Centre for Climate
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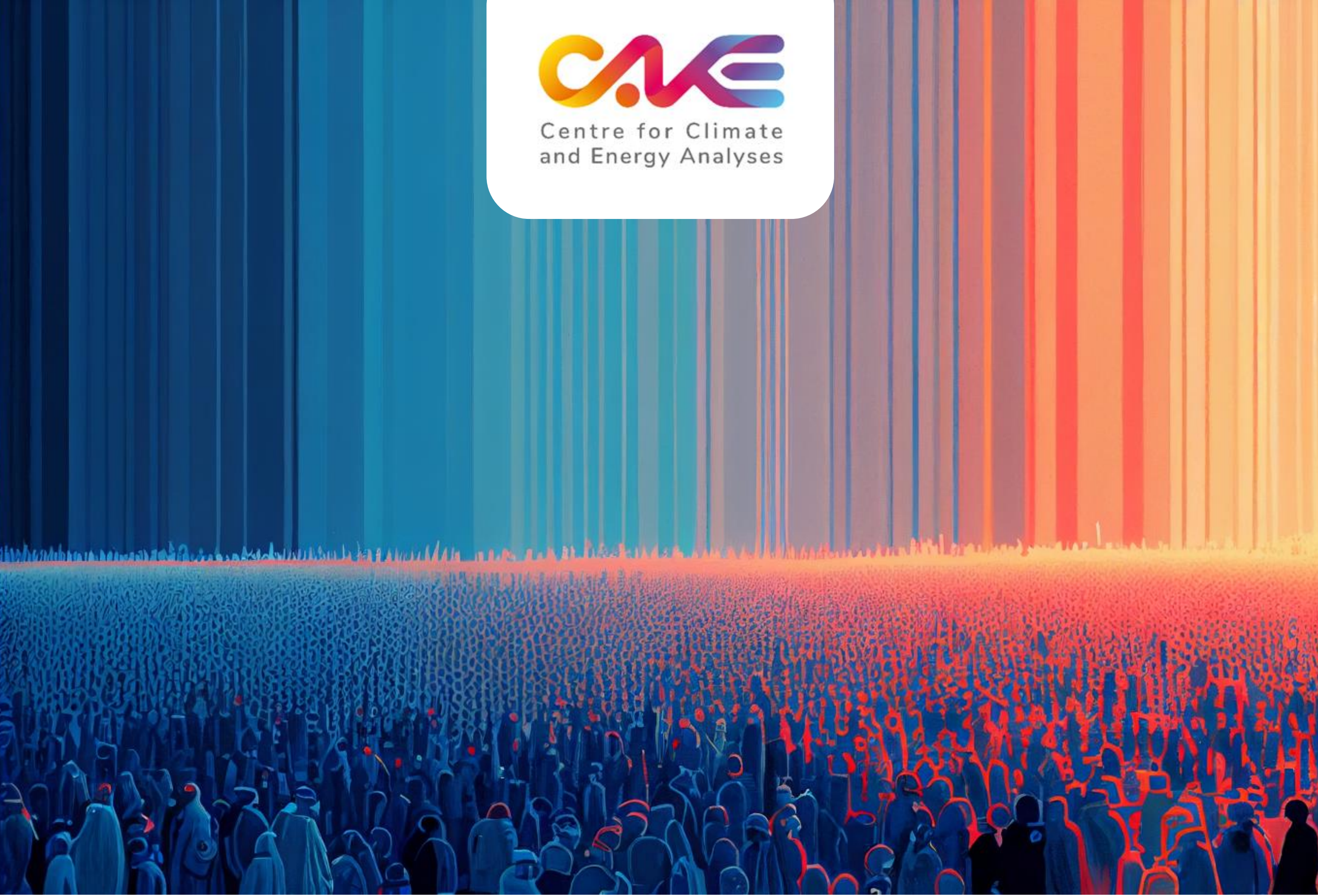

VIIEW 2050

CHANGING THE SCOPE OF THE EU EMISSIONS TRADING SYSTEM

LIFEVIIEW2050

KOBiZE

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IOŚ-PIB

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Maciej Pyrka, Robert Jeszke, Jakub Boratyński, Jan Witajewski-Baltvilks, Marek Antosiewicz, Igor Tatarewicz, Wojciech Rabiega, Adam Wąs, Izabela Tobiasz, Michał Lewarski, Sławomir Skwierz, Artur Gorzałczyński, Sebastian Lizak, Izabela Zborowska, Marzena Chodor, Paweł Kobus, Vitaliy Krupin, Maciej Cygler, Paweł Mzyk, Monika Sekuła

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If you have any comments or questions regarding this document, please contact cake@kobize.pl.

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Design, cover and editing: Robert Jeszke & AI.

Contact:

Address: 32 Słowicza St., 02-170 Warsaw
WWW: www.climatecake.pl
E-mail: cake@kobize.pl
Phone.: +48 22 56 96 570
Twitter: @climate_cake

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List of abbreviations

AFOLU	Agriculture, forestry and other land use
BECCS	Bioenergy with carbon capture and storage
BEV	Battery energy vehicle
BoP	Balance of payments
BRT ETS	Emissions Trading System for buildings and road transport
CAKE	Centre for Climate and Energy Analyses
CAP	Common Agricultural Policy
CBAM	Carbon Border Adjustment Mechanism
CGE	Computable general equilibrium
CCS/CCU	Carbon capture and storage/ carbon capture and utilization
CNG	Compressed natural gas
CO_2 eq.	Carbon dioxide equivalent
DACCS	Direct air capture with carbon storage
d-PLACE	Recursive dynamic, computable general equilibrium model used and developed by CAKE
EC	European Commission
EEA	European Economic Area
EED	Energy Efficiency Directive
EFTA	States included in European Free Trade Association: Iceland, Liechtenstein, Norway
ELE	Vehicles powered by electricity
EPBD	Energy Performance of Buildings Directive
EPICA	The Evaluation of Policy Impacts – Climate and Agriculture Model used and developed by CAKE
ESR	Effort Sharing Regulation
EU	European Union
EU27	27 European Union Member States
EU+	EU27 plus UK, Norway and Switzerland
EU ETS	EU Emission Trading System
EU Green Deal	Communication from the European Union of 11 December 2019: The European Green Deal
EUA	European Union Allowances allocated to the operators of stationary installations and used to account for emissions in the EU Emissions Trading System (EU ETS); 1 EUA = 1 t CO_2 eq.
Fit for 55 package	A set of proposals to revise and update EU legislation and to put in place a new initiative to ensure that EU policies are in line with the new climate goals of 14 July 2021
GDP	Gross Domestic Product
GECO	Global Energy and Climate Outlook
GHG	Greenhouse gases
H2	Vehicles powered by hydrogen
HDV	Heavy duty vehicles
ICAP	International Carbon Action Partnership
ICE	Internal combustion engine
IPCC	Intergovernmental Panel on Climate Change
KOBiZE	National Centre for Emissions Management
LDV	Light duty vehicles
LPG	Liquefied petroleum gas
LRF	Linear reduction factor
LULUCF	Land use, land use change and forestry
MBK	Two-wheeled motor vehicles
MEESA	Model for European Energy System Analysis used and developed by CAKE
MRV	The EU's Monitoring, Reporting and Verification system
MS	EU Member States
MSR	Market Stability Reserve

Non-ETS	Sectors which are not covered by the EU Emissions Trading System (EU ETS)
PPP	Polluter-Pays Principle
PV	Photovoltaics
RED	Renewable Energy Directive
RES	Renewable energy sources
RRF	Recovery and Resilience Facility
SMR	Small modular reactors
TCO	Total cost of ownership
TEN-T	Trans-European Transport Network
TNAC	Total number of allowances in circulation in the EU ETS
toe	Tonnes of oil equivalent
TR^{3}E	Transport European Economic Model used and developed by CAKE
ZEV	Zero-emission vehicles

Regional aggregation and respective codes

Code	Countries
BEN	Benelux countries (Belgium, the Netherlands, Luxembourg)
CEU	Central Europe (Austria, Czechia, Hungary, Slovakia, Slovenia)
DEU	Germany
FRA	France
IBI	Iberia (Spain, Portugal) + Italy
NTH	Nordics and Baltics countries (Denmark, Sweden, Finland, Lithuania, Latvia, Estonia)
POL	Poland
STH	South-eastern Europe (Croatia, Greece, Cyprus, Malta, Romania, Bulgaria)
UKI	United Kingdom + Ireland
EFT	Selected EFTA countries involved in the EU ETS (Norway, Liechtenstein, Iceland)
RWW	Rest of the World

Source: CAKE/KOBiZE

Sectoral aggregation and respective codes

List of sectors in d-PLACE model	Corresponding sectors in GTAP Data Base[1]
Coal	col
Crude oil	cru
Natural gas	gas
Refined oil	oil
Electricity	ely
Gas distribution	gdt
Agriculture	pdr, wht, gro, osd, c_b, vol, pfb, ocr, ctl, oap, rmk, wol, fsh, v_f
Food	omt, mil, pcr, sgr, ofd, b_t, cmt
Forestry	frs
Chemicals	crp
Non-metallic minerals	nmm
Iron and steel	i_s
Non-ferrous metals	nfm
Paper	ppp
Construction	cns
Other manufactures	ome, omn, lum, tex, wa, lea, eeq, fmp, omf
Air transport (aviation)	atp
Water trasport	wtp
Land transport	otp
Vehicles	mvh, otn
Services	trd, ofi, isr, obs, wtr, cmn, ros, osg, dwe

Source: CAKE/KOBiZE

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[1] See: Aguiar, A., Chepeliev, M., Corong, E., McDougall, R., & van der Mensbrugghe, D. (2019). The GTAP Data Base: Version 10. Journal of Global Economic Analysis, 4(1), 1-27.

Main conclusions

- The EU ETS as we know today is coming to an end due to the fact that the cap would reach zero close to 2040. Should this happen, there would be no allowances available for purchase on the primary market and the secondary market would be the only place to acquire them. This implies that the market side of the EU ETS could be jeopardized, due to the risk of illiquidity and price distortions. If the EU ETS is to remain a market-based instrument and continue to be the central pillar of the EU's climate policy, it will inevitably need to be reformed further and extended to more sectors of the economy. Extending the EU ETS to cover new sectors would mitigate the risk of its collapse and ensure that the system would continue to serve as the key measure to reduce emissions in the most efficient way. Simultaneously, we could utilise allowances from MSR or lower the annual reduction of allowances in the EU ETS (by changing the Linear Reduction Factor).

- We analyse the impacts of extending the EU ETS on the economy. Extending EU ETS to cover the ETS2/BRT (Building and Road Transport) has small impact at the EU level but significant impact on regional level. Countries with deficit in BRT sectors, including Poland, from 2030 benefit from merger because of lower price of allowances in the merged EU ETS. Further extention of the EU ETS to remaining sectors brings efficiency gains at the EU level but also increases the prices in newly included sectors (especially agriculture), which drags down the exports in some economies (including Poland) and could negatively affect the poverty indicators. Therefore, it would need to be supplemented with redistributive measures. In all scenarios, achieving the net-zero targets requires substantial adoption of carbon dioxide removal measures. Adopting climate policy to support negative emissions will be critical.

Carbon prices under various scenarios of the EU ETS extension

- Simulations suggest that inclusion of new sectors into the EU ETS will be associated with an increase in the marginal emission abatement costs in the trading system due to more expensive reduction options available in the other sectors (currently not covered by EU ETS). In our reference scenario where the EU ETS and the BRT ETS operate separately (Fit55 scenario), the marginal abatement costs increase over time from approx. EUR 180/t CO_2 eq. in 2030 to EUR 440/t CO_2 eq. in 2050. In 2030, in alternative scenarios, we observed the strongest increase in costs when road transport is included in the EU ETS (approx. EUR 250/t CO_2 eq.). Since 2045, the highest cost occurs in the scenario with the EU ETS covering all sectors of the economy (One ETS scenario), hitting EUR 1000/t CO_2 eq. in 2050.

Macroeconomic impacts of the EU ETS extension

- Overall, inclusion of the BRT ETS in the EU ETS has a negligible effect on average consumption. However, this result masks significant differences across regions. In the long-run Southern Europe is the main beneficiary of the EU ETS extension to new sectors. Poland will report a modest loss in the 2030s and a modest gain in the 2040s.

- Inclusion of emissions from buildings and transport sectors in the EU ETS results in efficiency gains at the EU level: a broad EU ETS prevents a sector from not using its abatement options if they are less costly than abatement in other sectors.

- However, from the perspective of individual regions, the macroeconomic impact of extending the EU ETS depends on whether the region has a surplus or deficit of allowances in the BRT ETS and the EU ETS. The value of the surplus in BRT sectors is determined by the carbon price applicable in the BRT sectors. When the BRT ETS and the EU ETS are maintained as two separate systems, the carbon price in the BRT ETS is significantly higher than in the EU ETS from the mid-2030s onwards. This situation benefits countries that have a surplus of allowances in the BRT ETS and/or a deficit of allowances in EU ETS. Once the systems are merged, these countries are worse off.

- Furthermore, the impact on the economy depends on foreign trade adjustments related to changes in international competitiveness. The price of emissions is higher when the BRT ETS is added to the EU ETS, compared to the scenario where BRT ETS remains in a separate system. This higher price implies higher costs for exporters. The impact on individual economies depends on the structure of exports.

- Consumption is noticeably higher in the long run if the EU ETS covers all sectors of the economy, including agriculture. However, this scenario is associated with the introduction of a carbon price in agriculture, which leads to a significant increase in food prices. This raises equity concerns. Such a system, if ever considered, should be complemented by redistributive policies and a completely revised EU's Common Agricultural Policy.

- In addition, a carbon price in the agricultural sector leads to severe production drop strongly affecting the farmers' income, practically eliminating food exports and forcing half of the food consumed in the EU to be imported. This also increases agricultural production outside EU27+UK, contributing to the "carbon leakage".

The EU ETS extension - Impacts on power sector

- The role of the power sector in achieving net-zero target in 2050 is very important, due to its large emission reduction potential. However, in the power and heat sector the impact of the extension of the EU ETS is negligible. This sector is heavily decarbonised in all scenarios, therefore, despite the differences in CO_2 prices, the scenarios do not differ significantly in terms of energy mix, investment costs and the average energy price. As a result, the electricity demand is similar in all scenarios.

The EU ETS extension - Impact on transport sector

- Emissions in the road transport sector account for around a quarter of EU emissions, so the transformation of this sector is important to achieving climate neutrality. Implementing a separate emission trading system for the road transport sector would result in greater emission reductions compared to scenarios including this sector in the EU ETS. However, the differences in the achieved emission reductions in 2050 between different scenarios reach only 2 p.p. in EU27+UK.

- There are also no significant differences in the rate of deployment of electric cars by 2050 between the different scenarios extending the EU ETS. More pronounced differences are observed in the adoption of higher emission vehicles (i.e., buses, light- and heavy-duty vehicles) (LDVs and HDVs). Because of the separate trading emission system for the transport sector, result show highter level of carbon price and different relation between the prices of fossil and zero-emission fuels (hydrogen and electricity).

