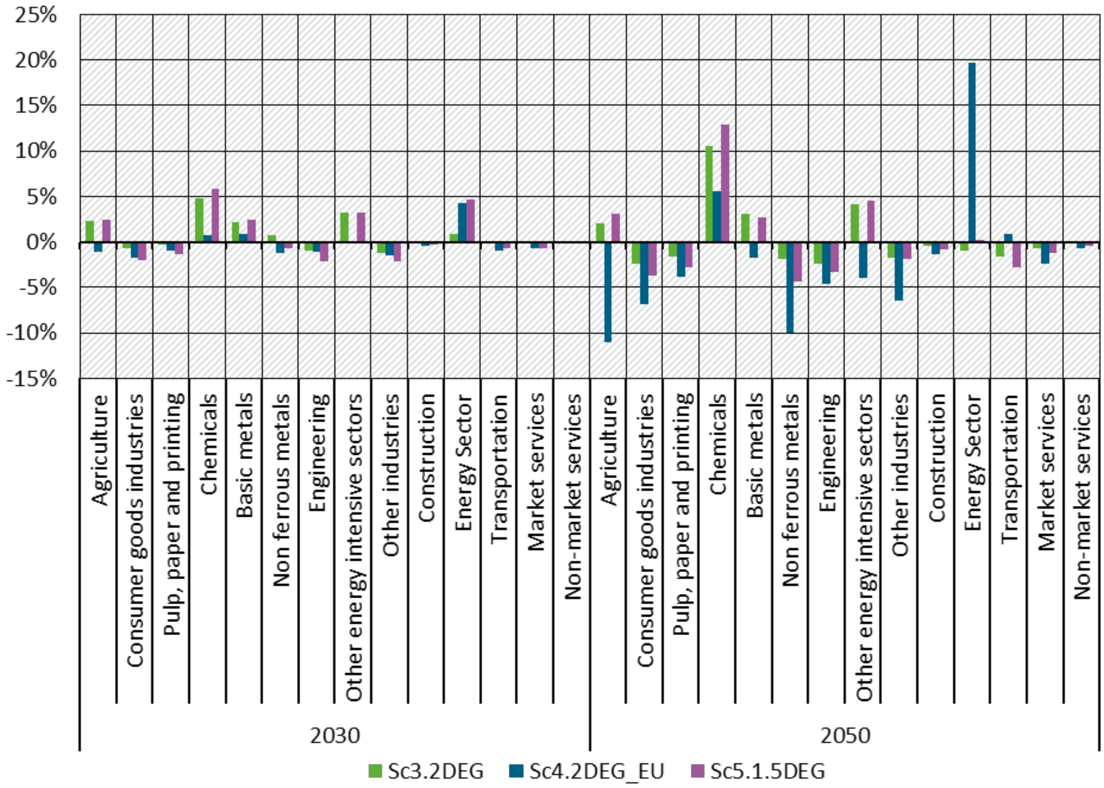
Source: GEM-E3

The decarbonization of the energy system affects production sectors unevenly (Figure 25). Energy intensive industries and the fossil fuels sector register the highest reduction in output due to rising capital and production costs. On the contrary, sectors such as engineering, RES equipment manufacturers, clean energy fuels etc. increase their production from reference levels (scenario 2).

In energy intensive sectors, a uniform carbon price in scenario 3 (2DEG) and 5 (1.5DEG) brings about competitiveness gains in the EU-28, as non-EU countries have higher carbon intensity than the EU-28 in average and their ambition to reduce CO_2 emissions is low.

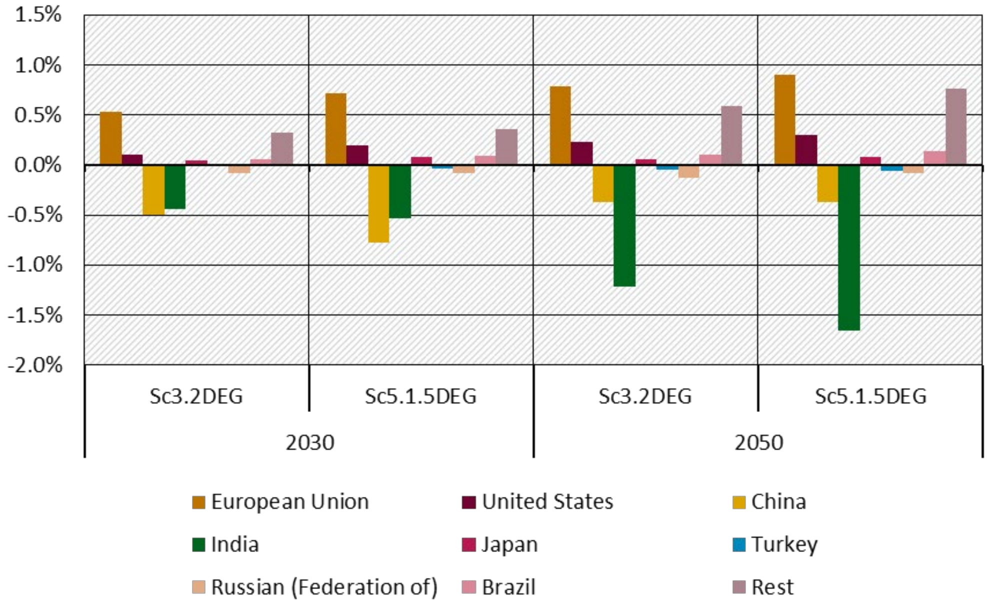
Figure 25 shows the impact in competitiveness for the energy intensive industries. The market share of energy intensive products increases in the EU-28 and the USA but drops in China and India.

Figure 25: Deviations in EU sectoral production, scenarios 3, 4, and 5 compared to scenario 2



Source: GEM-E3 -* Energy sector includes RES.

Figure 26: Change in the share of production of energy intensive products by country (Scenario 3 and 5 compared to 2)

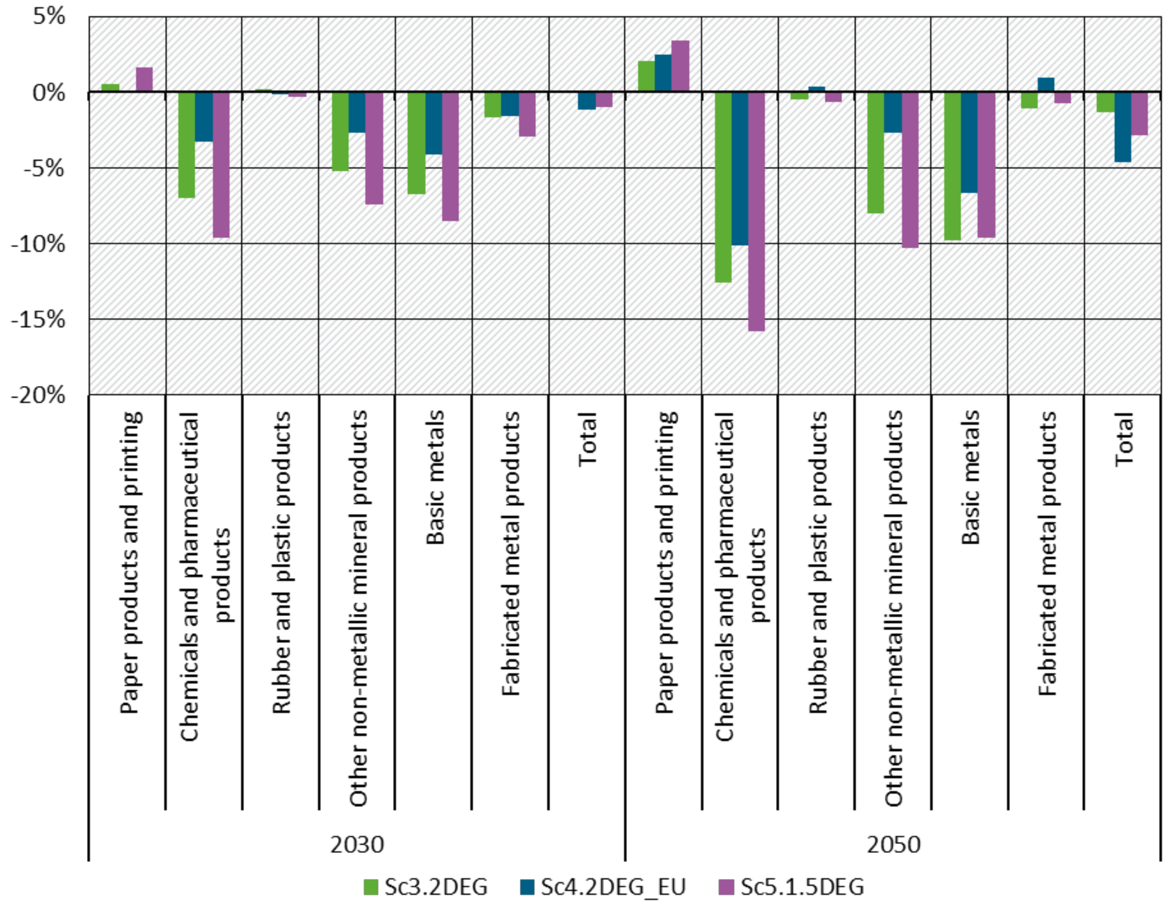


Source: GEM-E3

Note: Energy intensive products include Chemicals, Basic metals, Non-ferrous metals, Paper and pulp and Non-metallic minerals.

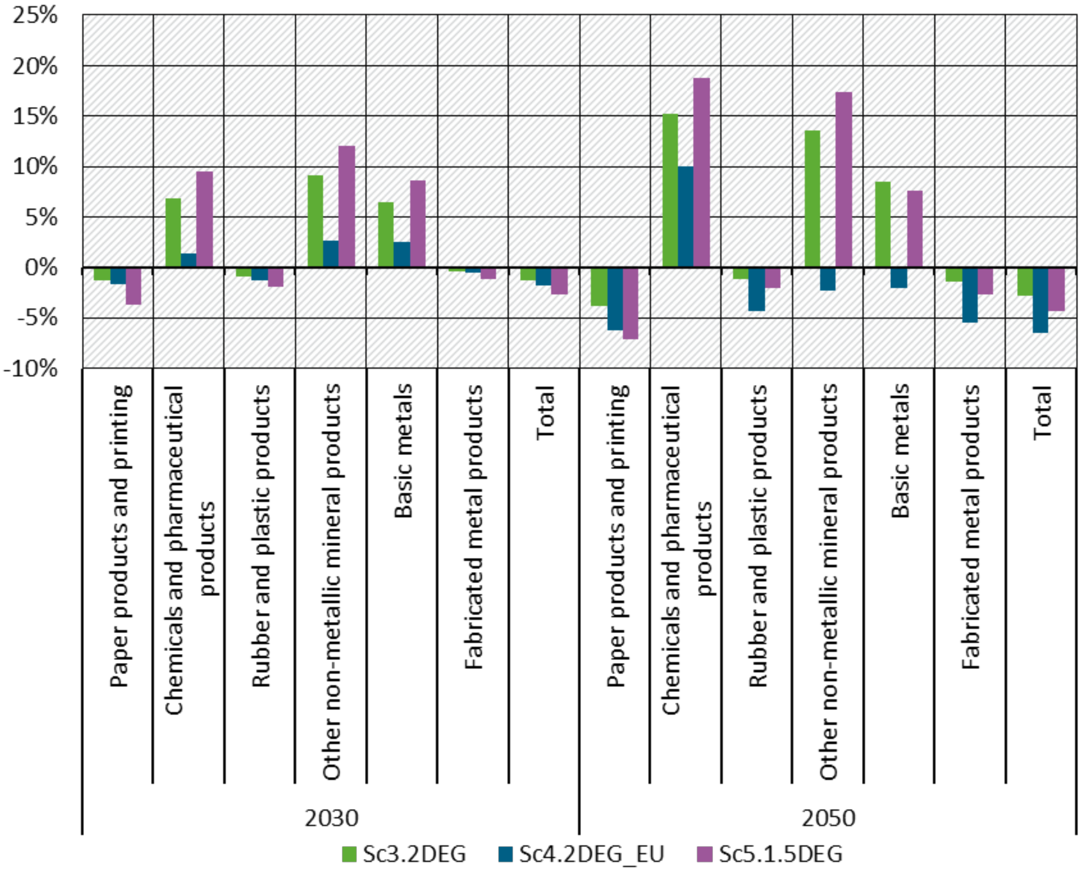
A rising carbon price forces non-EU countries to reduce their emissions under scenario 3 (compared to scenario 2). Subsequently, production costs go up, causing exports to the EU to drop. The competitiveness gains recorded in the EU boost exports, however with economic activity in non-EU countries shrinking, the demand for EU products reduces.

Figure 27: Deviations in EU sectoral imports, scenarios 3, 4, and 5 compared to scenario 2



Source: GEM-E3

Figure 28: Deviations in EU sectoral exports, scenarios 4, 5, and 6 compared to scenario 2

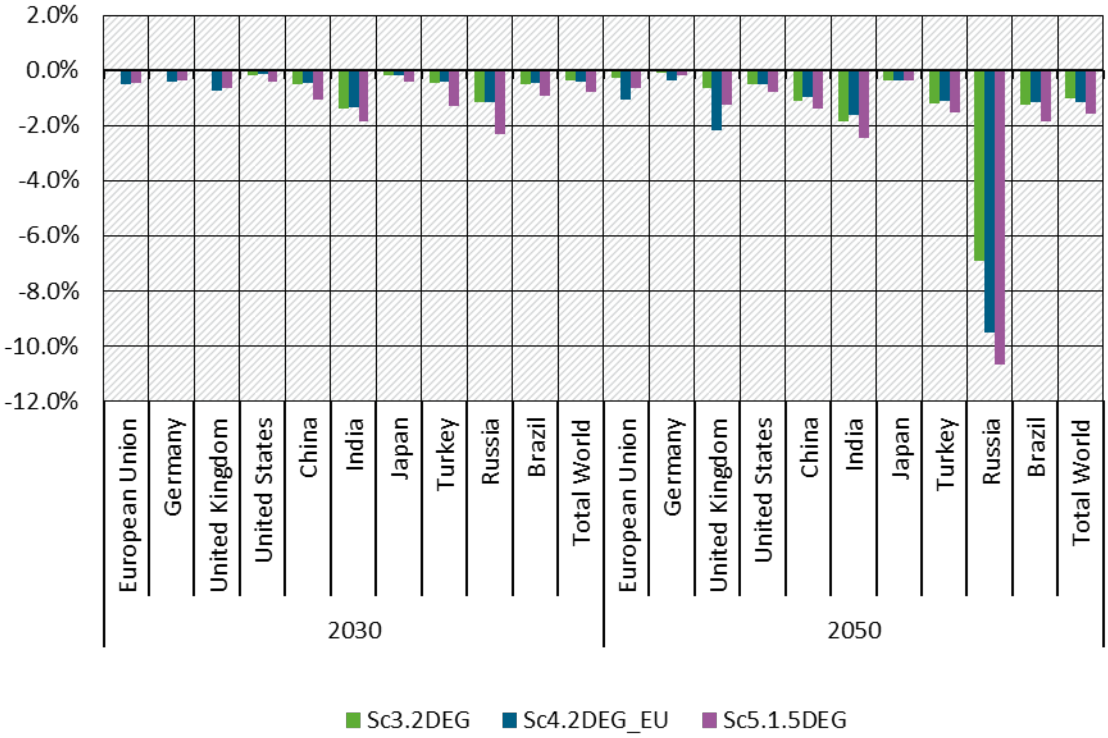


Source: GEM-E3

In the GEM-E3 setup the financing of the transition to a global decarbonized energy system is made through the economic agents' own funds (e.g., full crowding out). This means that new investment plans that are characterised by higher capital costs need to be financed by cancelling investments of equal amount in other sectors of the economy. This is a highly constraining case (as opposed to the case where financing is abundant and is supplied in the form of loans) as it stresses the capital markets and increases economy-wide capital costs. Hence as the decarbonization of the energy system requires the adoption of more expensive technologies the (non-climate related) impact on GDP is negative[4] (when compared to the reference scenario 2) in all scenarios examined. However, the impact is not uniform across countries. Regions like the EU that have already performed significant GHG emission reductions in the reference scenario, but are also suppliers of clean energy technologies, register small negative impacts as opposed to energy producing countries – especially Russia - that are quite negatively impacted. In general, the reduction in GDP is limited to a maximum of 2% for all countries except Russia. Employment (Figure 30) follows the trend of GDP and sectoral production with the biggest reduction taking place in Russia, Brazil, and India.

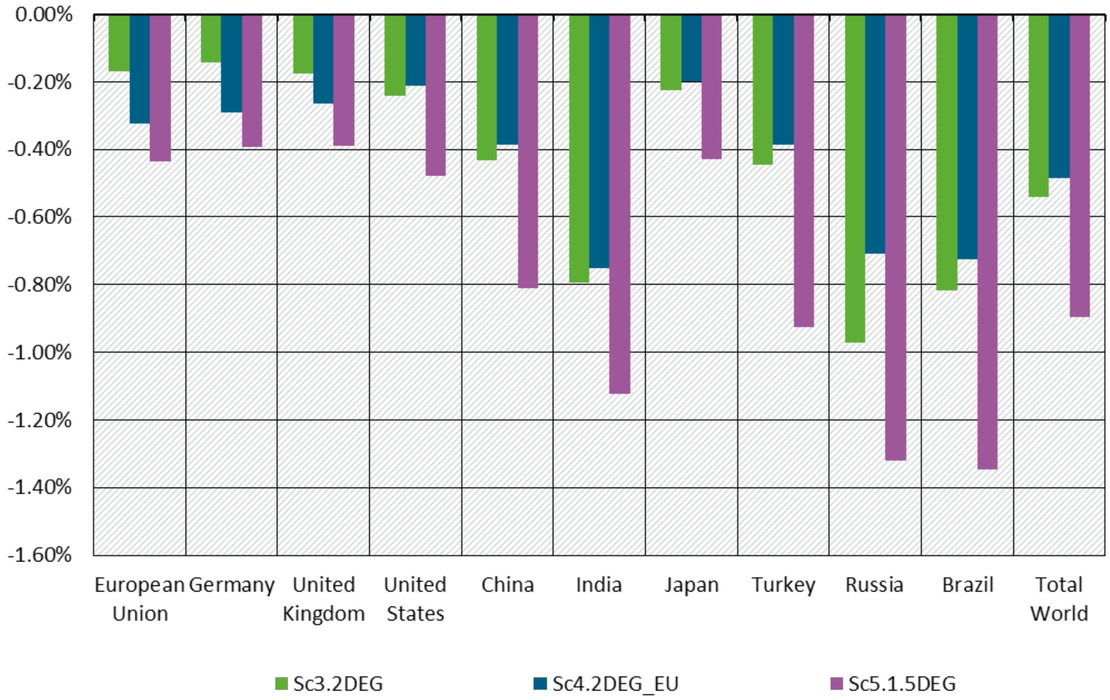
[4] Non-monetary benefits (i.e., climate damages) are not considered for the evaluation of the GDP impact.

Figure 29: Deviations in GDP, scenarios 3, 4, and 5 compared to scenario 2



Source: GEM-E3

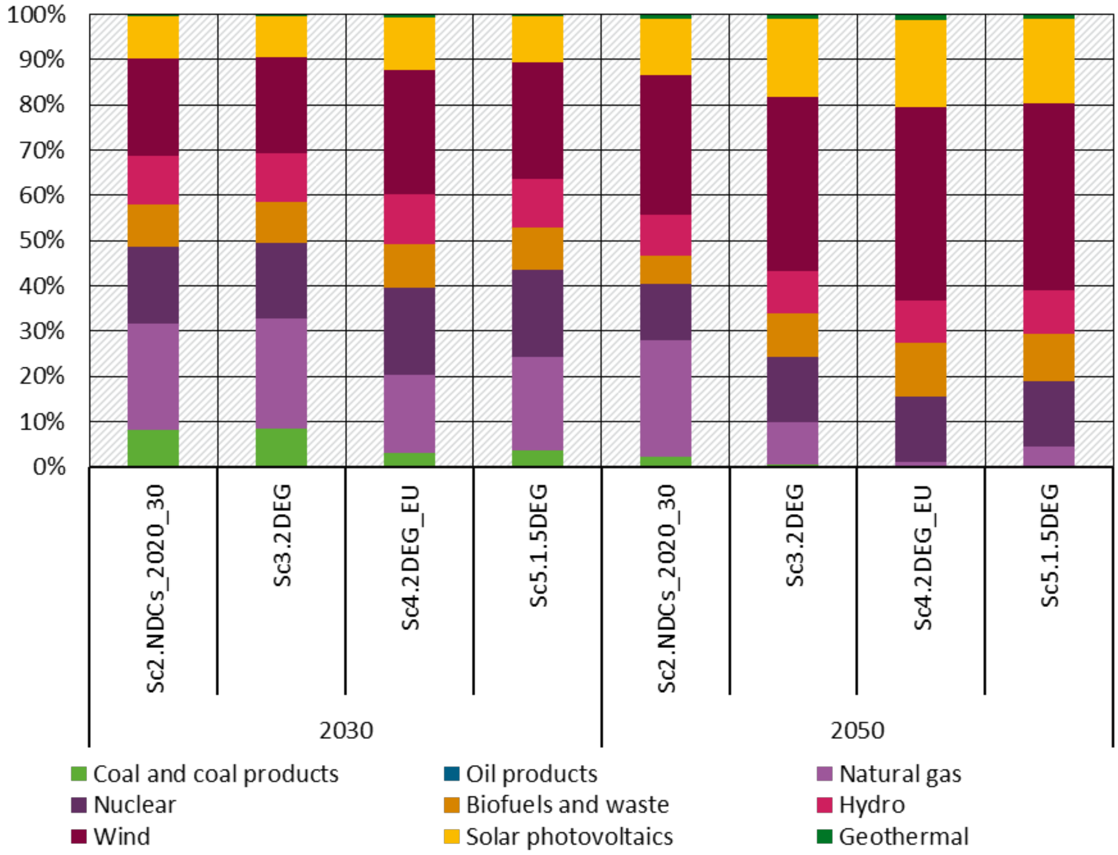
Figure 30: Deviations in employment in 2030, scenarios 3, 4, and 5 compared to scenario 2.