The EU ETS extension - The role of CCS and negative emissions

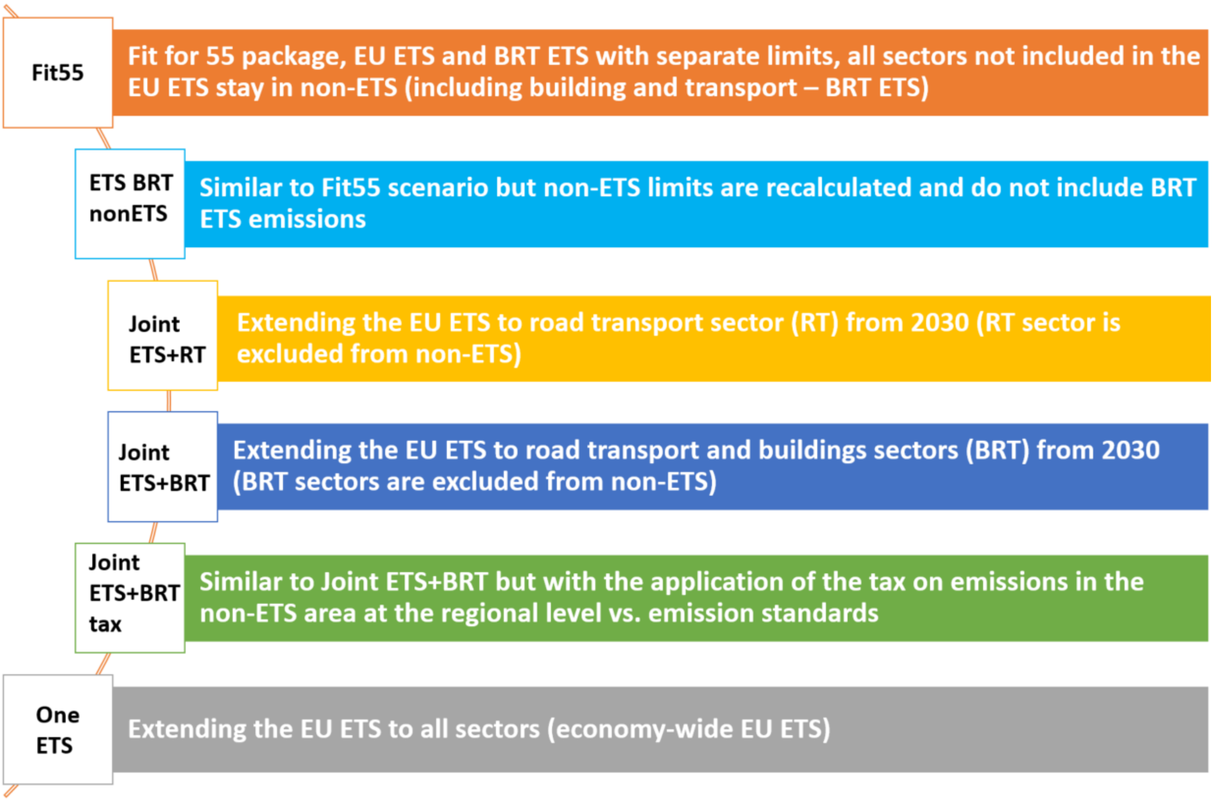
- Achieving the economy-wide net-zero emission reduction target in 2050 would be very difficult without the adoption of a wide range of technologies such as CCS/CCU. The role of negative emissions from BECCS and AFOLU would be significant as the remaining emissions would need to be abated. In this case, backstop technologies as direct air capture with carbon storage (DACCS), which by removing CO_2 from the atmosphere reduces the need to curb emissions in those sectors (where the marginal costs of reduction are very high) may also be crucial.

Summary

1. The report analysed options of transition towards climate neutrality in line with the goals set in the European Green Deal. Our main focus was on changing the climate policy architecture through gradual extension of the EU ETS. We analysed the impact of inclusion of new sectors in the EU ETS on the economy and sector-specific production at EU and regional levels.

2. Figure 1 presents analysed scenarios for different scopes of the EU ETS (carbon pricing) and non-ETS (emission standards).

Figure 1. Scenarios analysed in the report



Source: CAKE/KOBiZE

3. Extending the EU ETS to new sectors may be inevitable in view of the end of the EU ETS in its current form. Some experts indicate the EU ETS cap would reach zero close to 2040[2]. It means there would be no allowances available for purchase on the primary market and the secondary market would be the only place to acquire them. The main reason is the new highly steep linear reduction factor (LRF) and continued intake of 24% in the MSR, implying a substantial tightening of the cap due to higher EUA's cancellations. The zero EU ETS cap near 2040 implies that the market character of the EU ETS could be

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[2] See Pahle M., et. al. (2023)

jeopardised. There are several options to mitigate this risk, e.g., expansion of the EU ETS, lowering the proposed reduction targets (LRF) or using EUA allowances from the MSR. In this report we focus on analysis of the first option.

4. The central scenario of our analysis assumes the implementation of climate policy that is consistent with the Fit for 55 package and functioning of the EU ETS and a separate ETS for buildings and transport after 2030. In that scenario, which we label Fit55, the GDP growth rate is very close to the productivity growth, with the differences between the two rates below 0.3 p.p. in every region in the 2020s and below 0.2% in the 2030s and 2040s in almost all regions. This result confirms the findings of IPCC (2022) that the impact of decarbonisation trends on macroeconomic variables is negligible.
5. The growth of investment is slightly faster than GDP growth in all regions. At EU27+UK level, the investment growth rate will be 2.3% in 2020s, 1.5% in 2030s and 1.7% in 2040s. In Poland, the growth rates in these three periods will be 3.2%, 2.2% and 0.9%, respectively. The reason why investment grows faster than GDP is the additional demand for capital in the energy sector and capital required for energy-efficiency improvement in other sectors (i.e. capital that substitutes energy in other sectors' production functions).
6. In the alternative scenario, which assumes adding the BRT ETS to the EU ETS (Joint ETS+BRT scenario), the carbon prices in such EU ETS are higher compared to the Fit55 scenario from mid-2030s (in 2050 the price is EUR 800/t CO_2 eq., compared to EUR 440/t CO_2 eq. in the Fit55 scenario). This results in an increase in the price of electricity, which stimulates additional investment dedicated to the improvement of energy efficiency.
7. At the EU level, the overall macroeconomic results regarding GDP, investment and consumption for the Joint ETS+BRT scenario are similar to the results for the Fit55 scenario. The only noticeable difference is that investment in 2040 is 0.3% higher than in the Fit55 scenario. Consumption in 2050 is 0.2% higher than in the Fit55 scenario, which is due to the higher efficiency of the merged system.
8. The impact of adding the BRT ETS sectors to the EU ETS varies significantly across regions. In the long-run countries that had a surplus of emission allowances (EUA) in EU ETS will benefit and those with a deficit will suffer a loss. Similarly, countries with a surplus of allowances in the BRT will suffer and those with a deficit will benefit.
9. In the scenarios that assume adding BRT ETS to the EU ETS and, in addition, the introduction of a carbon price in the remaining sectors, including agriculture (scenario Joint ETS+BRTtax), simulations suggest relatively low economic activity in Poland. In 2030, GDP in Poland is 0.5% lower than in the Fit55 scenario. In 2040 this loss is already at 0.7% and in 2050 it amounts to 0.9%. The reason is that in the Joint ETS+BRTtax scenario, the revenue from the non-ETS sectors is not recycled back to these sectors and goes to

households instead. As a result, the price of output in non-ETS sectors increases and exports of these sectors drop.

10. In the scenario where all sectors are covered under one ETS, the macroeconomic results at the EU27+UK level are close to the results for Fit55 scenario in the 2030s and 2040s. In 2050 the simulations suggest the investment is lower by 1%, which is due to the high price of investment commodities inflated by the high price of emissions in the EU ETS. However, in the same year, consumption for households increases by 0.7% due to lower exports and lower investment.
11. In the One ETS scenario, in the long-run no region experiences a significant drop in consumption, confirming the intuition that a scenario with one ETS allowing for free trade of allowances between sectors results in the highest possible efficiency in the long run.
12. Results for the Fit55 scenario indicate far-reaching changes in the structure of electricity generation in the EU. Gradual decarbonisation of the electric power sector will lead to its complete remodelling in the perspective of 2050. Modernisation of the sector will be stimulated by the rapidly rising costs of emission reductions and increasing availability of renewable energy sources.
13. In Poland, changes in the structure of power generation will not rely solely on the development of RES with intermittent operation. Nuclear power plants will play an important role in the new energy system, as they are one of the few sources providing a stable supply of electricity, without greenhouse gas emissions, at a moderate cost. In addition, by supplying a large amount of energy in the load base, nuclear power plants will create conditions for using surplus RES production to produce hydrogen, significantly influencing the stabilisation of electricity prices, as well as increasing the potential for green hydrogen.
14. Green hydrogen will be an important driver on the way to achieving ambitious emission targets for 2050. In the Fit55 scenario, by 2050 the green hydrogen production will reach 5530 PJ for the entire EU+ and almost 240 PJ for Poland. Approximately 30% of green hydrogen production is used by the power sector itself for electricity and district heat generation - as a sort of long-term energy storage.
15. The Fit55 scenario is associated with a significant increase in the costs of electricity generation over time. The increase is particularly noticable in the period up to 2030 and is driven by the rising cost of purchasing CO_2 emission allowances – especially in the case of Poland, where ca. 70% of today's electricity is generated in coal-fired power plants.
16. Total electricity demand in all scenarios is similar for the periods considered. The final electricity demand in each scenario is almost the same, the only differences pertain to electricity consumption for hydrogen production and e-mobility purposes. In scenarios

assuming the inclusion of the transport sector in the ETS or assuming the imposition of any costs related to CO_2 emissions, e-mobility development is slightly higher.

17. Putting a price on emissions in the road transport sector in the Fit55 scenario will increase the cost of driving the fossil fuel-powered vehicles. In EU27+UK, in the period between 2030 and 2050, operating ICE cars will become up to average 30% more expensive, whereas the cost to operate battery and hydrogen-powered cars will drop by 2% and 27%, respectively. In case of Poland, in the period between 2030 and 2050, operating ICE cars will become up to 25% more expensive, whereas the cost to operate battery and hydrogen-powered cars will drop by 8% and 14%, respectively.

18. In 2030, the share of zero-emission passenger vehicles in EU27+UK will be approx. 14%, while in Poland it will be lower by 5 p.p. due to their relatively high prices, lower incomes and limited infrastructure for charging or hydrogen refuelling. In 2050, the share of zero-emission vehicles in EU27+UK will equal approx. 72%, and in Poland – approx. 67%.

19. Transformation towards a zero-emission bus fleet will take place gradually and will begin in the sector of urban public transport. In EU27+UK the share of zero-emission (electric and hydrogen) buses will be approx. 8% of fleet in 2030, 30% in 2040 and between 60% and 65% depending on the scenario in 2050. In Poland, compared to the EU27+UK, the share of zero-emission buses is initially lower (approx. 6% in 2030). However, by 2050 it will increase to 65-75%.

20. A rapid process of electrification of light-duty vehicles (LDV) is expected, which is largely driven by relatively low total costs of ownership. By 2030 the TCO of electric LDV will reach the same level as for its diesel powered counterpart. After 2030 we will see a rapid replacement of the fleet, especially since the sale of new fossil fuel-powered LDVs will be banned after 2035. The total replacement of the LDV fleet takes place much faster than for passenger vehicles, as the average lifespan of LDVs is much shorter, typically less than 10 years. By 2050, almost the entire LDV fleet will consist of zero-emission vehicles.

21. Replacement of the fleet of heavy-duty vehicles (HDV) with zero-emission vehicles will initially be hampered by a combination of high costs related to both charging infrastructure and the purchase of new vehicles. We expect that the structure of the fleet will start to change only after 2040. In the Fit55 scenario in 2050 zero-emission HDVs could cover approx. 77% of transport in EU27+UK.

22. In EU27+UK we will observe growing electricity demand from the transport sector. By the year 2030, we expect passenger vehicles to consume approx. 80 TWh of electricity, with this number set to triple by 2040 and reach 415 TWh by the middle of the century. In 2050, energy demand from road freight transport will be between 180-183 TWh.

23. After 2040, the hydrogen technology in the transport sector will become more widespread due to its decreasing costs. In 2050, we expect that demand for hydrogen in EU27+UK might reach 7800 kt (mainly for freight transport – HDVs and, to a lesser extent, buses).

24. In the Fit55 scenario, total EU27+UK transport emissions will fall to 274 Mt CO_2 in 2050, a 70% reduction compared to 2020. We expect 189 Mt CO_2 emissions from passenger transport and 85 Mt CO_2 from freight transport. In Poland, total emissions in the transport sector drop to 13 Mt CO_2 in 2050, which amounts to reduction of 77%.

25. Due to the use of relatively simple production technologies in agricultural sector, concentration, globalisation and technological progress are still lagging behind the other sectors of economy. Thus, food production is strongly supported in the EU to provide adequate income for farmers. This makes agriculture vulnerable to climate policy changes, especially those connected with the additional economic burden.

26. The Joint ETS+BRTtax and One ETS scenarios, which assume introduction of the "*Polluter-Pays Principle*" (PPP) involves substantial mitigation of the emission of GHG from the EU agricultural sector by 57 Mt CO_2 eq. compared to the Fit55 scenario. However, it also strongly decreases production in the EU and contributes to the "carbon leakage" by inducing an increase of the agricultural production and GHG emission in the countries outside of the EU27+UK by 133 Mt CO_2 eq. compared to the Fit55 scenario.

27. GHG emission reduction due to taxation of GHG emissions from the agricultural sector is slightly greater in Poland compared to the EU average, while the relative production drop is similar. However, decreased production causes a stronger relative price reaction in Poland, primarily due to a lower initial food price level[3].

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[3] Based on the Eurostat (prc_ppp_ind), the food price index in Poland in 2015 equalled 61% of the EU27's average.

1. Policy background

1.1 The European Green Deal

28. The *European Green Deal Communication*[4] launched a new development strategy for the EU that aims to transform the EU into a fair and prosperous society with a modern, resource-efficient and competitive economy. It reaffirms the Commission's ambition to increase its climate targets and make Europe the first climate-neutral continent by 2050. Furthermore, it aims to protect the health and well-being of citizens from environment-related risks and impacts.

29. The European Green Deal is a package of policy initiatives, which aims to set the EU on the path to a green transition, with the ultimate goal of reaching climate neutrality by 2050. The structure of this package is introduced on Figure 2 and 3.

Figure 2. The European Green Deal structure

Source: European Commission

30. In line with the scientific findings of the Intergovernmental Panel on Climate Change (IPCC) Special Report, global net-zero CO_2 emissions need to be achieved around 2050, and neutrality for all other greenhouse gases should be reached as soon as possible in the next decades. This urgent challenge requires the EU to step up its action and demonstrate global leadership by becoming climate neutral by 2050. This objective is set out in the

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[4] https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2019)640&lang=en

Communication "A *Clean Planet for all*[5]" – the European strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy.

Figure 3. The European Green Deal initiatives

Source: European Commission

31. Based on the European Green Deal strategy and its comprehensive impact assessment, the Commission's Communication of September 2020 on "Stepping up Europe's 2030 climate ambition[6]" ("*2030 Climate Target Plan*") proposed to raise the EU's ambition and put forward a comprehensive plan to increase the European Union's binding target for 2030 towards at least 55% net emission reduction, in a responsible way. Raising the 2030 ambition now affirms policy-makers and investors that decisions made in the coming years will not lock in emission levels inconsistent with the EU's objective to be climate neutral by 2050. The 2030 target is in line with the Paris Agreement objective to keep the global temperature increase to well below 2°C and pursue efforts to keep it under 1.5°C. To ensure that it was immutable, the Commission proposed to embed the net-zero 2050 target and the interim 2030 target in the European Climate Law. A proposal for the European Climate Law was put forward by the Commission on 4 March 2020.

32. The European Council endorsed the new EU binding target for 2030 at its meeting in December 2020. A political agreement on the law was reached by the EU Member States

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[5] https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A52018DC0773
[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0562

and the European Parliament on 24 April 2021. The European Parliament adopted the law at its first reading on 24 June 2021. The European Council adopted its position on the European Climate Law at first reading on 28 June 2021, ending the adoption procedure and setting into legislation the objective of a climate-neutral EU by 2050. In this respect, the *European Climate Law*[7], as agreed with the co-legislators, makes the EU's climate neutrality target legally binding and raises the 2030 ambition by setting a target of at least 55% net emission reductions by 2030 compared to 1990, with the interim 2040 target to be proposed at the latest within 6 months after the first Global Stocktake (GST) under the Paris Agreement, taking place in the years 2021-2023.

1.2 Fit for 55

33. To follow the pathway proposed in the European Climate Law and deliver this increased level of ambition by 2030, the Commission has reviewed the climate and energy legislation currently in place expected to only reduce greenhouse gas emissions by 40% by 2030 and by 60% by 2050. The *Fit for* 55 legislative package[8] announced in the 2030 Climate Target Plan is the most comprehensive building block in the efforts to implement the ambitious new 2030 climate target. To meet the "at least 55% by 2030" reduction target all economic sectors and policies need to make their contribution. The "Fit for 55" package was published by the European Commission in July 2021. The package translates the "polluter pays principle" into practice. It aims to reverse the declining trend in nature's capacity to remove carbon from the atmosphere. The package puts forward interconnected legislative proposals to deliver on the ambitious target through measures adopted in all sectors of its economy. It is a policy mix that respects a balance between pricing, targets, taxes, standards and support measures as presented in Table 1.

34. The package strengthens the ambition of eight pieces of legislation that were adopted by 2019, in line with the new target of at least -55% GHG reduction by 2030, and presents five new initiatives across a spectrum of policy areas and economic sectors encompassing climate, energy and fuels, transport, buildings, land use, land use change and forestry. It lays the regulatory foundation to reach targets in a fair, cost-efficient and competitive way. It puts a price on carbon in sectors that have not been affected by carbon pricing before, bringing significant additional revenues that will be directed to ensure a just transition and equitable transformation. It supports greater use of renewable energy and more energy savings, it facilitates growing sales of clean new vehicles and cleaner transport fuels. It ensures that the industry can lead the transition and gives it the certainty

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[7] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law') (OJ L 243, 9.7.2021, p. 1).

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

it needs for boosting investment and innovation. It focuses on taxing energy sources in line with the EU climate goals and environmental objectives. Encouraging global climate action, it seeks to ensure that the EU climate goals are not undermined by the threat of carbon leakage. The work on each legal act included in the package is continuing. Due to the complexity of the topic, more details regarding specific regulations are being published almost every week, for example, in the last days of March, Market Stability Reserve (MSR) decision, new RES targets and the EU Council arrangement to make new cars (except for e-fuel) zero-emission from 2035.

Table 1. Delivering the European Green Deal through the Fit for 55 package

Pricing	Target	Rules
• Stronger Emissions Trading System (including in aviation). • Extending Emissions Trading to maritime, road transport and buildings. • Updated Energy taxation directive. • New Carbon Border Adjustment Mechanism Targets.	• Updated Effort Sharing Regulation. • Updated Land Use, Land Use Change and Forestry Regulation. • Amended Renewable Energy Directive. • Amended Energy efficiency Directive.	• Stricter CO_2 performance for cars and vans. • New infrastructure for alternative fuels. • ReFuelEU: More sustainable aviation fuels. • FuelEU: More and cleaner maritime fuel.
Support measures		
• Using revenues and regulations to promote innovation, build solidarity and mitigate impacts for vulnerable, notably through the new Social Climate Fund and enhanced Modernistation and Innovation Fund.		

Source: European Commission

35. One of the key elements of the Fit for 55 package is the revision of the EU ETS Directive (all other elements are presented in Figure 4). Currently, it covers GHG emissions from industrial installations and intra-EU flights (and part of extra-EU flights from or between EU airports). To contribute to the "at least 55% reduction" that the EU has pledged for 2030 in its NDC[9] (and regulated under the EU Climate Law) the share of the EU ETS in the overall EU reduction will increase from 43% to 62% by 2030 compared to 2005 levels. Leading to this new emission cap in EU ETS, the annual reduction rate will be increased to 4.3% per year between 2024 and 2027 and it will go up to 4.4% in the years 2028-2030. The "one-off" reduction of EUA supply of 90 million in 2024 and 27 million in 2027 will also be introduced. The Market Stability Reserve will be strengthened by increasing the

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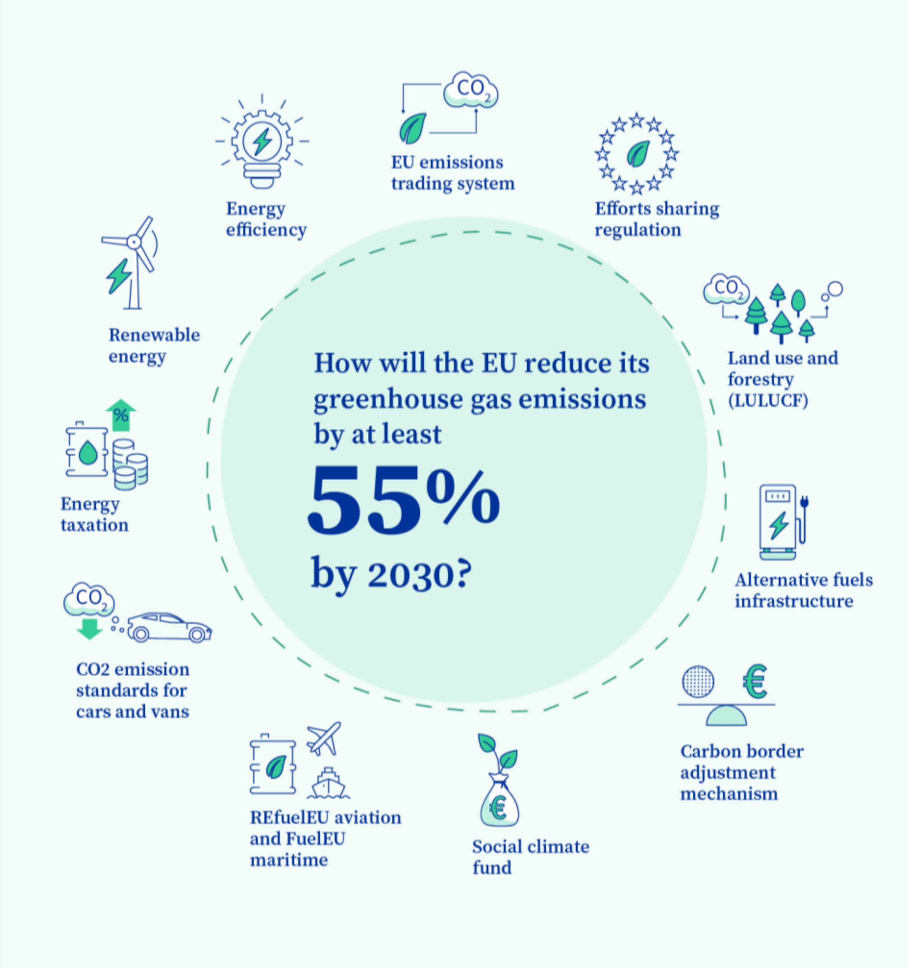
[9] Nationally Determined Contribution under Paris Agreement.

so-called "intake rate" to 24% till 2030 and by the rule of "invalidation mechanism" - the EUA in the MSR exceeding 400 Mt will be invalidated from 2023.

Figure 4. Elements of the Fit for 55 package



Source: European Commission

36. Pahle et. all[10] points out that the EU ETS cap could reach zero in 2039 which means there would be no one allowance in the system. The main reason for that is the continued intake of 24%, implying a substantial tightening of the cap due to higher levels of EUAs cancellations. The stronger banking behaviour of regulated entities in anticipation of increasing allowance scarcity substantially accelerates the need to reduce emissions. That is why in Pahle's analysis, the TNAC[11] is also significantly higher (TNAC is above the upper threshold for allowance intake until 2040). Therefore, the substantial volume of allowances is transferred to the MSR and cancelled.

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[10] Pahle M., Günther C., Osorio S., Quemin S., "The Emerging Endgame: The EU ETS on the Road Towards Climate Neutrality" February 2023.

[11] Total number of allowances in circulation in the EU ETS.

37. The Commission has also proposed to extend the EU ETS to the maritime sector and to reduce the free allowances for airlines. A new, separate, BRT ETS (also called ETS2) has been proposed for road transport and buildings, including machinery and vehicles with combustion engines from other sectors. The Carbon Border Adjustment Mechanism (CBAM) has also been proposed, to put on equal footing the EU producers that pay for the carbon they emit and the importers of goods into the EU who do not. A list of affected sectors will be adopted in due course. Importers from non-EU countries participating in the EU ETS: Norway, Iceland, and Switzerland will be exempt.

38. CBAM is not a new idea as a way to address carbon leakage. Carbon leakage is a term used to describe the closure of operations in the EU that are covered by the EU ETS with the aim of moving production to jurisdictions that do not put a price tag on the emitted carbon, and then importing the goods back into the EU. In the current architecture of the EU ETS, operators of installations that may be affected by carbon leakage are issued free-of-charge allowances to address this problem. CBAM will put a carbon price on imports of a targeted selection of products so that ambitious climate action in Europe does not lead to 'carbon leakage' and global growth in GHG emissions. CBAM will equalise carbon prices between the domestic production of certain goods and imports. EU importers will purchase carbon certificates reflecting the price of carbon paid by the EU producers of these goods.

39. Supplementing the overhaul of the EU ETS, new legislation has been proposed on clean maritime and aviation fuels. The reform of the ETS and introduction of BRT ETS will be complemented by reviews of the Effort Sharing Regulation (ESR), LULUCF Regulation (LULUCF), Energy Efficiency Directive (EED), Energy Performance of Buildings Directive (EPBD), and Renewable Energy Directive (RED), to name the key updates necessary to bring in the increased reduction targets.

40. Trilogue negotiations between the Parliament, the Council and the Commission ended in December 2022 with preliminary agreements on individual elements of the “Fit for 55” package. On 18 December 2022, the Council and the European Parliament reached a provisional political agreement on two legislative proposals of the “Fit for 55” package, namely the revision of the EU ETS and the Social Climate Fund. The agreement raises the overall ambition of the EU ETS sectors to 62%. The Council and the European Parliament have also reached a provisional agreement on a new, separate BRT ETS for road transport and buildings starting in 2027.

41. This agreement was preceded by a provisional agreement on increasing the ambition of carbon removal targets for land use and forestry reached on 11 November 2022 and setting an EU-level objective for the LULUCF sector to remove by 2030 310 Mt CO_2 eq., in line with the initial EC proposal included in the “Fit for 55' package in July 2021. By proposing the revision of the LULUCF the Commission aimed at reversing the current

trend of declining sinks in the land sector, delivering, by 2030, 310 million tonnes of CO_2 equivalent removals from the LULUCF sector and, ultimately, arriving by 2035 at the climate-neutral land sector. Until 2025 emissions from the LULUCF sector have to be balanced with removals. In the period 2026-2030, removals should exceed emissions. To ensure that relevant policies and plans are in place and implemented, Member States will have binding national targets for 2030 and will be obliged to submit to the EC integrated mitigation plans for the land sector. In addition to the national 2030 targets, the provisional agreement includes a commitment for each Member State to achieve in the years 2026-2029 a sum of net greenhouse gas emissions and removals based on a trajectory of indicative annual values of removals and emissions (budget 2026-2029). The provisional agreement keeps the possibility to purchase and sell removal units between Member States and an option for Member States to use flexibilities with the effort-sharing target permitting the use of surplus annual emission allocations under the Effort-sharing Regulation in accounting for the LULUCF targets. The scope of the regulation will be expanded to cover the whole land sector from 2031 by including non-CO_2 emissions from the agriculture sector. From 2026 the revised LULUCF regulation would move away from the current 'no-debit' rule and it would introduce a carbon removal certification scheme with the possibility to trade in certificates. The monitoring requirements would be enhanced by using digital technologies supported by the European Environment Agency and the Copernicus programme.

42. The Effort Sharing regulates GHG emissions from those sectors that fall outside the scope of the EU Emissions Trading System: road transport, buildings, agriculture, industry outside the scope of the EU ETS, and waste. Emissions from these sectors account for almost 60% of total domestic EU emissions although in some countries, with a bigger share of industry, these proportions may be different. Under the current regulation, EU Member States have binding annual GHG emission targets which they have to meet, with some flexibilities that were designed to help Member States to achieve their targets.

43. The revised ESR will have an increased target to help meet the overall at least 55% reduction target against 1990 levels for the EU as a bloc. In the draft revision of the ESR, the Commission proposed a reduction from ESR sectors by at least 40% compared to 2005 levels (an increase of 11 percentage points), to reflect the increased overall EU 2030 reduction target of -55%. The principles for setting national targets would remain based on the GDP per capita with adjustments made to take into account the cost efficiency criteria. Targets per country would become more ambitious, ranging from -10% applied to Bulgaria to -50% applied to Germany, Denmark, Luxembourg, Finland, and Sweden. Annual emissions allocations set for each Member State will be progressively reduced until 2030. In 2025, the Commission will propose an adjustment of allocations for the 2026-2030 period.

44. Road transport and buildings will remain in the ESR but from 2028, subject to the provisional agreement becoming adopted legislation, these sectors will become part of the new emissions trading system which will be separate from the ETS for industry, aviation, and maritime transport. In the July 2021 Fit for 55 package, the Commission proposed a new ETS for road transport and buildings (BRT ETS), starting in 2026. Both sectors are currently regulated by the Effort Sharing Regulation on the level of Member States, with supplementary measures such as CO_2 standards and decarbonisation of electricity also playing a role in their gradual decarbonisation. The introduction of an upstream ETS for both sectors from 2028 will speed up the decarbonisation process.

45. On 8 March 2022, the EC called for a rapid phase out of Russian fossil fuels and an acceleration of the European Green Deal in its Communication "REPowerEU: Joint European action for more affordable, secure and sustainable energy[12]". On 24 and 25 March 2022 European Council agreed fully phase out EU dependency on Russian gas, oil and coal imports as soon as possible and asked the EC to develop a comprehensive and ambitious REPowerEU plan.

46. Building on the Fit for 55 package of proposals and completing the actions on energy security of supply and storage, the main strands of action under the REPowerEU plan are saving energy by promoting energy efficiency, diversifying energy supplies, quickly substituting fossil fuels by accelerating Europe's clean energy transition and smartly combining investments and reforms (massive scale-up of renewables – e.g., hydrogen). REPowerEU builds on the Fit for 55 proposals and calls for their speedy adoption. It does not modify the ambition of achieving at least -55% net greenhouse gas emissions by 2030 and climate neutrality by 2050 in EU, but it does propose a legal amendment[13] to raise the targets therein for energy efficiency and RES to 13% and 45%, respectively. This will therefore mean a greater effort by the EU to achieve the above objectives.