Source: GEM-E3

The figure below shows the decarbonization of the power system in order to achieve the 2° and 1.5° degree target in scenario 3,4 and 5 compared to scenario 2. Wind energy figures out as a dominant RES technology in all scenarios examined.

Figure 31: EU electricity generation mix, scenario 2, 3, 4 and 5



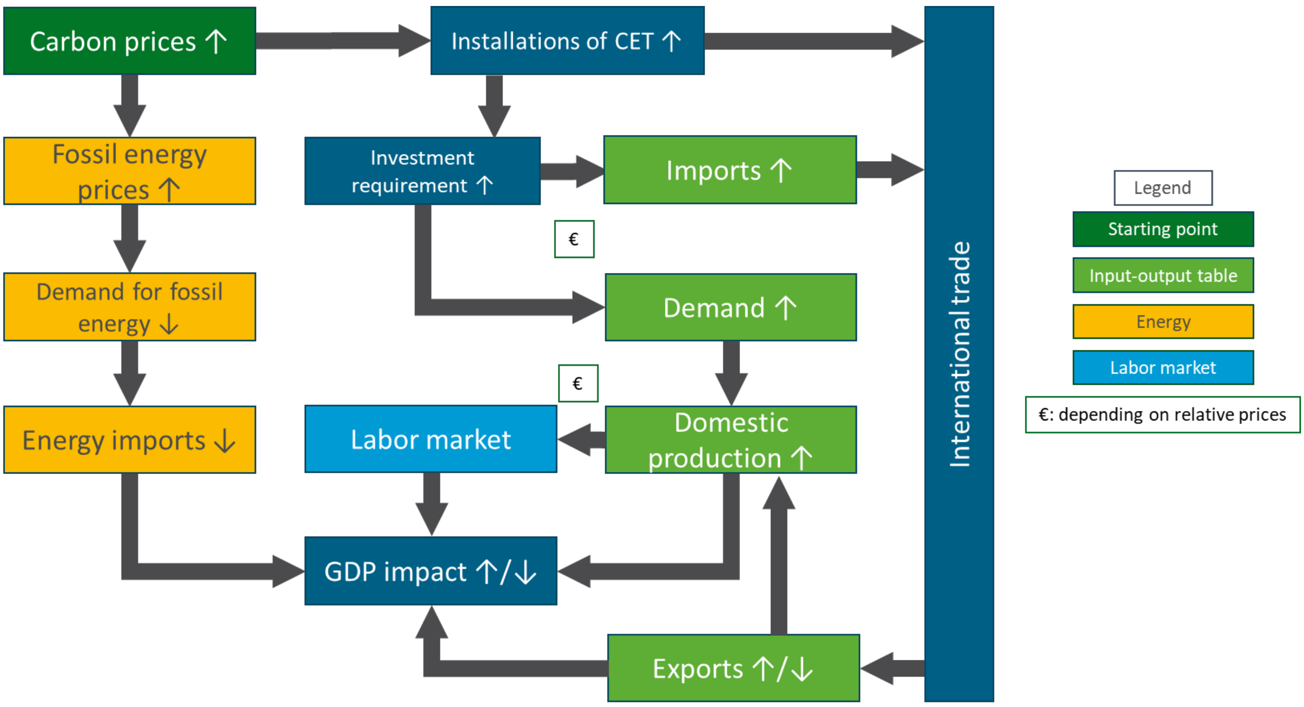
Source: GEM-E3

5 GINFORS-E – Scenario results

In addition to the harmonisation scenario used to harmonise the two models, other scenarios are described in section 3.1 and compared below. The **NDCs-2020** scenario 2 is the benchmark for further scenarios with a global CO_2 price. Two scenarios assume globally uniform CO_2 prices to achieve the 2° target and the 1.5° target, the **2DEG** scenario 3 and the **1.5DEG** scenario 5. Another scenario **2DEG_EU**, builds on the **2DEG** scenario and at the same time assumes that the EU achieves its target within the framework of the Green Deal. The EU achieves a 95% GHG reduction by 2050 and the world must achieve a correspondingly lower reduction. This requires a higher carbon price for Europe and allows a slightly lower price for the rest of the world.

In addition to the changes in energy use and the associated emissions, the scenario comparison shows the macroeconomic and sectoral effects of ambitious global climate policy. Different effects occur, which are shown in a simplified form in Figure 32: Higher CO_2 prices lead to higher prices of and reduced demand for fossil fuels. As a result, fossil energy imports also decline, which places a heavy burden on the fuel extracting countries. On the other hand, investments in low and zero carbon technologies increase, which in turn can be produced domestically or imported. 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, which also influence domestic production and GDP. Imports of one country are always exports of another in the global model, so that shifts can occur here. The effects on national GDP are initially open and depend on a whole set of model specifications and interrelations, finally, on the relative impact of a country compared to important competitors and trading partners.

Figure 32: GINFORS-E modelling – impacts of carbon price increase



Source: own depiction.

The carbon price is only a proxy for a variety of policy measures, some of which could have quite different effects. For example, the promotion of electric cars massively favours deployment early and possibly leads to additional vehicle purchases compared to a pure carbon pricing. The same applies to subsidy programmes for building insulation or the promotion of RES 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 as long as no crowding-out is assumed.

Table 15: Changes in GDP and CO_2 emissions from Sc2.NDCs_2020_30

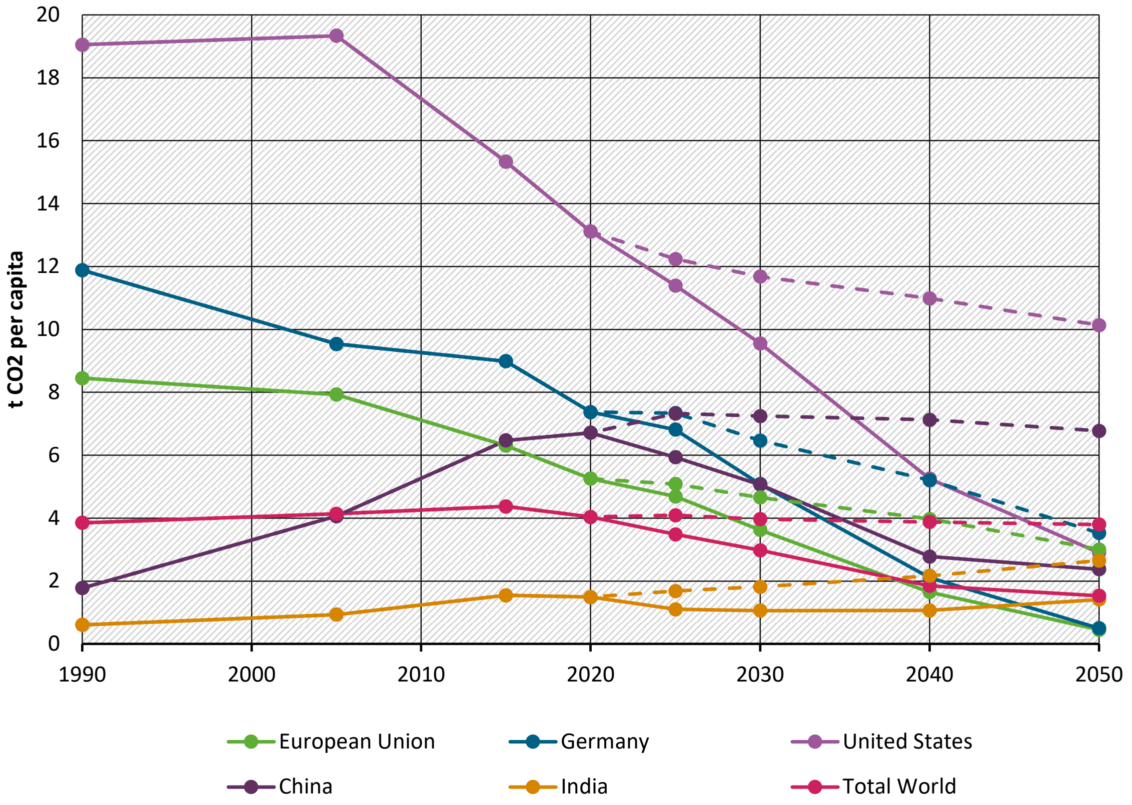
	GDP (2050)		CO_2 (2020-2050)		Cumulative CO_2 emissions (2020-2050)
Scenario	World	EU	World	EU	World
Sc3.2DEG	-1.05%	-0.22%	-37.60%	-24.67%	674,007
Sc4.2DEG_EU	-0.90%	0.15%	-37.45%	-37.13%	675,523
Sc5.1.5DEG	-1.09%	-0.14%	-50.92%	-36.42%	530,068

Source: GINFORS-E.

In scenarios 4 and 5, the CO_2 price for achieving the 2° target leads on global level to slightly negative macroeconomic effects of about 1% in 2050 compared to the reference (Table 15). 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. In the EU, the macroeconomic effects are even slightly positive in scenario 4 and slightly negative in scenarios 3 and 5. The last column of the table shows global energy related CO_2 emissions in the period 2020 to 2050 in the scenarios. These impacts on GDP are low compared to the expected cost of climate change. Mitigation to climate change will bring macroeconomic benefits by reducing damages and the reduction of these costs of climate change.

The resulting CO_2 emissions per capita in Figure 33 show a clearly higher ambition level of scenario **2DEG**, that allows to reach the 2° target in comparison to scenario **NDCs_2020_30**. Emission reductions in the EU and US are more in line with the decreasing path observed between 2005 and 2020 in scenario 3 as opposed to a slower decrease or stagnation in scenario 2. China reduces its per capita emissions in the 2DEG scenario, while they even slightly increase in scenario 2. In the case of India, CO_2 emissions per capita in the 2DEG scenario plateau under the current level of 2020. In total, the world needs to reduce emissions per capita down to close to 1 t/person in 2050 from 4 t/person in 2020 to reach the 2° target.