47. REPowerEU entails additional investment of EUR 210 billion[14] between now and 2027, on top of what is needed to realise the objectives of the Fit for 55 proposals[15]. Such investment will pay off. Implementation of the Fit for 55 framework and the REPowerEU plan will save the EU EUR 80 billion in gas import expenditures, EUR 12 billion in oil import expenditures and EUR 1.7 billion in coal import expenditures per year by 2030. The REPowerEU objectives can be financed through a mix of national and EU funding sources as well as private funding. At EU level, the Recovery and Resilience Facility (RRF) fund is at the heart of the REPowerEU Plan implementation. Already, EUR 225 billion in loans is available to help finance REPowerEU objectives and may be requested up until 31 August

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[12] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0222&from=EN

[14] 1 billion = 10^9

[15] https://ec.europa.eu/commission/presscorner/detail/en/qanda_22_3132

2023. In addition, the RRF financial envelope will be increased by EUR 20 billion, financed from the auctioning of EU ETS (40% from frontloaded auctions in EU ETS and 60% from the Innovation Fund)[16].

1.3 Contribution of the EU ETS to the overall climate ambition

48. The EU ETS has been a key element of the EU's strategy for reducing greenhouse gas (GHG) emissions since 2005. Since it was launched in 2005, emissions in the power and heat generation, as well as energy-intensive industrial sectors, covered by the EU ETS, have fallen by around 43%. Together with other legislation, such as on renewable energy and energy efficiency, it has contributed significantly to achieving the EU's overall target of reducing GHG emissions by 20% by 2020 from 1990 levels.

49. Throughout phase 3 of the EU ETS (2013-2020) and despite the difficult economic situation due to the COVID-19 crisis in the 2020 and 2021 compliance cycles, the level of compliance in the EU ETS remained consistently very high. Operators responsible for over 99% of emissions from both stationary installations and aviation in most years, had complied with their legal obligations. The EU ETS architecture remained robust and the administrative organisation put in place across participating countries has proven to be effective.

50. Compared to the previous year, 2021 emissions from sectors covered by the EU ETS increased by 6.6%, but still were 5.6% lower than in 2019. The increase reflects both the economic recovery from COVID-19 and the developing energy crisis. To date, emission reductions from stationary installations have been driven mostly by the power sector (electricity and heat generation, including part of the industrial heat). In 2021, however, the power sector gained 8.4% increase in emissions. This was mainly due to higher electricity demand in the context of economic recovery after the COVID-19 pandemic and an increased use of coal caused by a rise in fossil fuel prices. Nevertheless, overall power sector emissions in 2021 were still 8.1% below the 2019 levels, with a similar level of electricity demand in these two years.

51. Emissions from industrial installations also increased in 2021 by 4.6% compared to 2020. High increases were observed in most sectors, including iron, steel, and chemicals. This was triggered by the economic recovery after the pandemic, marked by a 5.3% increase of EU27's GDP between 2020 and 2021. Nonetheless, industrial emissions in 2021 were 2.6% lower than in 2019 despite the total levels of industrial production in both years were at similar levels.

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[16] https://www.consilium.europa.eu/en/press/press-releases/2023/02/21/eu-recovery-plan-council-adopts-repowereu/

52. Following a drop of ca. 60% in 2020, the EU ETS aviation emissions rebounded in 2021 by 30% but remained 50% lower compared to 2019. Since the introduction of the EU ETS in 2005, emissions covered by the system have been cut by around 34.6%. In parallel, Member States have raised over EUR 100 billion in auction revenues since 2013, to be used for further climate action and energy transition measures[17].

2. Extension of emissions trading to other sectors

53. Since its inception in 2005, the European Emission Trading System (EU ETS) has undergone significant changes, the aim of which was to increase its ambition, scope and effectiveness. Until 2020, the functioning of the EU ETS was divided into 3 phases, and in each phase extensions to the original system have been added. They encompassed both the inclusion of new countries such as Norway, Iceland, Lichtenstein and Croatia, as well as adding additional sectors. For example, at the end of the second phase, aviation[18] was included in the EU ETS, while in the third phase, the EU ETS began to cover aluminium, carbon capture and storage, petrochemicals and other chemicals. Finally, to improve the efficiency of the system as a whole and to deal with fluctuations in the supply and demand of emission allowances, a Market Stability Reserve mechanism was introduced in 2019. Currently, along with the introduction of the European Green Deal and the Fit for 55 package, the EU ETS system is to undergo deeper changes. Along with an emission reduction ambition, regulators are looking to significantly increase the sector coverage of the Emission Trading System: in particular, the system is to cover maritime transport, and in the future – all transport, buildings and waste.

54. These sectors, especially transport, have been the most problematic in terms of reducing emissions. Contrary to electricity generation, emissions in the transport sector have been relatively stable over the last 30 years, with increases in fuel efficiency being offset by increased transport activity. Achieving an economy-wide reduction in emissions planned for 2030 will not be possible without profound changes in the transport and heating sectors. The EU will not be the first to put a carbon price on these sectors, however, when introduced, the Buildings and Road Transport (BRT) ETS will be the largest system among such in the world. According to the International Carbon Action Partnership (ICAP), as of January 2023, there are at least 10 regions with an emission trading system for the buildings and transport sector and an additional 3 for just the buildings sector. Most of these systems are either experimental approaches and/or are limited to a relatively small

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[17] Report from the Commission to the European Parliament and the Council on the Functioning of the European carbon market in 2021 pursuant to Article 10(5) and 21(2) of Directive 2003/87/EC (as amended by Directive 2009/29/EC and Directive (EU) 2018/410), Brussels, 2022.

[18] Intra-EU and part of extra-EU flights (from or between EU airports).

region. The few exceptions are the ETS systems for the Republic of Korea and New Zealand, which cover all major sectors and the majority of their emissions.

55. The new BRT ETS system will cover all emissions from road transport and buildings, while also including fuels in other sectors such as construction, yet temporarily exempting rail transport, fishing vessels and agricultural machinery. The preliminary agreement between the Council and the European Parliament reached in December 2022 established that the new system will be implemented by 2027, with a possibility to postpone it for one year in the event of high fuel prices. Monitoring of emissions by fuel suppliers will start in 2024, and small companies in this line of business will be allowed to use a simplified monitoring, reporting and verification (MRV) system. The participants will have three years to set up their MRV frameworks and get used to participating in the system before compliance will be enacted and they will be obligated to purchase allowances to surrender for compliance. An additional 30% of allowances will be auctioned in the first year of the functioning of the BRT ETS to ensure a smooth start. Part of the revenue from auctioned allowances will go to the Social Climate Fund.

56. The new BRT ETS system will apply to companies distributing fuels. There are several methods by which the system can be introduced, with the two extremes being the downstream and upstream systems. The current EU ETS is an example of the former, where entities consuming fossil fuels (such as power plants) are obligated to acquire allowances. Introducing such a mechanism in the BRT would pose significant logistic challenges and transaction costs since there are millions of individual emitters. Therefore, the system should be designed as an upstream one, in which the suppliers of fossil fuels are obliged to hold allowances and include their cost in the price of fuels they sell. Such a system could potentially face double counting issues, for example in the case of the aviation sector. Furthermore, a design in which suppliers pass on the tax to the end consumers makes the system akin to a simple fuel tax, therefore possibly reducing its potential to curb emissions.

57. The preliminary agreement between the Council and the European Parliament confirmed that the CO_2 emissions from the shipping sector will be included within the scope of the EU ETS, in the context of no meaningful action of the International Maritime Organization. The obligations for shipping companies to surrender allowances will be introduced gradually over three consecutive years: from 40% for verified emissions from 2024, 70% for 2025 and 100% for 2026. Initially, only CO_2 emissions from the maritime sector will be included in the EU ETS. The co-legislators agreed that non-CO_2 emissions (methane and nitrous oxide) will be monitored, verified and reported from 2024 and the other GHGs emitted by the shipping sector will be included in the EU ETS from 2026.

58. The majority of large vessels will be included in the EU ETS from the beginning. The MRV of CO_2 emissions from big ships of 5000 gross tonnage and above will apply from 2025

and these vessels will be fully included in the EU ETS from 2027. General cargo vessels and off-shore vessels between 400-5000 gross tonnage will apply the MRV regulation to their CO_2 emissions from 2025. In 2026 the Commission will review their participation in the EU ETS.

59. Waste incinerators have been exempt from the EU ETS, unlike other energy producers. The Parliament and the Council have not reached an agreement on including such power plants in the ETS in this round of negotiations. However, the Commission will assess and report by 31 July 2026 on the possibility of including the municipal waste incineration sector in the EU ETS to propose that it is included in the EU ETS from 2028. The Commission will also assess the need for an opt-out of some such installations and the basis for the opt-out until 31 December 2030.

3. The role of the LULUCF in climate policy

60. The Land Use, Land Use Change and Forestry (LULUCF) sector and its potential carbon sink capabilities are crucial for the achievement of the EU's policy goals and climate neutrality. Activities covered by the sector deal with the use of forest land, cropland, grassland, wetlands and settlements, covering both GHG emissions and CO_2 removals. To increase the positive impact of the sector upon climate change, the EU has initiated a set of rules and regulations aiming to incentivise positive actions, such as afforestation and sustainable forest management, and discourage negative actions, among which are deforestation or peatland drainage.

61. With the LULUCF Regulation[19] (2018/841), the EU established a framework for reporting and accounting for greenhouse gas emissions and removals from the sector, as well as set the necessity for the Member States to submit annual reports on these efforts. The European Green Deal and The European Climate Law include more specific measures aimed at reducing greenhouse gas emissions from the LULUCF sector while increasing the use of bioenergy and promoting sustainable land use practices. The Fit for 55 package assumes revision of the LULUCF Regulation to increase its positive contribution to the EU 2030 target, with the net GHG removal to be set at 310 Mt CO_2 eq. The current rules are to apply until 2025, with the linear trajectory beginning with 2022 and leading to the 2030 targets for each of the EU's Member States by the Annex IIa to LULUCF Regulation.

62. Despite the ambitious plans, the achievement of the 2030 GHG emission reduction goals (and even more as regards the 2050 goals) is challenging, taking into account the EU27's net removal of 230 Mt CO_2 eq. in 2020 and the decline in net removals from forest land in the past decade. This especially applies to several countries (e.g., Germany, Poland or

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[19] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018R0841

Spain), which by the new expectations are to be among the largest contributors to CO_2 removal across the EU. As stated in the "Stepping up Europe's 2030 climate ambition" impact assessment[20], a climate-neutral EU will have to rely on a substantial amount of carbon removals, well beyond the current sink, with ca. 500 Mt CO_2 eq. of annual carbon dioxide removal required to offset residual emissions too difficult to abate. This creates high expectations towards future policies aiming to withstand extreme weather events leading to excessive loss of forest resources, the introduction of the sustainable forest, grassland and wetland management practices, stimulate afforestation on land currently utilized under agricultural activities, as well as motivate conversion of land to types of utilization supporting carbon storage and sink.

4. Objective and scope of the analysis

63. The effectiveness of the EU ETS system also critically depends on its interaction with the sectors it does not cover, i.e. the non-ETS sectors. One such interaction is the influence of the EUA prices on emissions outside the EU ETS: high emission allowance prices could result in a leakage of emissions out of the EU ETS. The purpose of this study is to explore different options for the possible inclusion of road transport and/or buildings and all non-ETS sectors in the EU ETS system with the view on 2050. The current reform of the EU ETS, included in the Commission's Fit for 55 proposal, is expected to achieve the targeted emission reductions in the 2030 timeframe. However, the future of the EU ETS and its role as a key EU climate policy instrument in the fight against climate change will require deeper change and reflection.

64. The coupling of the energy, transport and CGE model allows for a more comprehensive assessment of the impact of the inclusion of different sectors in the EU ETS. The use of a similar set of tools for the analysis of different policy options will allow the identification of sectors the inclusion of which in the EU ETS will contribute the most to the increase in welfare and possible emission reduction. By using mutually cooperating models (i.e. macroeconomic d-PLACE and sectoral: energy MEESA, transport TR^3E and agricultural EPICA), it is possible to show the interaction between different sectors and take into account how changes in one sector affect the possible development of other economic sectors, as well as the household consumption and GDP.

65. Results of the study serve as input for the assessment of various options for possible inclusion of the road transport and/or buildings sectors and all non-ETS into the emissions trading system.

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[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020SC0176

5. Policy scenarios used in the analysis

5.1 Reduction options

66. In terms of implementing the EU's climate policy, it is possible to indicate at least two basic options for reducing GHGs: through carbon price (e.g., via emission trading systems) or imposing emission standards (without direct carbon price). The following analysis looks at what could happen if different reduction options for different scopes of emission areas or economic sectors were to be implemented. Thus, the most likely options considered for the EU are the following:

- **Emission trading system (ETS)** – sectors covered by the ETS must surrender allowances to cover their emissions. The total amount of allowances is reduced annually to achieve the appropriate GHG emission levels. Within the ETS, sectors receive or buy emission allowances, which they can trade. The price of emissions is the same in all countries and for all sectors covered by the specific ETS. The system is modelled by endowing the government with allowances which are defined exogenously taking into account the emission reduction target. Each GHG emission appearing in the sectors requires a certain number of allowances, which creates a demand for them. The price of emissions is defined as the equilibrium price between the supply and demand.

- **Emission standards** – are defined as governmentally imposed sets of limits for GHG emissions from any process or activity. Under this abatement mechanism, sectors are not charged directly for emissions. They do not have to purchase allowances or pay carbon taxes but they must adapt production processes to meet a certain emission limit. Emission standards are relatively simple to apply and can provide an effective way of achieving basic emission reduction objectives. The mechanism is modelled by putting an endogenous internal tax within the group of sectors in a certain region. Each GHG emission appearing in the sector requires to pay a tax, which comes back to the sector as a subsidy to final production (the sum of the taxes paid and subsidies received equal to zero). The value of tax is set on a level to achieve the emission limit. The tax creates an incentive to reduce emissions by changing the production process to a less carbon-intensive one. From the model perspective, such less carbon-intensive production process is more expensive, but the final production is not burdened with an additional fee for carbon emissions as it is in the emission trading systems.

5.2 EU climate policy architecture

67. Table 2 describes the envisaged climate policy architecture in the EU until 2050. In the context of climate policy implementation, the key question is whether the scope of the EU ETS and the Effort Sharing Regulation proposed in the Fit for 55 package should be maintained or whether the scope of both instruments should be changed. There are still reasons to reconsider in the future the scope of the EU ETS to what we agreed on in the Fit for 55 package. This thesis can be supported by a quote from the EC proposal to amend the EU ETS directive, which mentions the possibility of merging the BRT ETS with the existing EU ETS, based on experience after several years of operation of the BRT ETS[21]. In the report, several scenarios assumed the inclusion of new sectors into the EU ETS or the possible implementation of emission standards. The scenarios are constructed in such a way that they assume a gradual extension of the EU ETS. The introduction of new sectors in the EU ETS is not a new option because the EU ETS Directive (art. 24) makes it possible for Member States to include non-ETS sectors in the EU ETS at the national level.

68. The main questions addressed by the proposed scenarios are the possible consequences of applying the ETS (carbon pricing) and emission standards to specific sectors. The following analysis examines only the economic consequences of changing the climate policy architecture. The introduction of presented policy options would require appropriate legislative proposals.

Table 2. Description of scenarios related to the climate policy architecture

Scenarios	EU ETS Scope / Carbon Pricing	Non-ETS coverage	Description
Fit55	**EU ETS:** ▸ Power ▸ Industry ▸ Aviation and maritime[22] **BRT ETS:** ▸ Road transport ▸ Buildings	All sectors not included in the EU ETS	Scenario based on the Fit for 55 package, i.e.: ▸ **EU ETS:** current scope extended with the maritime sector. ▸ **BRT ETS:** new carbon trading scheme for road transport and buildings with separate reduction limit. ▸ The non-ETS limits for sectors outside the EU ETS are set at a country level. Non-ETS limits also include BRT ETS emissions. Emissions in non-ETS sectors (excluding road transport and buildings) allowed in a given country equals the non-ETS limit set in the ESR (including road transport and buildings), reduced by emissions from road transport and buildings at a national level calculated as a result of the BRT ETS operation. ▸ **EU ETS, BRT ETS:** emission trading system (carbon price) applied. ▸ **Non-ETS sectors** (excluding transport and housing): emission standards applied.

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[21] Proposal for a Directive of the European Parliament and of the Council amending directive 2003/87/EC, Brussels, 14.7.2021 com (2021) 551 final, Explanatory Memorandum page 3.
22 We included part of emission from maritime and aviation which is or will be (in case of maritime) covered by the EU ETS.

ETS BRT nonETS	**EU ETS:** ▸ Power ▸ Industry ▸ Aviation and maritime **BRT ETS:** ▸ Road transport ▸ Buildings	All sectors not included in the EU ETS and BRT ETS	▸ Scenario similar to the Fit55 but the non-ETS limits are recalculated and do not include the BRT ETS emissions from road transport and buildings (in practice this scenario means separating the reduction targets for BRT ETS and non-ETS). ▸ **EU ETS, BRT ETS:** emission trading system's (carbon price) applied. ▸ **Non-ETS sectors:** emission standards applied.
Joint ETS+RT	**EU ETS:** ▸ Power ▸ Industry ▸ Aviation and maritime ▸ Road transport	All sectors not included in the EU ETS	▸ A scenario of the EU ETS with the extension to the road transport sector (RT) from 2030. The non-ETS limits are calculated and do not include road transport. ▸ **EU ETS+RT:** emission trading system (carbon price) applied. ▸ **Non-ETS sectors:** emission standards applied.
Joint ETS+BRT	**EU ETS:** ▸ Power ▸ Industry ▸ Aviation and maritime ▸ Road transport ▸ Buildings	All sectors not included in the EU ETS	▸ Scenario with an extension of the scope of the EU ETS to road transport and buildings sectors (BRT) from 2030. The non-ETS limits are recalculated and do not include road transport and buildings. ▸ **EU ETS+BRT:** emission trading system (carbon price) applied. ▸ **Non-ETS sectors:** emission standards applied.
Joint ETS+BRTtax	Scenario assumptions are the same as the Joint ETS+BRT in terms of reduction targets (emission limits) and the scope of EU ETS and non-ETS. The difference between the Joint ETS+BRT scenario is only in the application of the tax on emissions in the non-ETS area at the regional level (vs. emission standards). (This scenario has been used in some parts of the report where its results differ significantly in economic effects compared to the Joint ETS+BRT scenario).		
One ETS	**EU ETS:** ▸ all sectors	N/A	▸ Scenario-based on the EU ETS with an extension to all other sectors (non-ETS, RT ETS, BRT ETS, etc.) and a single unified price for emissions.

Source: CAKE/KOBiZE

5.3 GHG emission reduction targets

69. All scenarios following the Union's commitments assume an increase of the 2030 net GHG emissions reduction target to 55% compared to 1990 levels and put the EU on the way to implement the objective of climate neutrality by 2050. Without taking into account removals, the assumed reduction of GHG emissions was estimated at 53% in 2030 compared to 1990. For 2050, the GHG emissions reduction target in the EU without removals was set up at the level of 90%. Based on the previously set reduction targets for 2030 and 2050, the EU achieves a reduction of 75% in 2040 compared to 1990 levels. To achieve net-zero emissions in 2050, it will be necessary to take into account removals

from the LULUCF sector (estimated to be ca. 500 Mt CO_2 eq.) and the backstop technologies[23] (e.g., direct air capture with carbon storage).

70. The GHG emission paths analysed in the scenarios are intended to show how the same level of emission reduction at the EU level can be achieved by the implementation of one of the two reduction options (EU ETS or emission standards at the national level) which leads to a different total cost, and as a consequence – different development speed of specific technologies.

5.4 A detailed description of scenarios

5.4.1 Fit55

Emission targets

71. The Fit55 scenario simulates the implementation of the EU climate policy objectives in accordance with the Fit for 55 package (Table 3). The Fit55 scenario assumes that in 2030 the EU ETS sectors must reduce their emissions by 62%, and the non-ETS sectors by 40% compared to the 2005 level.

72. Additionally, emission trading system for the buildings and road transport (BRT ETS) has been implemented. According to the package, by 2030 the emission reduction target in the BRT ETS is 43% compared to 2005.

Table 3. Emission targets in the Fit55 scenario

	Total (vs. 1990 level)	non-ETS (vs. 2005 level)	BRT ETS (vs. 2005 level)	EU ETS (vs. to 2005 level)
2030	53%	40%	43%	62%
2050	90%	85%	87%	95%

Source: CAKE/KOBiZE

73. For 2050, the reduction target for the EU ETS sectors was set at 95%. As a result of adopting the emission reduction level for the EU ETS sectors and in order to achieve the Community reduction target for all sectors, the rest of the economic sectors located in the non-ETS area must reduce emissions in 2050 by 85%. The assumed reduction target for the new BRT ETS system in 2050 is 87% compared to the 2005 emissions.

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[23] A backstop technology is defined in the d-PLACE model as a new technology of absorbing GHG emissions, which will be implemented after exceeding the marginal cost of emission reduction of EUR 1000/t CO_2 eq. by using relatively height capital inputs.

Emission limits in the EU ETS and BRT ETS sectors

74. At the technical level, the emission limits for the EU ETS and BRT ETS (Figure 5), which determine the amount of GHG that can be emitted, are defined by the number of allowances. The total number of emission allowances in both cases enters the modelling simulations as an exogenous parameter. In order to achieve the assumed targets, the total number of emission allowances in the projection period is set linearly[24] connecting the starting point (drawn from the historical emissions in 2021) and two following milestones based on the 2030 and 2050 reduction targets (compared to 2005).

75. The governments are responsible for the supply of allowances and collect the EU ETS and BRT ETS revenues. The total number of emission allowances in the EU ETS is generally divided into two categories:

    - 57% are auctioned (including redistribution for the Modernization Fund until 2030) – the amount of auctioned emission allowances that have been distributed among the Member States according to the rules defined in Article 10 (2) and Article 10d of the amendment to the Directive 2003/87/EC.
    - 43% are allocated free of charge: the total amount of free allocation (an exogenous parameter) is distributed among regions in proportion to the volume of emissions in the sector exposed to the risk of carbon leakage (an exogenous variable calculated in the model). Additionally, free allocation is reflected through a grant to sectors (for more information and the list of sectors with free allocation see the d-PLACE documentation[25]).

76. In the BRT ETS emission allowances are auctioned and none are provided for free. Allowances have been distributed among the Member States according to the rules defined in Article 30d of the amendment to Directive 2003/87/EC. Generally, allowances to be auctioned are distributed among all Member States based on their share in the average emissions of the 2016-2018 period from the sectors covered by the BRT ETS. It should be noted this does not take into account additional support mechanisms based on income redistribution, i.e. the Social Climate Fund. The BRT ETS works as a separate scheme not integrated with the existing EU ETS. It means that buildings and road transport sectors allowances cannot be used by the existing EU ETS entities, and vice versa.

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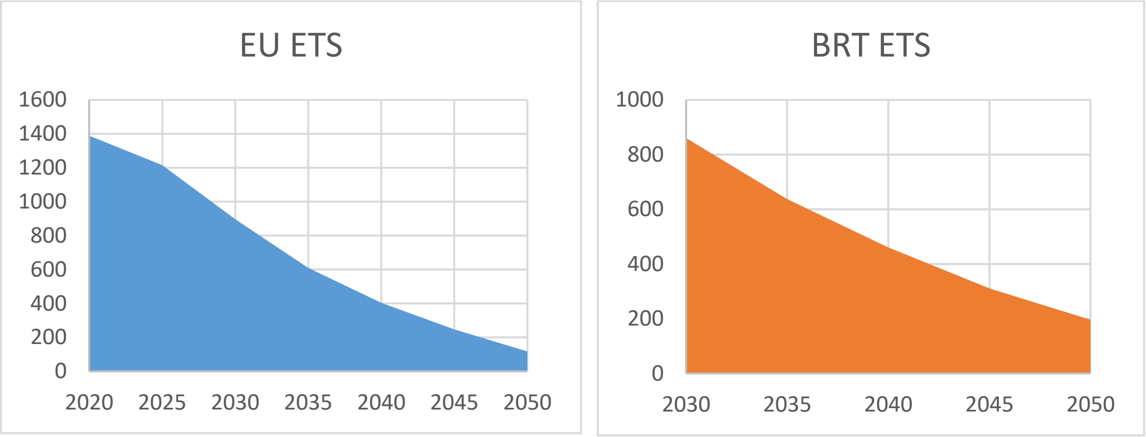
[24] The trend line is not a simple linear approximation but a function that takes into account the fact that while the cheapest abatement options are running out, emissions are decreased slower.

[25] Boratyński J., Pyrka, M., Tobiasz I., Witajewski-Baltvilks J., Jeszke, R., Gąska, J., Rabiega, W.(2022). The CGE model d-PLACE, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

Figure 5. Emission limits in EU ETS and BRT ETS [Mt CO_2 eq.]



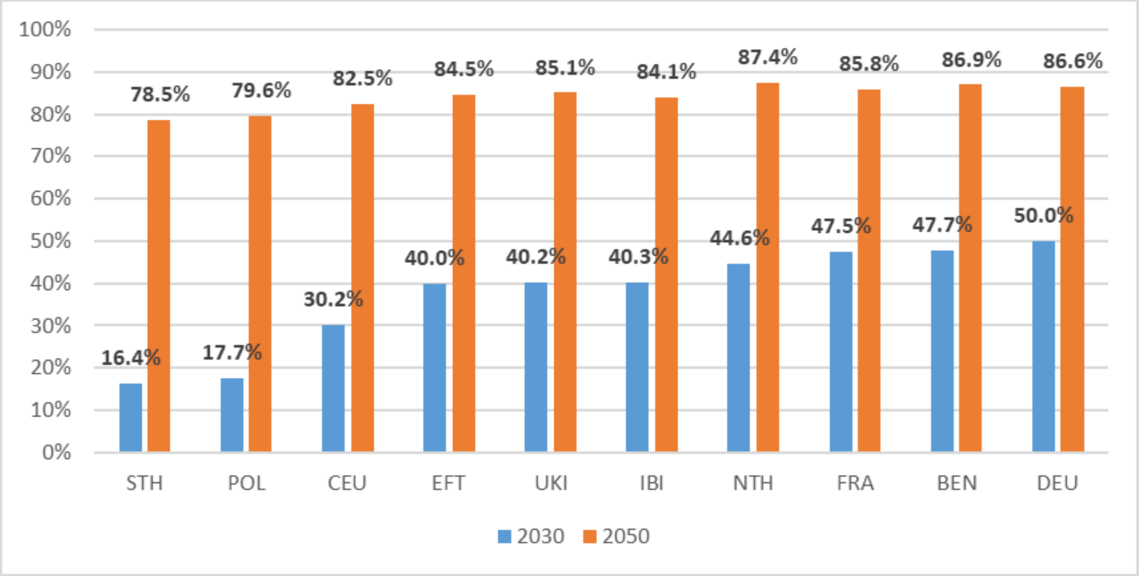
Source: CAKE/KOBiZE

National targets and emission limits in the non-ETS sectors

77. The Fit for 55 package includes an amendment to the Effort Sharing Regulation (ESR). It transfers the European-wide emission reduction target in the non-ETS into binding national targets for 2030. The values of national reduction targets in 2030 were assumed in the Fit55 scenario directly based on the proposal contained in Annex II of the amendment to the ESR, ranging from -50% to 0% depending on the Member State (e.g., for Poland the target is set at -17.7%).

78. The calculation of emission reduction targets is more complex for 2050. The method used to determine the national reduction targets for the year 2050 is based on adjusting the method used in ESR for 2030. Distribution of the emission reduction targets among the EU Member States for 2050 was calculated taking into account the projected values of GDP per capita (adopted based on the EU Reference Scenario 2020). It was assumed that the EU Member States will achieve targets ranging from -75% to -90%. Targets at the national level were estimated using a line passing through two points: the maximum target and maximum GDP per capita, and the minimum target and minimum GDP per capita index. Next, in place of the average value of GDP per capita, the line was adjusted to reach the -85% target for the entire EU. In this approach, the reduction target remains proportional to the value of GDP per capita, but there are two different lines with different steepness, separate for countries with GDP per capita below and above the EU average.

Figure 6. Emission targets in non-ETS scenario compared to 2005 in the Fit55 for each region



Source: CAKE/KOBiZE

79. The level of emissions in the non-ETS for a specific country is defined by setting the emission limits resulting from previously assumed reduction targets. Annual emission reduction limits until 2050 for each EU Member State are formulated by the line connecting the starting points (historical emissions in the year 2021) and emission targets for 2030 and 2050. The values of annual emission limits enter simulations as exogenous parameters.

Including part non-ETS emission into BRT ETS

80. The inclusion of buildings and road transport sectors in the new pan-European BRT ETS system does not assume excluding these sectors from the reduction area defined by the ESR (non-ETS reduction targets at the national level). This means that the reduction target and the resulting emission limit in the non-ETS area must also be met taking into account emissions from buildings and road transport in a given EU country.

81. To model such an option proposed in the Fit for 55 package, the total supply of allowances for carbon dioxide emissions in the BRT ETS was determined in the first step. At the same time, carbon dioxide emissions may not exceed the assumed number of allowances issued by the governments and set in accordance with the adopted reduction targets for the Fit55 scenario in BRT ETS. The price of emissions is calculated endogenously and is the result of market clearing (balance between the total demand and total supply of allowances).

82. Emissions in the BRT ETS are reduced, as a result of a set price. The level of these reductions differs between regions, which is resulting mainly from the starting structure of the transport fleet and the share of fuels in the heating of buildings (fuel mix in a given country). The level of emissions that must be met by other non-ETS sectors (without buildings and road transport) within a given country is changed as a result of imposing a specific price in the BRT ETS. Therefore, in the next step, the emission remaining in the sectors covered by the BRT ETS is subtracted from the emission limit of a given country in the non-ETS. This way, a new level of limit for sectors remaining in the non-ETS (without buildings and road transport sectors) is set endogenously.

5.4.2 ETS BRT nonETS

83. In this scenario, the EU ETS and BRT ETS reduction targets remain the same as in the Fit55 scenario. Therefore, there are also no differences in the allocation of allowances in these systems. The main difference between the ETS BRT nonETS and the Fit55 scenarios is that the implementation of the BRT ETS excludes buildings and road transport sectors from the reduction area defined as non-ETS. To achieve the EU's overall GHG reduction target, sectors covered by the non-ETS (after exclusion of emissions from buildings and road transport) must reduce their emissions in 2030 by 36% and in 2050 by 82% compared to 2005 levels (Table 4).