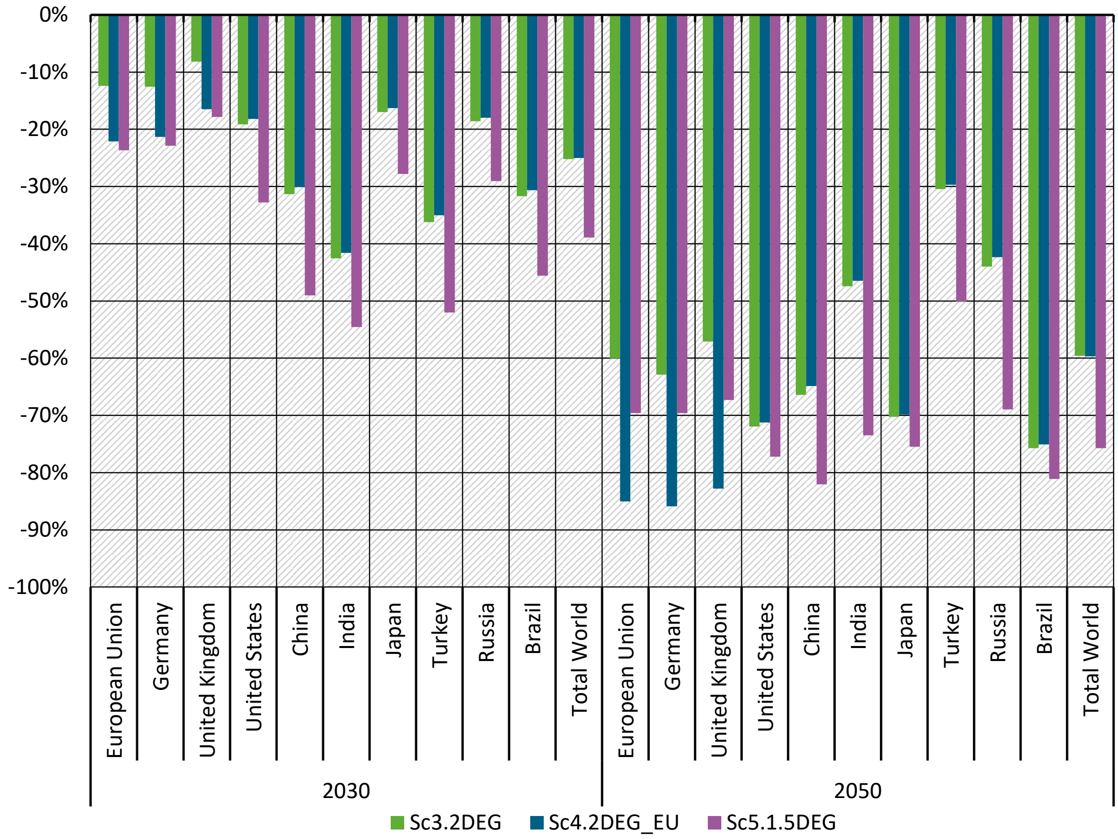
Figure 33: CO_2 per capita - Sc3.2DEG (continuous) compared to Sc2.NDCs_2020_30 (dotted line) [CO_2 /c]



Source: GINFORS-E.

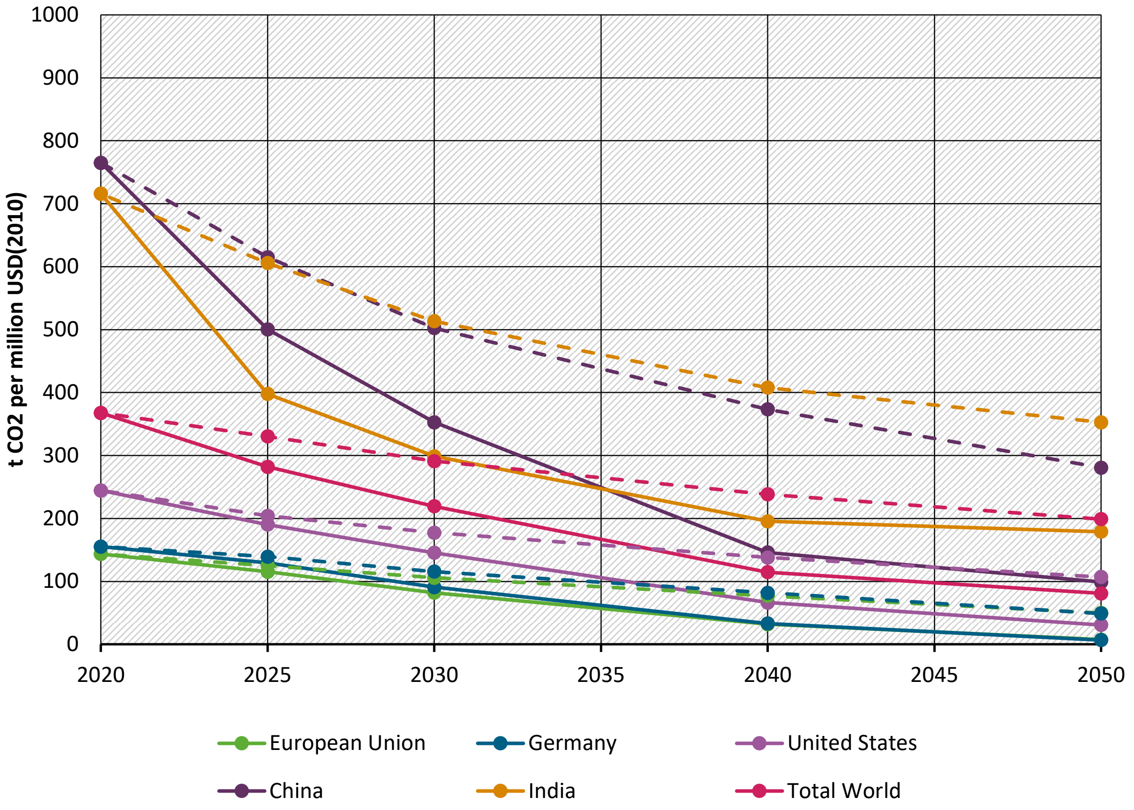
The depiction shown in Figure 34 broadens the scope and extends the comparison to the scenarios 4 and 5. Due to higher EU ambitions in Sc4.2DEG_EU, per capita emissions are lower compared to Sc3.2DEG. For the rest of the world, the higher emission reductions in the EU have small impact. In the 1.5DEG scenario (Sc5.1.5DEG), global emissions are lower than in the 2DEG scenario. For the EU, it is striking that the reduction in 2030 in this case is similar to the target achievement in scenario 5. In contrast, the differences of the 1.5DEG scenario for the EU in 2050 are quite small compared to the 2DEG scenario. In other parts of the world as India, Turkey or Russia and other countries, there are cheaper mitigation options at the global carbon price after 2030.

Figure 34: Deviations in CO_2 emissions per capita - Scenario Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to scenario 2 in 2030 and 2050



Source: GINFORS-E.

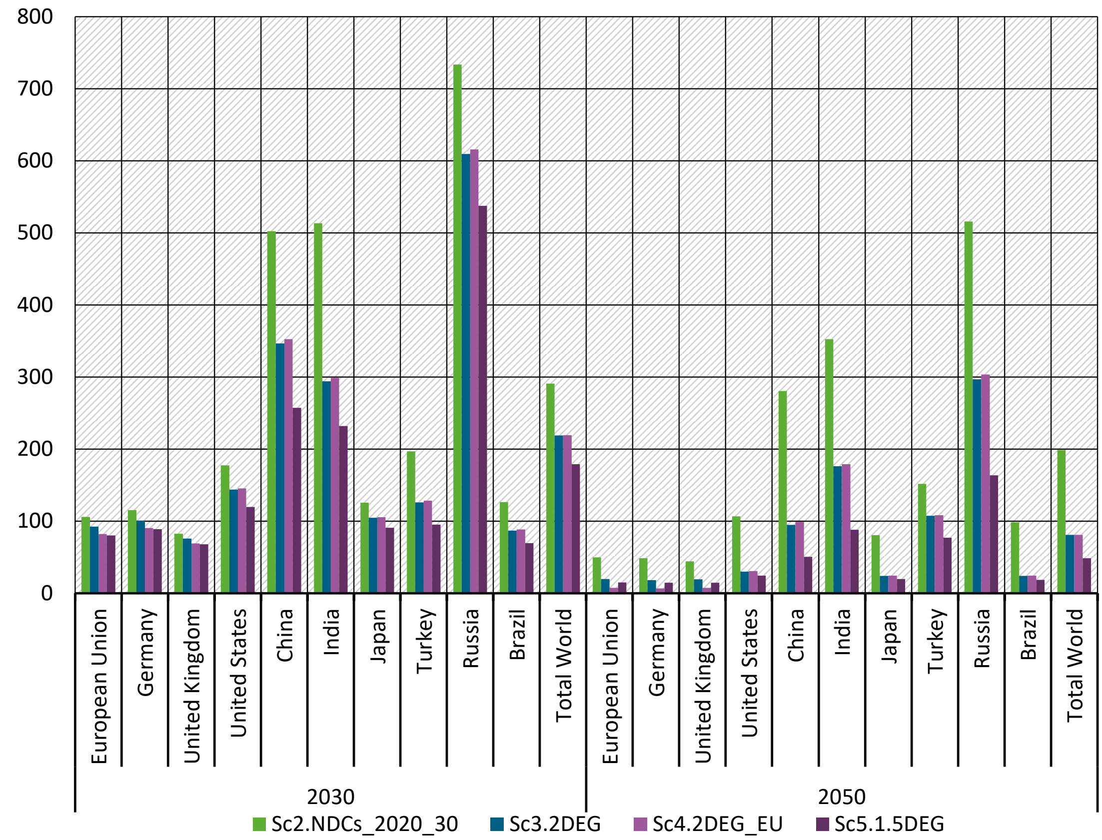
Figure 35: CO_2 per GDP - Sc3.2DEG (continuous) compared to Sc2.NDCs_2020_30 (dotted line) [t CO_2 per million USD (2010)]



Source: GINFORS-E.

The CO_2 intensity in GDP is also decreasing at a higher rate in scenario Sc3.2DEG compared to Sc2.NDCs_2020_30, as can be seen in Figure 35. China experiences the highest absolute and relative reduction between scenarios. US emissions per unit of GDP in Sc3.2DEG are also only a quarter of those in Sc2.NDCs_2020_30 by 2050.