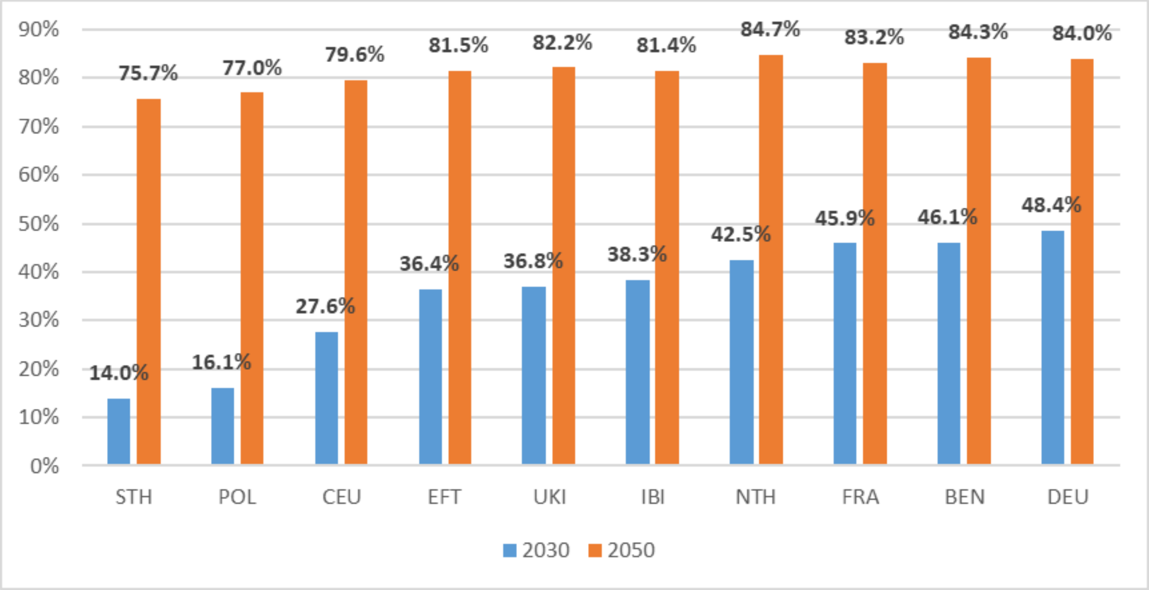
Table 4. Emission targets in the ETS BRT nonETS scenario

	Total (vs. 1990 level)	non-ETS (vs. 2005 level)	BRT ETS (vs. 2005 level)	EU ETS (vs. 2005 level)
2030	53%	36%	43%	62%
2050	90%	82%	87%	95%

Source: CAKE/KOBiZE

84. Thus, the reduction target and the resulting emission limit in non-ETS at the national level need to be updated. The reduction effort was lowered by the same value for all EU countries compared to the Fit55 scenario: 1.6 p.p. in 2030 and 2.6 p.p. in 2050. Figure 7 presents the values of national reduction targets in the non-ETS for each region for 2030 and 2050.

Figure 7. Emission targets in the non-ETS compared to 2005 in the ETS BRT nonETS and the Joint ETS+BRT scenarios for each region



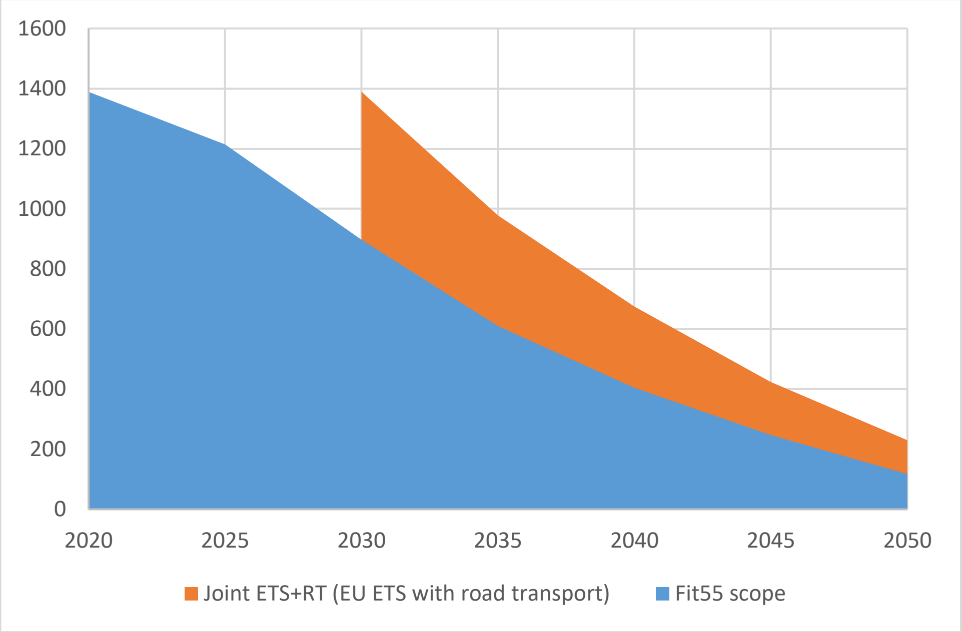
Source: CAKE/KOBiZE

85. Assumed reduction targets are transferred to emission limits in the same way as it was done for the Fit55 scenario. The base emission in 2005 used to calculate the new emission limits was also adjusted respectively for each EU Member State by excluding the buildings and road transport from the non-ETS.

5.4.3 Joint ETS+RT

86. This scenario covers the inclusion of road transport in the EU ETS. It assumes that road transport has become fully integrated in the existing scheme before 2030, which implies that the road transport sector can buy allowances from the existing EU ETS and the other way around – transport allowances can be used by the existing EU ETS sectors. To extend the EU ETS to road transport sector, additional emission limits for road transport were defined based on the proposed reduction targets, the same as for the BRT ETS in the Fit55 scenario. The potential allocation method also stays the same as for the BRT ETS, meaning the total auctioning for additional road transport cap and redistribution of this cap among all Member States based on the share in the average emissions for the 2016-2018 from the road transport. After merging the emission limits for road transport and the current EU ETS (Fit55 scenario), the reduction targets in the combined emissions trading scheme have changed to 57% in 2030 and to 93% in 2050 compared to 2005 (Figure 8).

Figure 8. Emission limits in the EU ETS (including road transport) in the Joint ETS+RT scenario [Mt CO_2 eq.]



Source: CAKE/KOBiZE

87. Consequently, the road transport was excluded from the current scope of the non-ETS sectors. After this exclusion, the non-ETS sectors need to reduce their emissions in 2030 by 39% and by 83% in 2030, compared to 2005 (Table 5).

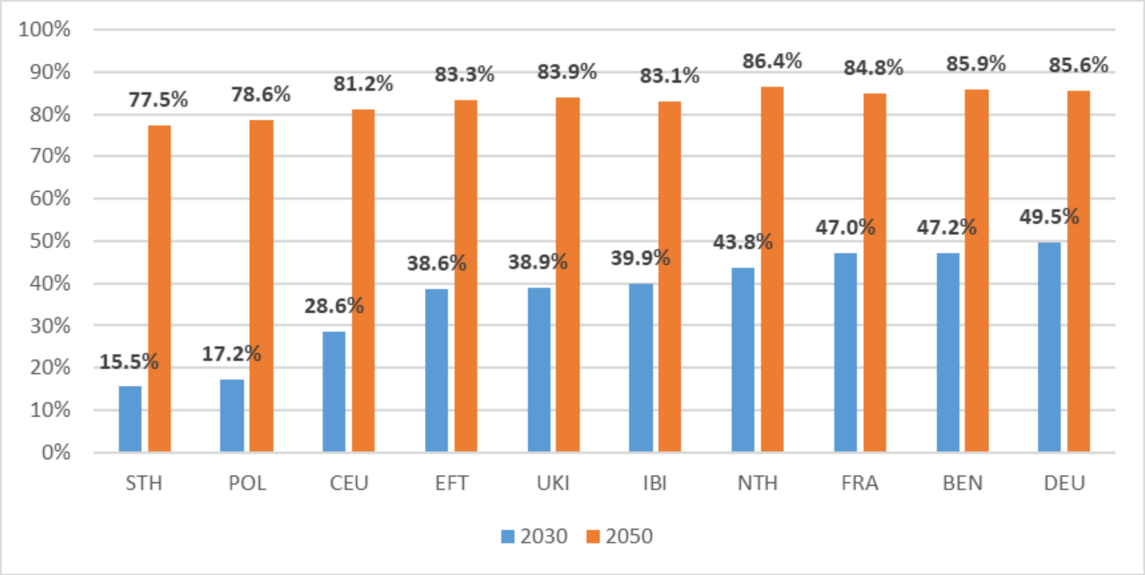
Table 5. Emission targets in the Joint ETS+RT scenario

	Total (vs. 1990 level)	non-ETS (vs. 2005 level)	EU ETS (vs. 2005 level)
2030	53%	39%	57%
2050	90%	83%	93%

Source: CAKE/KOBiZE

88. To achieve the overall EU target in the non-ETS the individual binding targets for each EU Member State were defined (Figure 9). The reduction effort was lowered by the same value for each EU Member State compared to the Fit55 scenario: by 0.5 p.p. in 2030 and by 1 p.p. in 2050. After adjusting the targets of non-ETS, the new emission limits at the country level were set without taking into account the emissions from road transport.

Figure 9. Emission targets in the non-ETS scenario compared to the year 2005 in the Joint ETS+RT scenario for each region



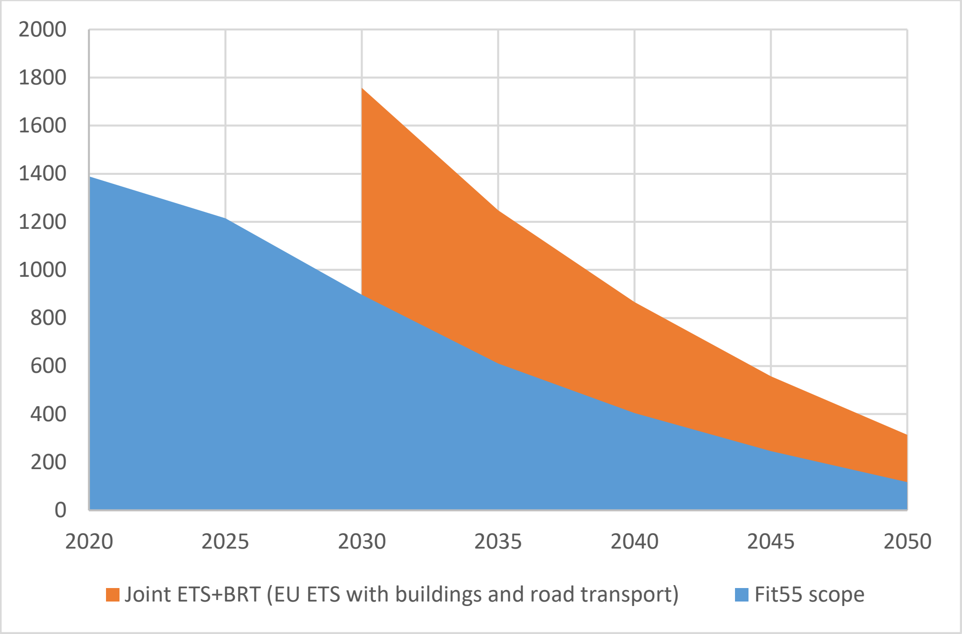
Source: CAKE/KOBiZE

5.4.4 Joint ETS+BRT

89. The assumptions for this scenario are similar to those in the previous Joint ETS+RT, with the key difference that, apart from road transport, buildings also become fully integrated into the existing EU ETS scheme by 2030 (Figure 10).

90. The way of redistribution of additional allowances in the EU ETS from the buildings and road transport sectors stays the same as in the Fit55 scenario for BRT ETS, meaning the total auctioned volumes of additional allowances and the redistribution scheme for sharing revenues between the EU Member States is calculated based on sharing the average emissions of 2016-2018. Thus, the allowances available for each Member State in the BRT ETS (as it was calculated in the Fit55 scenario) are added to their allowances in the EU ETS.

Figure 10. Emission limits in EU ETS (including buildings and road transport) in the Joint ETS+BRT scenario [Mt CO_2 eq.]



Source: CAKE/KOBiZE

91. Full integration of emission schemes would imply that emission targets for extended EU ETS are adjusted to 54% in 2030 and to 92% in 2050, compared to the 2005 emission level. After this change, emissions from buildings and road transport sectors are excluded from non-ETS, and new targets and limits are set for the rest of the non-ETS sectors.

Table 6. Emission targets in Joint ETS+BRT scenario

	Total (vs. 1990 level)	non-ETS (vs. 2005 level)	EU ETS (vs. 2005 level)
2030	53%	36%	54%
2050	90%	82%	92%

Source: CAKE/KOBiZE

92. Redistribution of effort among Member States is the same as in the ETS BRT non-ETS scenario, meaning national targets are lowered for all EU Member States compared to the Fit55 scenario: by 1.6 p.p. in 2030 and by 2.6 p.p. in 2050, with the national emission limits respectively adjusted to new targets. Accordingly, the national limits do not include buildings and road transport, just as in the ETS BRT non-ETS scenario.

5.4.5 One ETS

93. In One ETS scenario, the emissions trading is the cornerstone of the EU's climate change mitigation policy and provides incentives to reduce emissions in all economy sectors. In this scenario, the existing non-ETS sectors become fully integrated with the current EU ETS, which means a single price for GHG emissions is applied across the EU and all economic sectors. Table 7 presents reduction targets for this One ETS scenario.

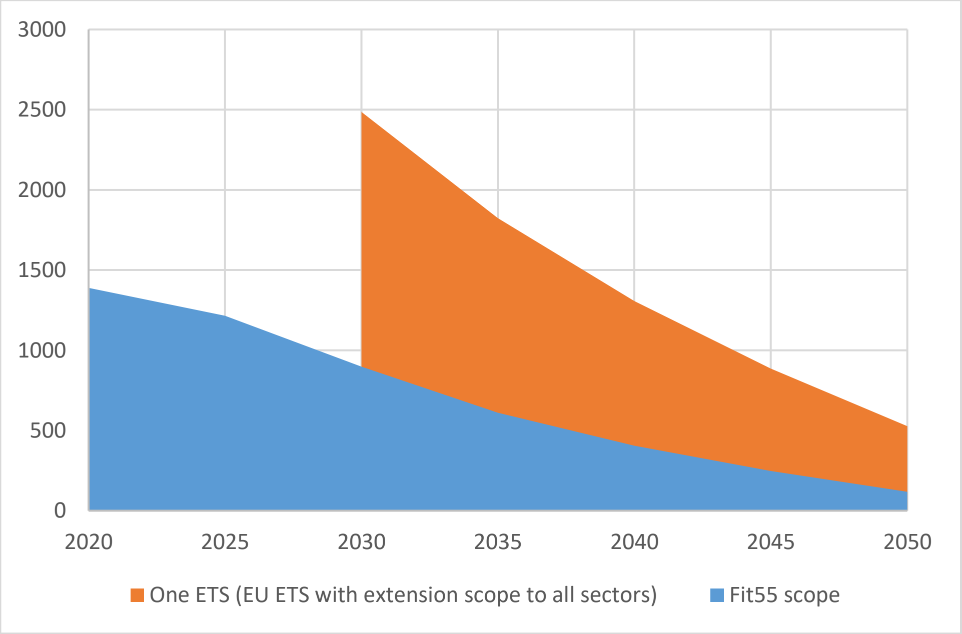
Table 7. Emission targets in the One ETS scenario

	EU ETS (vs. 1990 level)
2030	53%
2050	90%

Source: CAKE/KOBiZE

94. The total number of emission allowances in the One ETS includes the EU ETS (based on the Fit55 scenario) and additionally the limits for the non-ETS sectors (Figure 11). In absolute terms, this means that the total number of allowances and national limits in non-ETS (calculated within the Fit55 scenario) were combined.

Figure 11. Emission limits in the One ETS scenario [Mt CO_2 eq.]



Source: CAKE/KOBiZE

6. Models used in scenario analysis

95. The results presented in the study were prepared using a set of tools built and developed by the Centre for Climate and Energy Analysis (CAKE): the macroeconomic Computable General Equilibrium (CGE) model (d-PLACE[26]), energy model (MEESA[27]), transport model (TR^{3}E[28]) and agriculture model (EPICA[29]). Results for individual scenarios were obtained in the process of linking the models to ensure that changes due to mitigation efforts in one sector are reflected in the costs and potential of mitigation efforts in the other sectors. The linking is based on sequential solving, which is accompanied by the mutual transfer of selected information (simulation results). The procedure of solving is reiterated until the path of prices of emissions in all models converges. The information explaining the procedure for solving the models in the iterative mode and providing knowledge of the components of the models that facilitate the linking can be found in the technical documentation[30].

96. The d-Place model analyses simultaneously change in all key sectors of the economy (transport, energy, agriculture). However, this necessitates limiting the number of commodities in each sector, compared to sectoral models and does not include physical constraints, such as the availability of particular technologies or constraints on the availability of resources, which can be easily incorporated into the sectoral models.

97. The linking of the models ensures that the projections of the models provide a complete and detailed picture of actions aimed at reducing greenhouse gas emissions. In particular, the use of sectoral models made it possible to capture in greater detail the specificity of reduction potentials and technologies in key areas – energy, transport and agriculture. On the other hand, the linking ensures that the estimated changes in emissions in various sectors of the economy add up to the assumed total reduction targets, and moreover, the marginal costs of reducing emissions in individual sectors are equal.

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[26] Boratyński J., Pyrka, M., Tobiasz I., Witajewski-Baltvilks J., Jeszke, R., Gąska, J., Rabiega, W.(2022). The CGE model d-PLACE, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[27] Tatarewicz, I., Lewarski, M., Skwierz, S., (2022) The MEESA Model, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[28] Rabiega, W., Sikora, P., Gąska, J., Gorzałczyński A. (2022) The TR^{3}E Model, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[29] Wąs, A., Witajewski-Baltvilks, J., Krupin, V., Kobus, P. (2022). The EPICA model, ver. 2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[30] Boratyński, J., Witajewski-Baltvilks, J., Tatarewicz, I., Pyrka, I., Rabiega, W., Wąs, A., Kobus, P., Lewarski, M., Gorzałczyński, A., Tobiasz, I., Vitaliy, K., Jeszke, R., (2021) Procedure for linking sectoral models with the CGE model, Technical documentation version 1.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw , link: https://climatecake.ios.edu.pl/wp-content/uploads/2021/12/CAKE_Models_Linking_21.12.2021_final.pdf

98. Iterative exchange of results between the d-PLACE model and the sectoral models allows determining marginal abatement costs for EU ETS sectors for the EU as a whole (using exchange with the MEESA model) and for non-ETS sectors for each region (using exchange with TR^{3}E and EPICA models).

99. In the case of EU ETS price, initially, the price is determined endogenously within the d-PLACE model by equalizing the emission limit for a given scenario with the demand from all EU ETS sectors (including the power sector and carbon-intensive industries in all EU countries). Subsequently, this price is transferred to the MEESA model, which, using its much more detailed structure of the power sector, provides a new estimate of power sector emissions for this price level. At the beginning of the next iteration, this new estimate is used in the d-PLACE model to recalibrate the emission intensity of the power sector.

100. In case of non-ETS emission abatement cost, the initial estimate of the cost, obtained in the d-PLACE model, invokes changes in the emission intensity of transport and agricultural production in the TR^{3}E and EPICA models, which in the next iteration leads to a change in the “demand for emissions” in the d-PLACE model and the related correction of the marginal abatement costs. Note that mitigation options in sectors that are not covered by sectoral models (e.g., buildings, steel, paper, cement) are modelled in the d-PLACE model. Firms in these sectors can substitute fossil fuels with other energy carriers (electricity or hydrogen) and substitute their energy inputs with capital.

7. Results

7.1 Costs of GHG emission

EU ETS

101. The marginal emission abatement costs[31] represent a price signal for sectors in the emission trading schemes, urging cost-effective approaches and the search to implement technologies contributing to the low-carbon transition of the economy. The scopes of the EU ETS are different in the scenarios so the choice of a specific solution does not depend only on the assumed reduction target but also on available abatement technologies in individual sectors.

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[31] The emission abatement costs (i.e. the modelled carbon price) should not be directly identified as the price of emission allowances in the EU ETS/ BRT ETS system, as no market model was used to determine such price. In the analysis the following are not taken into account: surplus of allowances on the market, functioning of the MSR reserve, the possibility of banking allowances between years, the possibility of buying allowances by companies to meet future emission needs (heading needs), as well as activities of financial institutions.

102. Figure 12 shows the modelled marginal abatement costs in the period 2020-2050 depending on analysed scenario. Until 2025, no differences are observed in these costs between the scenarios due to the constant scope of the EU ETS and the implementation of identical reduction targets. For the same reason, no differences are detected between the Fit55 and the ETS BRT non-ETS scenarios, where the scope and targets of the EU ETS are the same until 2050.

103. From 2030 to 2035, abatement costs for most scenarios (Fit55, ETS BRT nonETS, Joint ETS+RT, One ETS) are very similar and are ranging:

- in 2030: from approx. EUR 140/t CO_2 eq. (in One ETS) to EUR 180/t CO_2 eq. (in Fit55 and ETS BRT nonETS),
- in 2035: from approx. EUR 290/t CO_2 eq. (in One ETS) to EUR 330/t CO_2 eq. (in Joint ETS+BRT).

104. Marginal abatement costs in the EU ETS strongly increase after the extension of the EU ETS to the road transport sector (between the Fit55 and the Joint ETS+RT scenarios), which indicates that forcing reductions in road transport requires a higher emission price. In the EU ETS, the reduction costs between the Fit55 and the Joint ETS+RT scenarios increase:

- in 2030: from approx. EUR 180/t CO_2 eq. (in Fit55 scenario) to EUR 250/t CO_2 eq. (in Joint ETS+RT scenario)
- in 2035: from approx. EUR 320/t CO_2 eq. (in Fit55 scenario) to EUR 500/t CO_2 eq. (in Joint ETS+RT scenario).

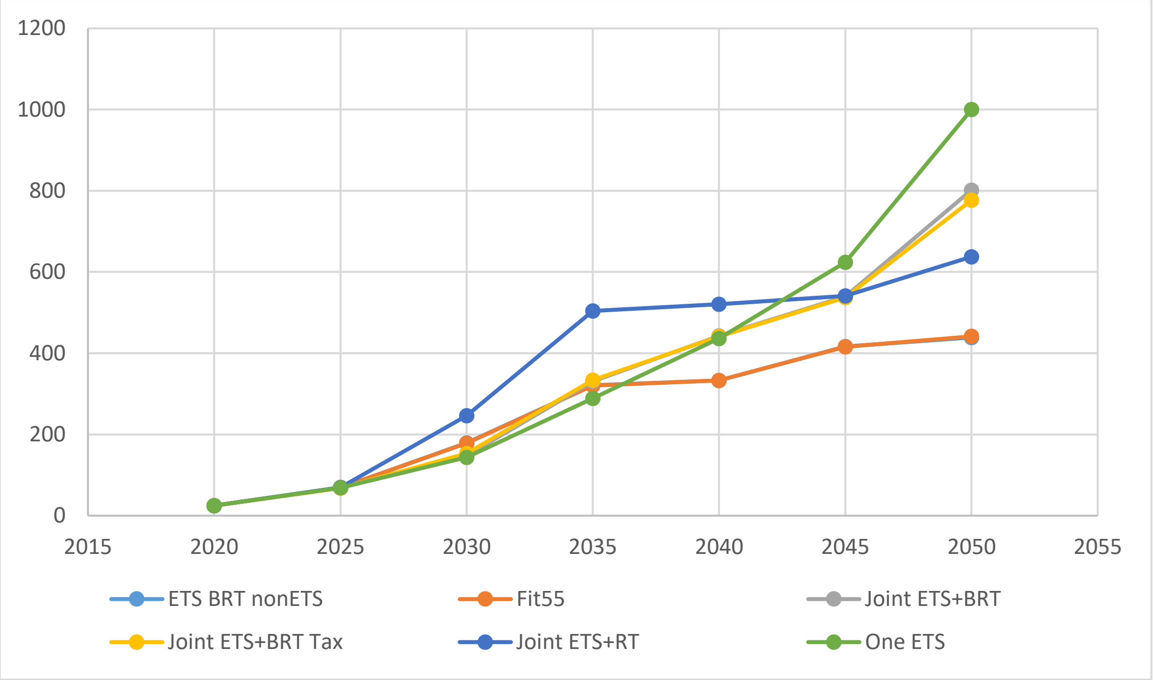
105. Another important observation is the strong increase in marginal abatement costs in the EU ETS in alternative scenarios, compared to the Fit55 scenario, at the end of the projection period. The highest marginal reduction cost after 2045 is found in the One ETS scenario, because sectors currently included in the non-ETS area (especially agriculture) have limited technologies to reduce emissions. In 2050 in One ETS scenario the cost is limited by the model to EUR 1000/t CO_2 eq. (see Annex I Section A for more information).

106. Generally, marginal abatement costs increase over time along with the reduction targets becoming increasingly ambitious. One exception is the Joint ETS+RT scenario, where the marginal abatement cost remains constant in the period 2035-2045, which is caused primarily by the small increase in the reference scenario price (i.e., Fit55 after 2035). Secondly, expansion of zero-emission technologies in road transport sector is observed in the simulations.

107. In the Fit55 scenario, lower growth rate of the emission cost is largely due to the change in the energy mix: phasing out the coal use, dynamic development of BECCS technology (allowing to achieve the negative emissions), and further development of

various RES. The abatement costs after 2040 are the lowest in the Fit55 scenario and remains so until 2050 when it reaches approx. EUR 440/t CO_2 eq.

Figure 12. Cost of emission reduction in EU ETS [EUR'2015/t CO_2 eq.]

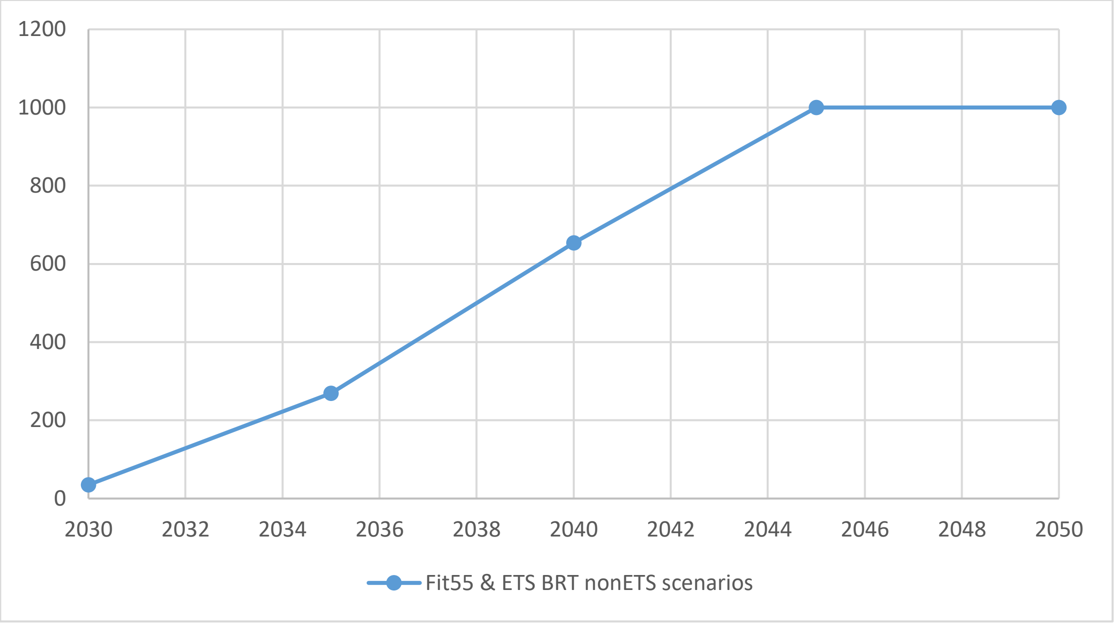


Source: CAKE/KOBiZE

BRT ETS

108. Changes in marginal abatement costs in the BRT ETS are the result of the assumed emission reduction target and reduction potentials in buildings and road transport. According to the obtained results (Figure 13), the costs of reductions in the BRT ETS between 2030 and 2040 increase from ca. 35 to approx. EUR 650/t CO_2 eq. After 2040, the growth path of the BRT ETS reduction costs is limited by the model to EUR 1000/t CO_2 eq. (see Annex I Section A for more information). Given these relatively high marginal abatement costs, the inclusion of buildings and road transport in the existing scheme generally increases the carbon price in the EU ETS (Figure 12).

Figure 13. Cost of emission reduction in BRT ETS [EUR’2015/t CO_2 eq.]



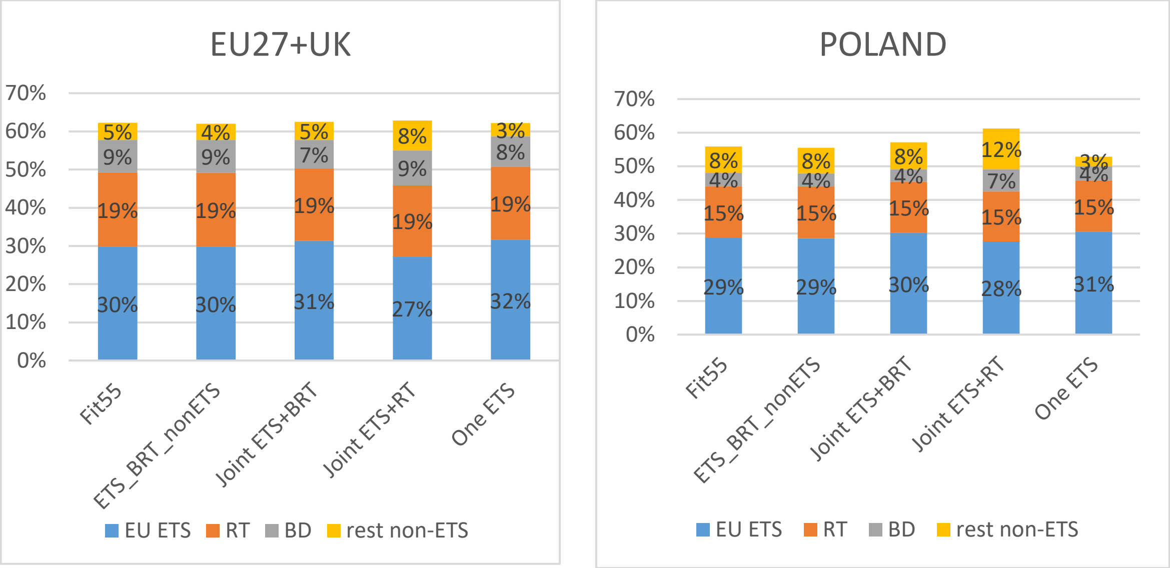
Source: CAKE/KOBiZE

7.2 GHG emissions

109. The GHG emission in all scenarios in the EU in the period up to 2030 is approx. 62% vs. 2020 level. The share of EU ETS in 2030 ranges from 27 p.p. in the Joint ETS+RT scenario to 32 p.p. in the One ETS scenario. Road transport (RT) remains with the second largest share of 19 p.p. in all scenarios. More visible differences between scenarios can be observed in buildings and other non-ETS sectors, however, their share in total emissions in 2030 is lower, ranging from 11 p.p. in One ETS option to 17 p.p. in the Joint ETS+RT scenario.