Figure 36: CO_2 per unit of GDP - Sc2.NDCs_2020_30, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG in 2030 and 2050 [t CO_2 per million USD (2010)]

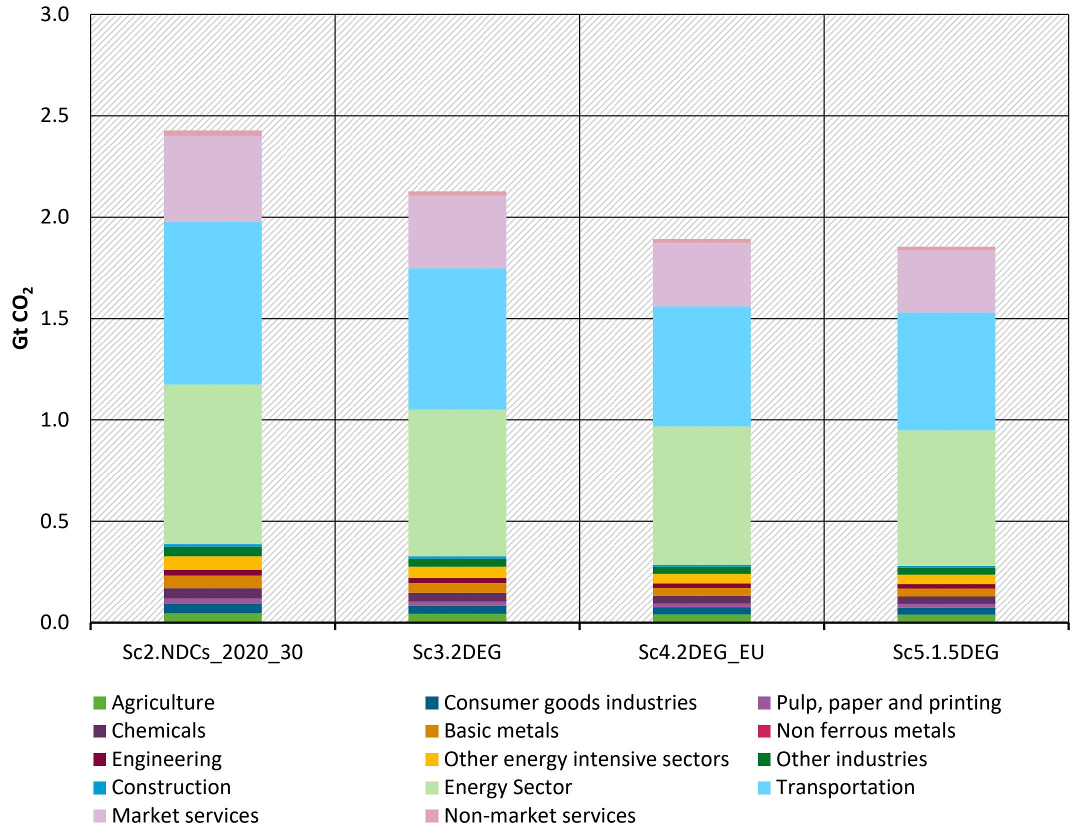


Source: GINFORS-E.

Looking at the intensity in absolute terms for the four scenarios considered (see Figure 36), it becomes clear, that the reduction in emission intensity across scenarios for China and India is quite pronounced for all other scenarios in 2030 when compared to Sc2.NDCs_2020_30. The EU shows less deviation by 2030, while the differences by 2050 are significant. Differences in CO_2 intensities between countries will still be large in 2050, with India, Turkey, and Russia above global average.

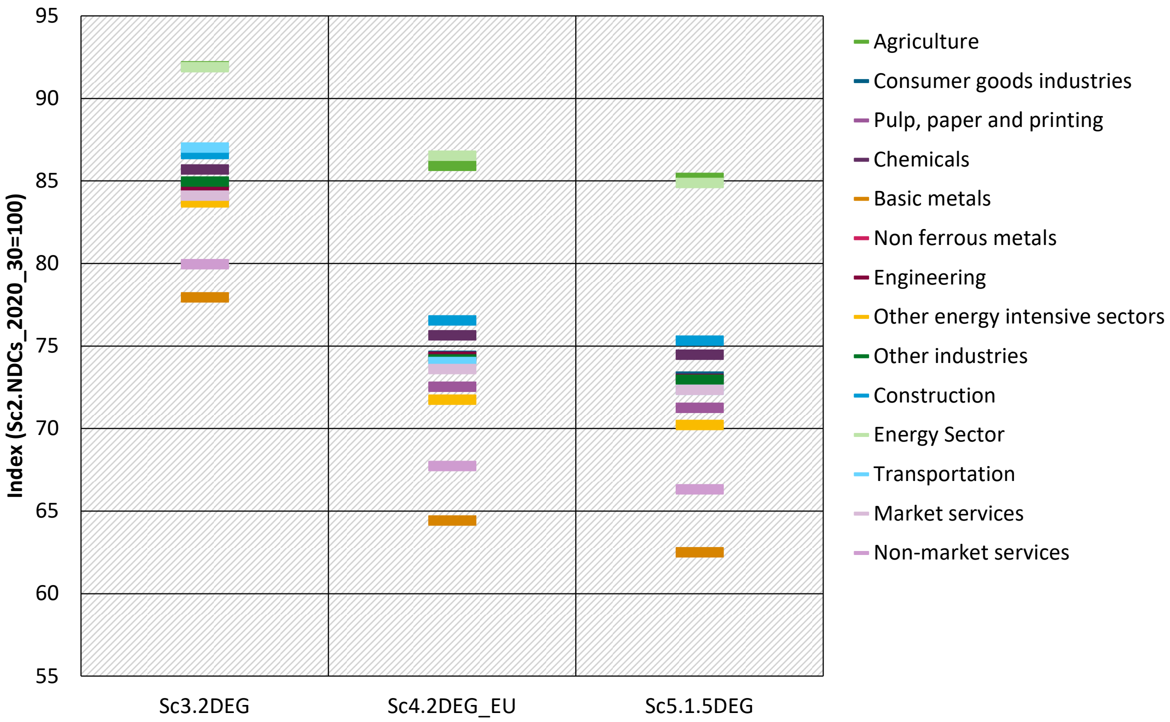
Focusing on the EU, most emissions will stem from energy and transport in 2030 (Figure 37). The sectors where the emission levels deviate most visible from Sc2.NDCs_2020_30 by 2030 are different industries as basic metals and non-market services (Figure 38). Sectors with high potential to substitute fossil fuels by electricity as some services report deviations above average. Figure 39 shows that deviations across scenarios are similar for each sector, with the highest reductions in energy and transport in 2050.

Figure 37: EU Energy-related CO_2 emissions of scenarios Sc2.NDCs_2020_30 to Sc4.2DEG_EU in 2030



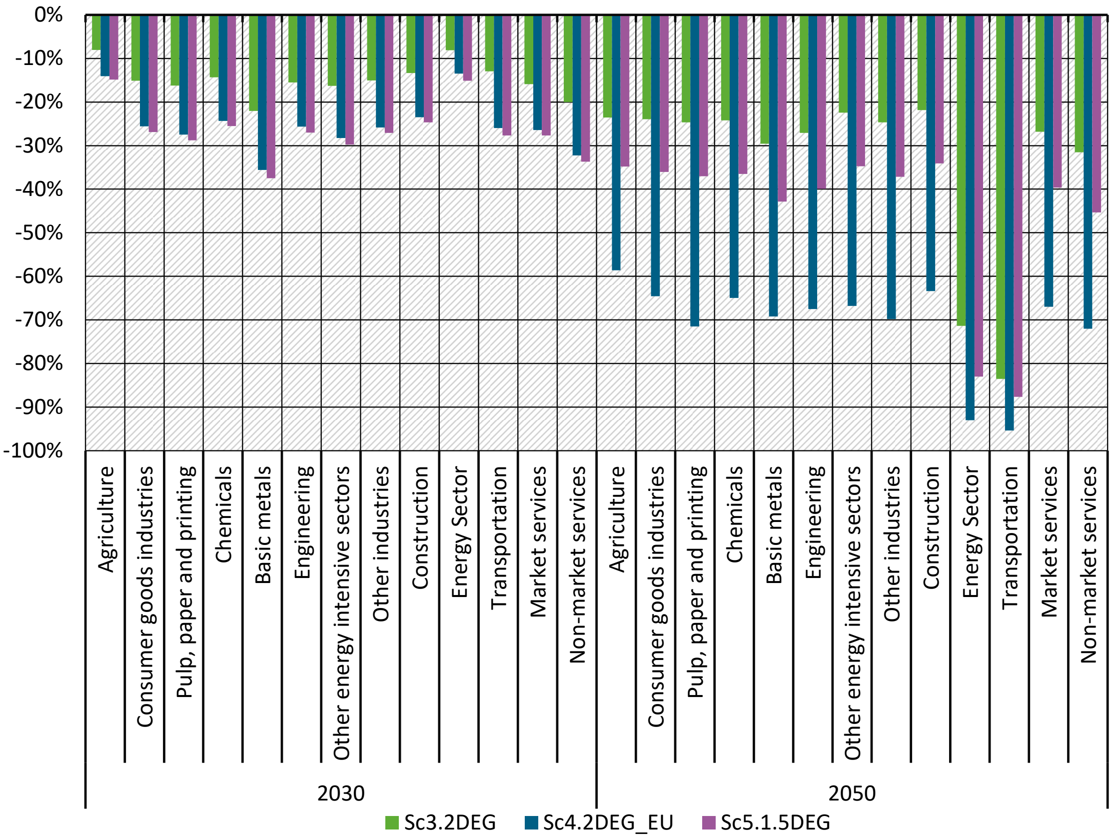
Source: GINFORS-E.

Figure 38: EU Energy-related CO_2 emissions of Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG, relative to Sc2.NDCs_2020_30 in 2030



Source: GINFORS-E.

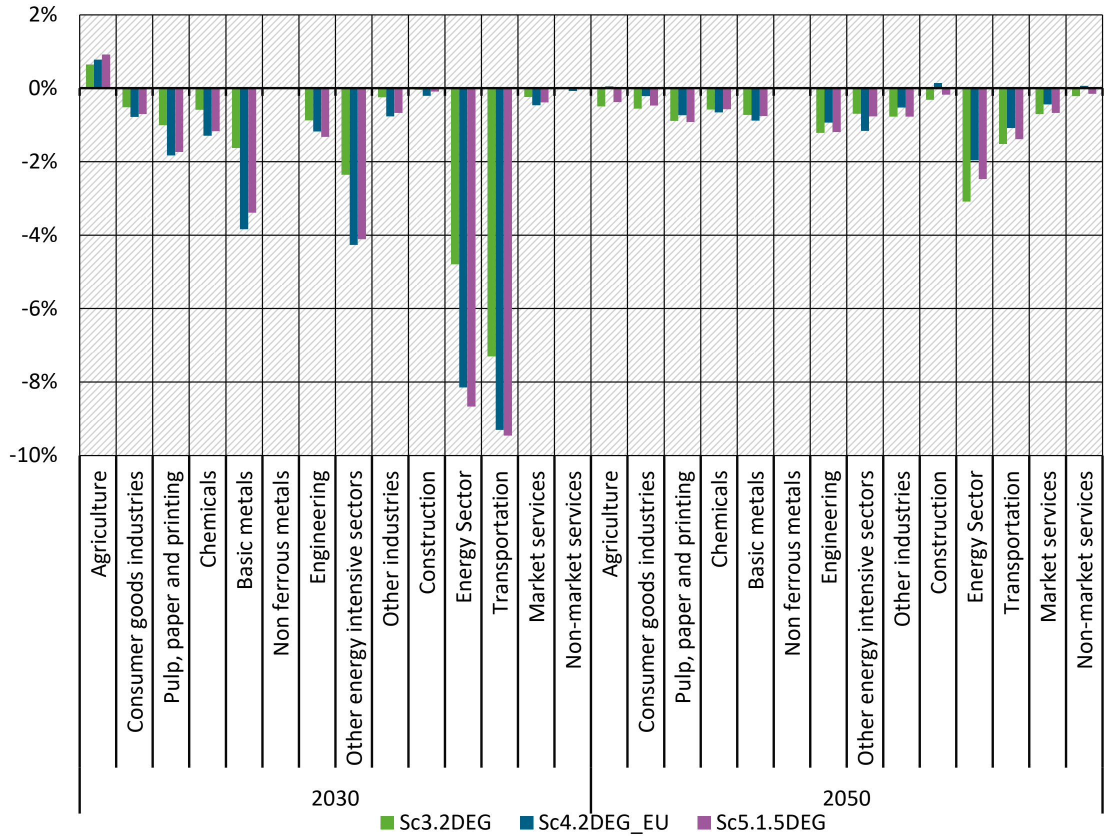
Figure 39: Deviations in EU sectoral energy-related CO_2 emissions, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

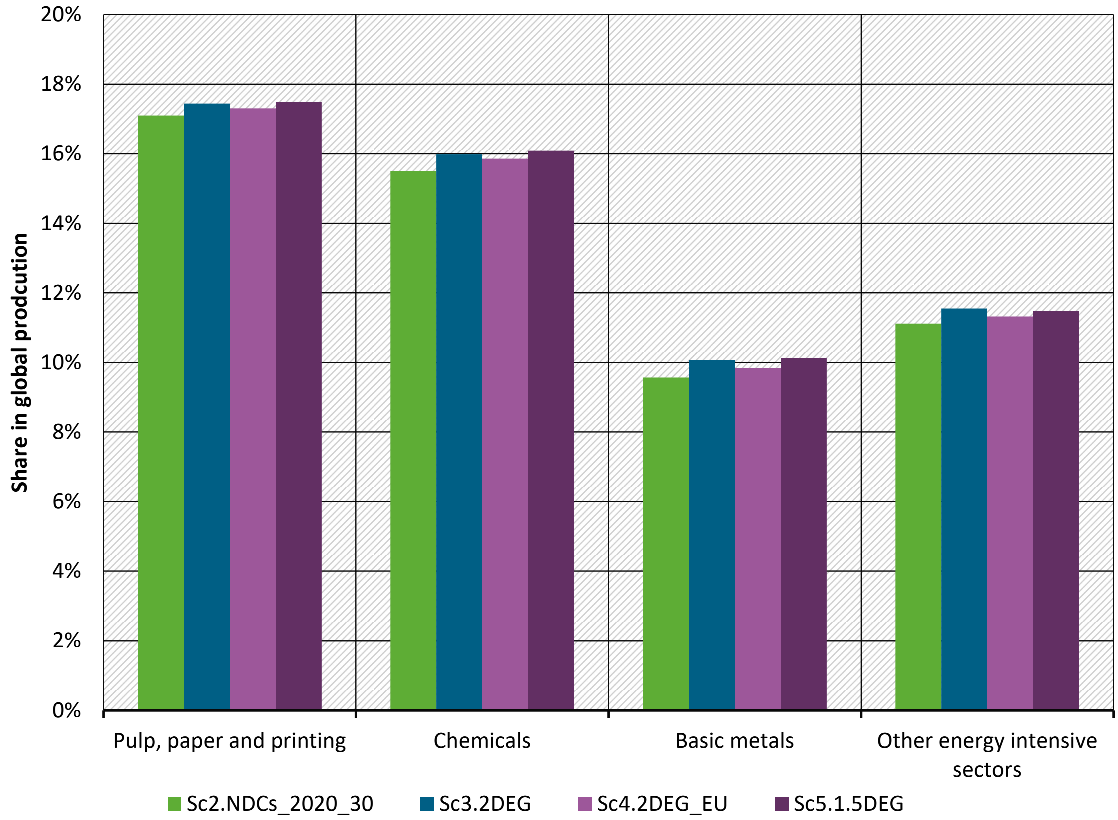
As can be seen from Figure 40 energy and transportation sectors face lower production in scenarios 3 to 5 in 2030, while they can recover compared to scenario 2, when they are decarbonised in 2050. Deviations for most sectors are smaller in 2050 than in 2030. While production effects are bigger in scenarios Sc4.2DEG_EU and Sc5.1.5DEG in 2030 due to higher carbon prices than in scenario Sc3.2DEG, they do not differ too much in 2050, when sectors will be decarbonised. In 2050 emissions level in the two sectors are about 80 or more percent lower in scenario Sc3.2DEG than in scenario 2, while production is less than 4 percent under scenario 4 levels. While most sectors experience lower production in Sc3.2DEG, it is slightly above Sc2.NDCs_2020_30 levels for agriculture in 2030 and almost unchanged for construction and market and non-market services, which are the most important sectors in terms of value added and employment.

Figure 40: Deviations in EU sectoral production, scenarios Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

Figure 41: **EU production shares in 2030, Sc2.NDCs_2020_30, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG**

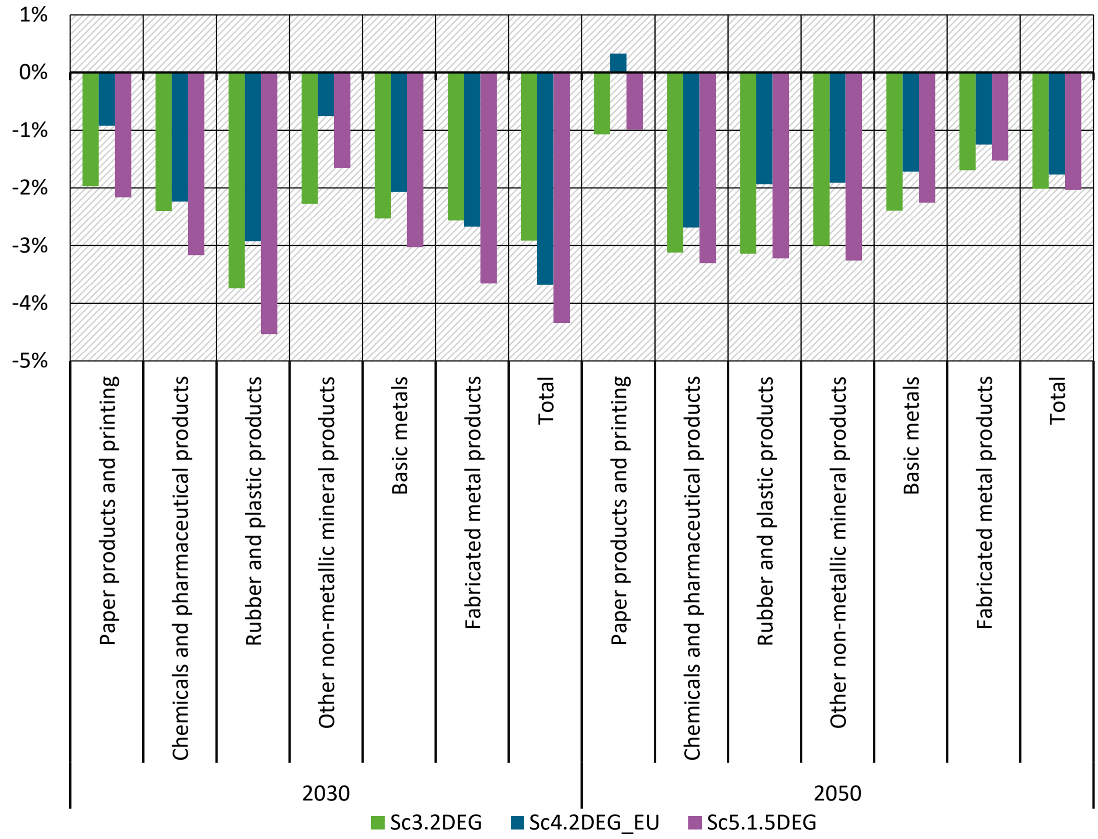


Source: GINFORS-E.

The relative share of EU production in energy intensive sectors lies above the values of Sc2.NDCs_2020_30 for all more ambitious scenarios. Sc4.2DEG_EU with higher carbon prices in Europe is slightly less favorable in this regard than Sc3.2DEG and Sc5.1.5DEG with globally uniform carbon prices, however, differences are small (Figure 41). The EU industries profit from higher carbon prices in the rest of world.

In scenarios 3 to 5, total EU imports are lower compared to scenario Sc2.NDCs_2020_30. Figure 42 depicts the deviations between the scenarios for energy intensive sectors and for total EU imports. The sectors with the highest deviations vary over time. In 2030 rubber and plastic products and fabricated metals differ the most, in 2050 chemical and pharmaceutical products mark the strongest deviation. Imports of paper products and printing are overall less affected by the scenario design than imports of other energy intensive sectors. It is also noticeable that total imports decrease somewhat more than the imports of energy-intensive sectors, which can be explained by the rising transport costs.

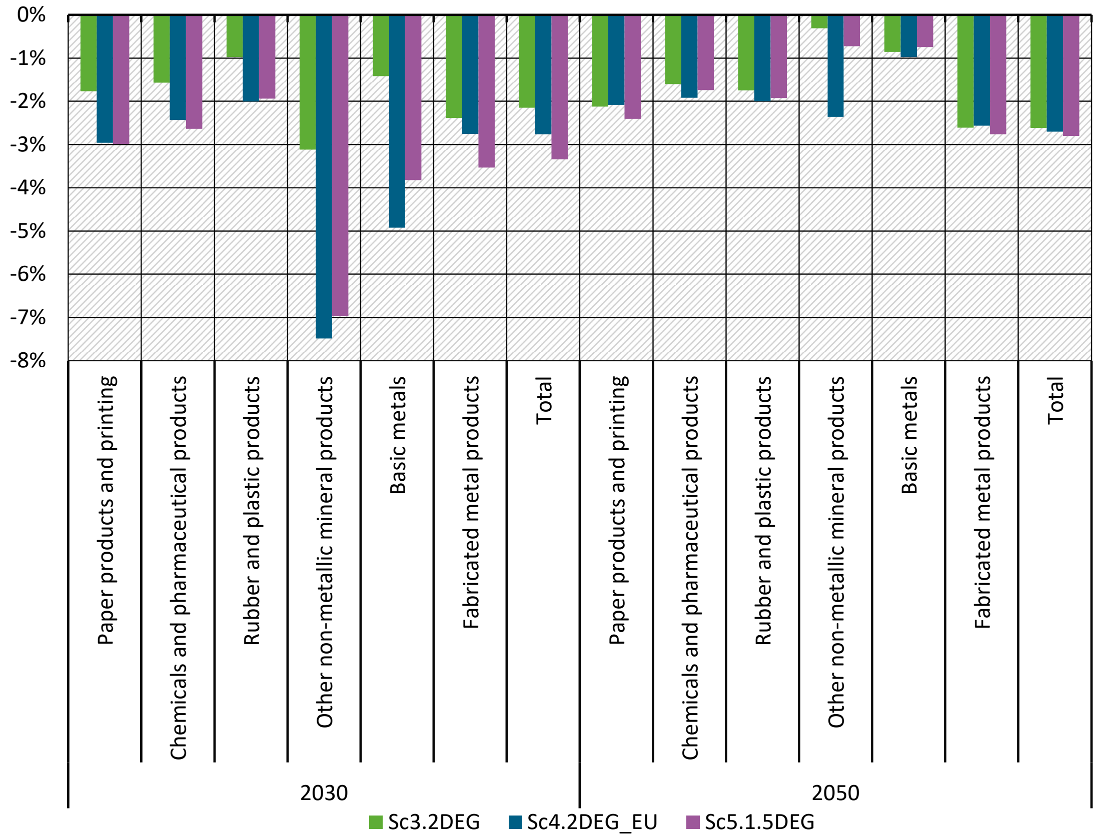
Figure 42: Deviations in EU sectoral imports, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

EU exports are beneath Sc2.NDCs_2020_30 levels as well, which implies that total EU international trade is lower compared to Sc2.NDCs_2020_30 in scenarios 3 to 5. Other non-metallic mineral products show the highest deviation in export volume in both 2030 and 2050. Export activity further decreases in Sc4.2DEG_EU and Sc5.1.5DEG in 2030 (see Figure 43) with individual sectors responding quite uniformly to the different carbon prices. Differences in 2050 are smaller for energy-intensive sectors compared to 2030.

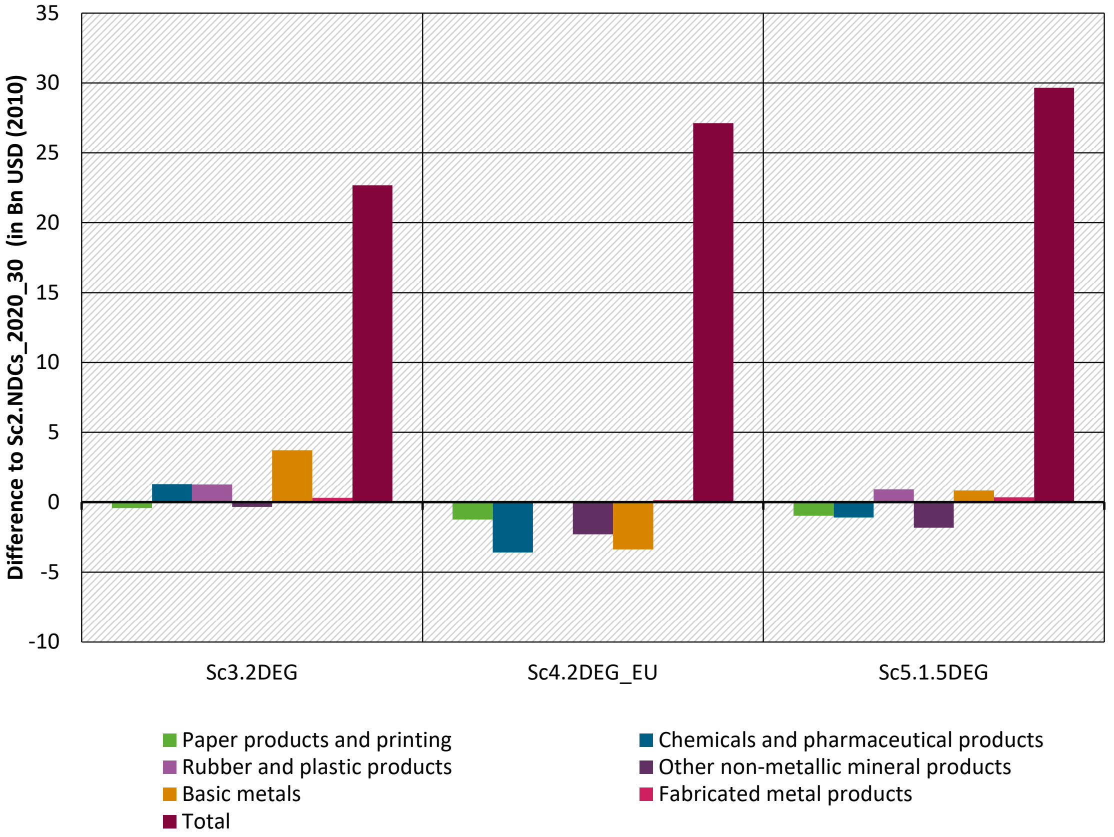
Figure 43: Deviations in EU sectoral exports, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

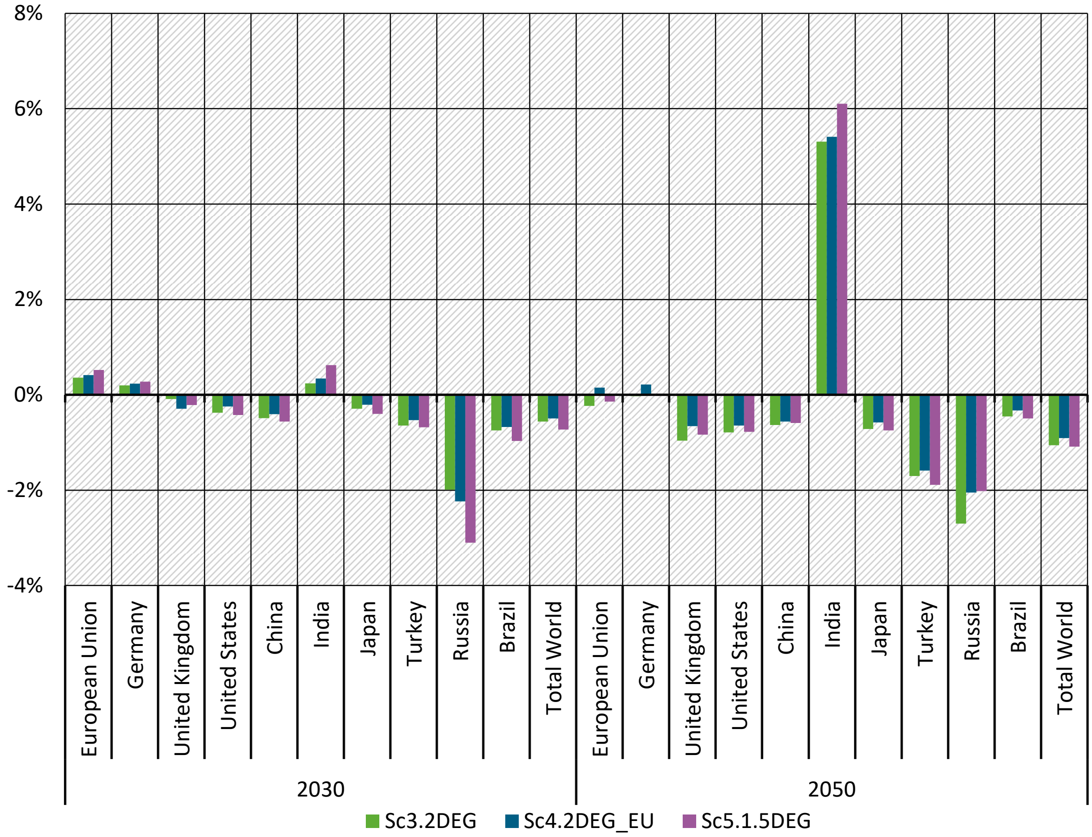
For energy intensive sectors, effects are more pronounced for exports, while import effects are below average, probably due to stronger price increase outside EU. As a result, this means that the EU's net exports for the energy-intensive sectors would decrease, but even increase slightly in total (Figure 44). With (largely) uniform global CO_2 prices, the EU obviously has small competitive advantages over other parts of the world.

Figure 44: EU net exports in 2030, differences of Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

Figure 45: Deviations in GDP, scenarios Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30

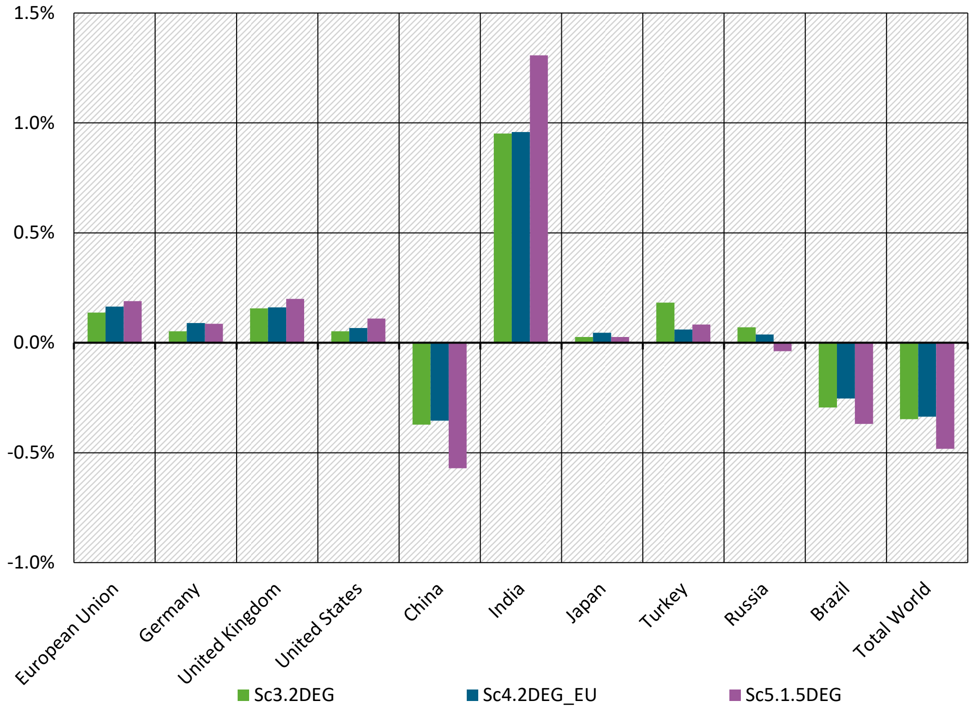


Source: GINFORS-E.

Looking at the deviations in GDP between scenarios 3 to 5 and scenario 2 yields an indication to which degree certain economies benefit or are burdened more than others from the carbon prices implemented. GDP deviations for the EU and Germany are positive for 2030, and around zero in 2050 (Figure 45). For China, the effects of increased climate protection in 2030 are negative in the order of 0.5%. By 2030 India is the country that lies most clearly above Sc2.NDCs_2020_30 levels, with the deviation being even more pronounced in 2050. Resource rich economies like Russia and Brazil tend to experience less economic activity under scenario Sc3.2DEG and Sc5.1.5DEG, in which the 1.5° target will be reached. Higher EU ambition in Sc4.2DEG_EU is slightly positive for other countries as USA, Turkey or Russia compared to Sc3.2DEG with a uniform global carbon price. But GDP is also slightly higher in the EU.

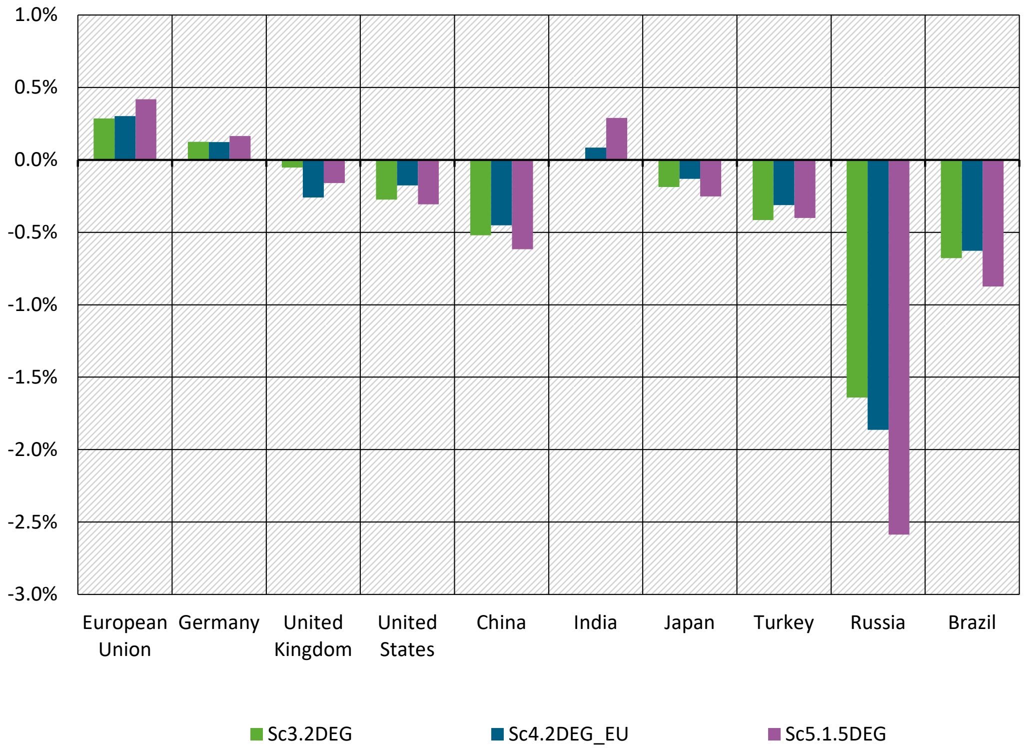
The development of employment follows for many countries the direction of the GDP effect but is weaker due to wage effects. For some countries total employment even slightly increases despite lower GDP (Figure 46). Private consumption largely follows the development of GDP (Figure 47).

Figure 46: Deviations in employment in 2030, scenarios Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



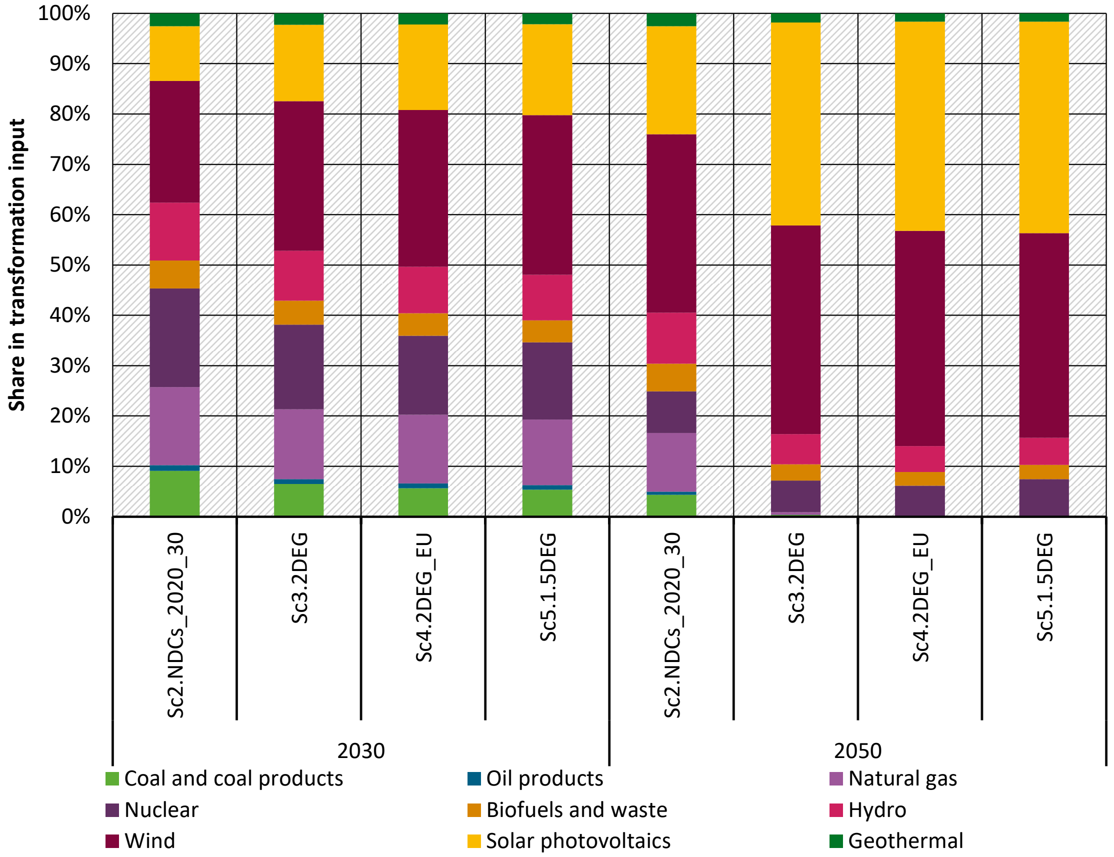
Source: GINFORS-E.

Figure 47: Deviations in private consumption in 2030, scenarios Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG compared to Sc2.NDCs_2020_30



Source: GINFORS-E.

Figure 48: EU electricity generation mix, Sc2.NDCs_2020_30, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG in comparison

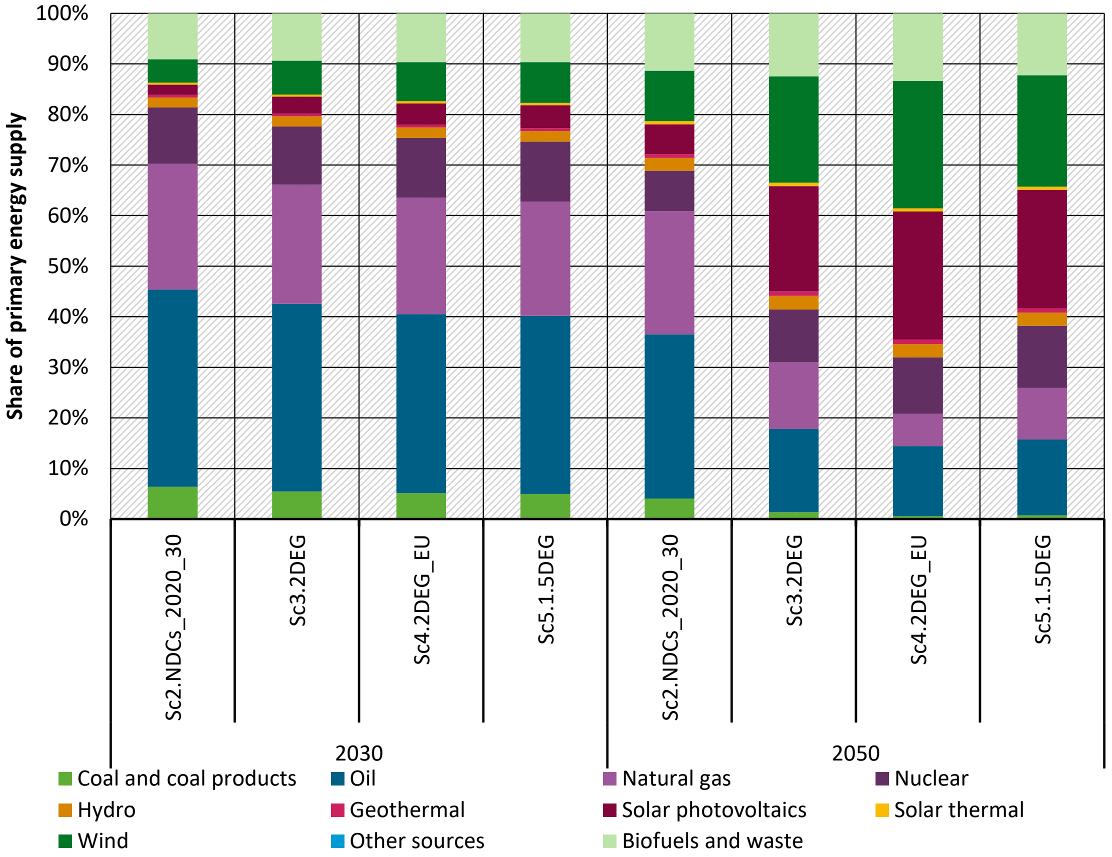


Source: GINFORS-E.

The input mix in electricity generation in the EU already shifts significantly towards renewable energies in scenario 2. In the other scenarios, electricity generation in 2050 is completely CO_2-neutral (Figure 48).

In terms of total energy consumption, larger shares of oil and gas will still be used in 2050 (Figure 49). Climate-neutral shares such as synthetic fuels or synthetic methane are included in these numbers. There is certainly still a greater technical challenge here to produce climate-neutral fuels on this scale.

Figure 49: EU primary energy supply by energy carrier, Sc2.NDCs_2020_30, Sc3.2DEG, Sc4.2DEG_EU and Sc5.1.5DEG in comparison



Source: GINFORS-E.

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