110. Poland in 2030 shows a better result in total emission reduction, but also more visible differences between scenarios ranging from 39% emission reduction in Joint ETS+RT scenario to 47% reduction in One ETS scenario, the EU ETS remains with the highest share in total Poland’s emissions in 2030, close to the level in the EU. Clearly, a lower share is represented by buildings (15 p.p.) and road transport (4 to 7 p.p.). Other non-ETS sectors seem to be more important for the emission reduction in Poland than in the EU with the highest emission share in the Joint ETS+RT scenario. Figure 14 illustrates emission levels and sources, and differences for the EU and Poland in 2030.

Figure 14. Emission reductions for the EU27+UK and Poland in 2030 [change in total emissions in % vs. 2020 and sectoral contributions in p.p.]

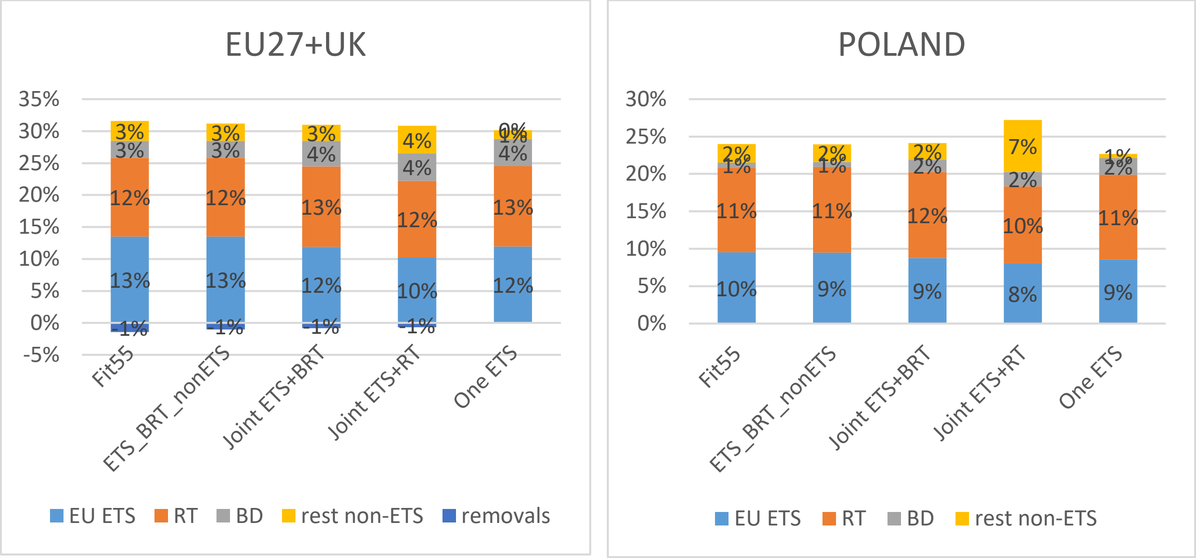


Source: CAKE/KOBiZE

111. The levels of emission reduction in the EU are approaching 70% in 2040 (ranging from 68% in Fit55 to 70% in the One ETS scenario). Results show an effective reduction in the EU ETS as its share in total emissions drops to 12-13 p.p. and even 10 p.p. in the Joint ETS+RT scenario. The leading position in the EU emissions in 2040 is taken by road transport (12-13 p.p.). Since total emission reduction is almost the same in all scenarios, outstanding reduction results of the EU ETS in the Joint ETS+RT scenario are offset by higher emissions from other non-ETS sectors.

112. Simulated 2040 emissions for Poland show similar differences in total emissions between scenarios. The joint ETS+RT scenario remains with the lowest reduction (73% vs. 2020 level) whereas others reach 76-77%. While EU ETS is the most effective in this option with just 8 p.p. in total emission, other non-ETS sectors are responsible for 7 p.p. what is much higher in this scenario, compared to 1-2 p.p. in other scenarios. Highest share in emissions is represented by road transport, ranging from 10 to 12 p.p. (see Figure 15 for details).

Figure 15. Emission reductions for the EU27+UK and Poland in 2040 [change in total emissions in % vs. 2020 and sectoral contributions in p.p.]

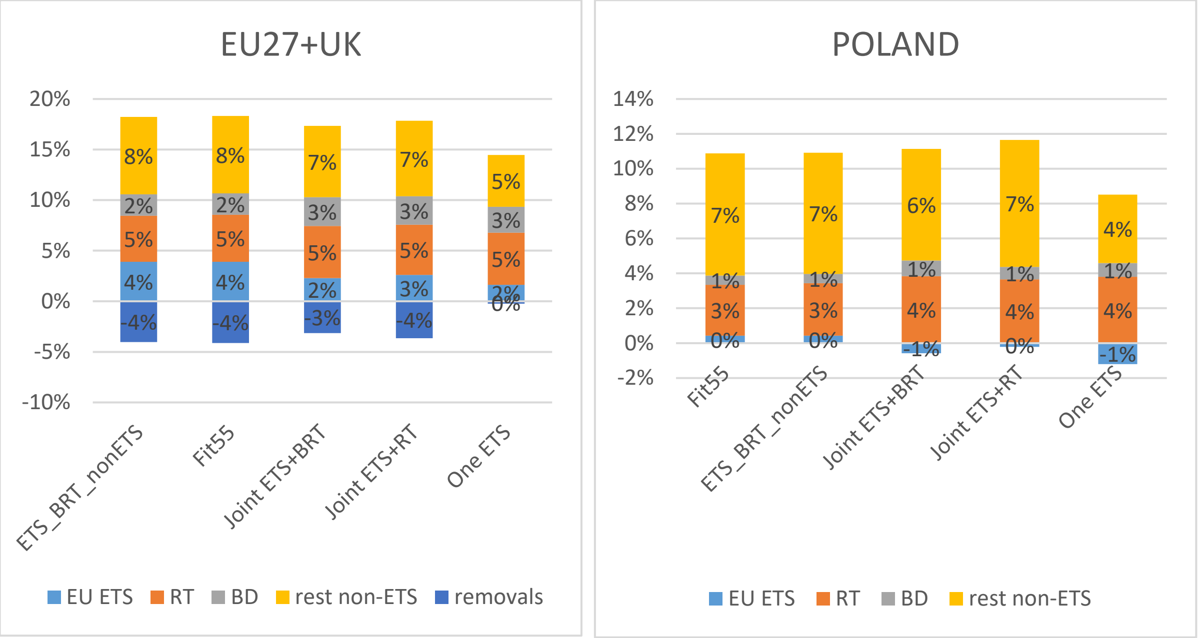


Source: CAKE/KOBiZE

113. Emission reduction in the EU in 2050 reaches 86% in the One ETS scenario only. Other scenarios show lower reductions, in the range of 82-83% vs. the 2020 level. The most visible differences are observed in both the EU ETS and other non-ETS sectors. The One ETS scenario demonstrates the highest effectiveness of the EU ETS, illustrated by the 2 p.p. only share in total emissions, while it gives 4 p.p. in scenarios Fit55 and ETS BRT nonETS. Other non-ETS sectors take the lead in total emissions, contributing by 7-8 p.p. in all scenarios, except for the One ETS with just a 5 p.p. share.

114. Net emission reductions in 2050 for Poland are visibly more effective than the EU average, reaching 93% in One ETS scenario and 89% in all others. Results comparable to the EU are represented by other non-ETS sectors (4 p.p. in total emissions in One ETS scenario and 6-7 p.p. in others), remaining with the highest shares in total emissions in 2050. EU ETS seems to be much more effective in Poland as its share in total emissions is even negative in both One ETS and Joint ETS+BRT scenarios, due to CO_2 removal exceeding emissions. Also, buildings' shares are visibly lower than in results for the EU (Figure 16).

Figure 16. Emission reductions for the EU27+UK and Poland in 2050 [change in total emissions in % vs. 2020 and sectoral contributions in p.p.]



Source: CAKE/KOBiZE

115. The EU net-zero target in 2050 is almost being achieved only in OneETS scenario (which includes operational removal technologies: BECCS and sinks by AFOLU sector). Other scenarios need additional removal technologies to meet the net-zero target that are not operational at the moment, however considered in modelling and defined as backstop technologies (see Annex I Section A for more information) and marked as removals on Figure 15 and 16). Model simulation shows that reduction milestones for 2040 need such additional removals in some scenarios as well, however they are much lower than in 2050.

7.3 Macroeconomic step by step analysis of scenarios

7.3.1 The step-by-step approach

116. Scenarios analysed in this report differ in:

- assignment of economic activities to carbon pricing systems (e.g., which sectors are included in the EU ETS),
- policy instruments ensuring meeting the reduction targets – explicit carbon pricing or command-and-control policies (energy and emission standards, etc.)
- how non-ETS targets are assigned.

This makes comparison and interpretation challenging. Therefore, in this subsection we analyse the scenarios step-by-step: we start with the Fit55 scenario (which is our reference) and with each step along the sequence of scenarios we add one change in the assumptions. To explain these changes we divide GHG emissions in the model into five broad segments (denoted A, B, C, D, E), primarily based on the sector of origin.

- **A:** power, energy-intensive industry, part of aviation and maritime (covered by EU ETS)
- **B:** buildings
- **C:** road transport
- **D:** agriculture, other manufacturing and services, waste
- **E:** part of extra-EU aviation and maritime (not covered by EU ETS)

Different segments can be linked together, thus being subject to a joint emission limit and the same pricing. For example, the notation AC indicates that segments A (the current EU ETS) and C (road transport) form a single system, with a common carbon price and a single emission limit. Note that A alone is equivalent to the current EU ETS scope, whereas BCD is equivalent to the current non-ETS scope.
Sectoral emission segmentation scheme in our scenarios is presented in Table 8.

Table 8. The sectoral emission segmentation scheme

Scenario	2020, 2025	2030-2050
Fit55	A, BCD, E	A, BC, D*, E
ETS BRT nonETS		A, BC, D, E
Joint ETS+RT		AC, BD, E
Joint ETS+BRT		ABC, D, E
Joint ETS+BRTtax		ABC, D, E
One ETS		ABCD, E

* *indicates endogenous emission limit in a given segment. Color indicates type of policy instrument – carbon pricing, emission standards, no policy.*

Source: CAKE/KOBiZE

7.3.2 Step 1 – changing allocation of non-ETS limits

117. In this step, we move from Fit55 to ETS BRT nonETS scenario. The only change concerns how emission limits are assigned to different regions. In the Fit55 scenario, non-ETS emission limits (allocated at the country level) include segments BCD from Table 8. At the same time, segments BC are included in the BRT ETS cap and trade system, with EU-level emission cap, and allocation of emission allowances to countries. In such a setting, the required emission reduction in segment D in a given country depends on how much reduction was achieved in segments BC (functioning under the BRT ETS) in that country, so that joint emissions from BCD segments meet the non-ETS target:

$$Limit_r(D) = Limit_r(BCD) - Emissions_r(B)$$

$$Limit_r(BCD) = \ Effort\ Sharing\ Regulation_r$$

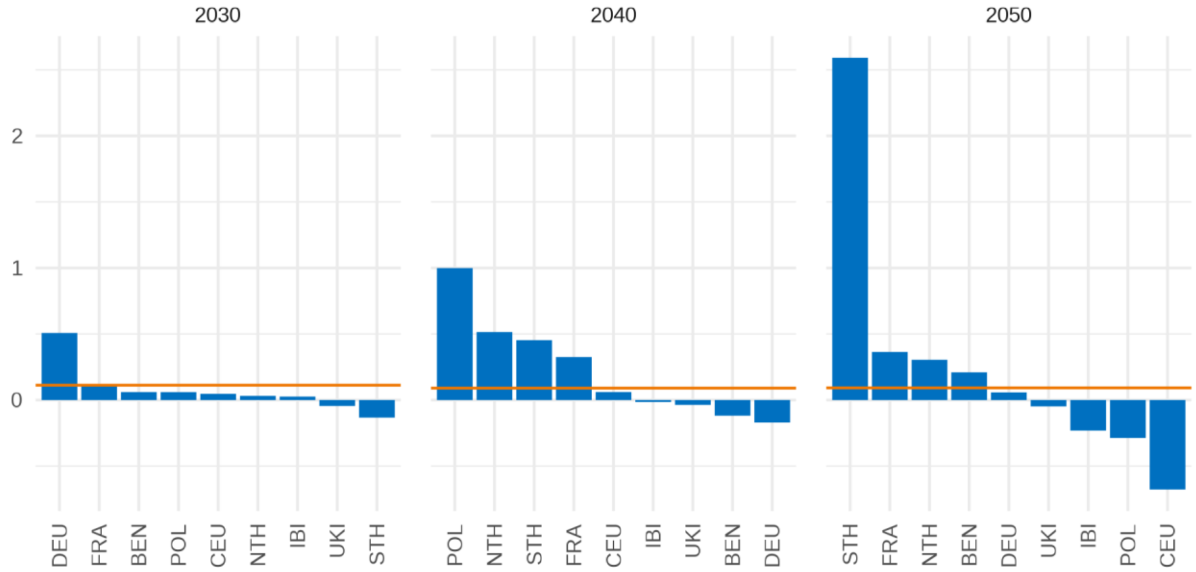
where r denotes a country or group of countries (region), and the non-ETS emission limit for region r is determined by the Effort Sharing Regulation. Instead, in the ETS BRT nonETS scenario country-level limits are set for the D segments alone. This can also be interpreted as narrowing the current non-ETS definition just to activities covered by sector D:

$$Limit_r(D) = \ new\ Effort\ Sharing\ Regulation_r$$

Although the general allocation approach, hinging on countries' GDP per capita (see Chapter 5.4) remains the same in both scenarios, the fact that it is applied to different emission bases makes a difference. Consequently, the shock considered in this scenario can be written as $\Delta Limit_r(D)$.

118. The main outcome variable that we will consider in this section across all scenarios is real consumption (the sum of real household and government consumption). In the CGE model, changes in consumption embody all costs and benefits of changes in policies. In some cases, household consumption alone is the headline result. However, in our case this would be a little misleading, as government consumption is not fixed across scenarios – rather it is proportional to domestic final demand, i.e., the sum of consumption and investment. Also, note that consumption is a preferred measure to that of GDP. In fact, GDP and consumption may change in different directions when comparing a policy scenario to a reference scenario. For example, terms of trade improvement could make consumption increase, even though GDP goes down. Moreover, an investment increase may lead to an increase in GDP in the short run (by increasing total demand), but it will typically also crowd-out consumption in our model setting. Changes in consumption, associated with the move from Fit55 to ETS BRT nonETS scenario are shown in (Figure 17). In all years we can see a very small increase in consumption in EU27+UK as a whole. However, individual region effects are much larger. Consequently, the change in limits for the "narrow non-ETS" (that is limits for segment D) yields a negligible aggregate result but redistribution results across regions are significant.

Figure 17. Step 1: Real consumption ETS BRT nonETS, deviations from Fit55 [%]



** horizontal line indicates the result for the EU27+UK as a whole.*

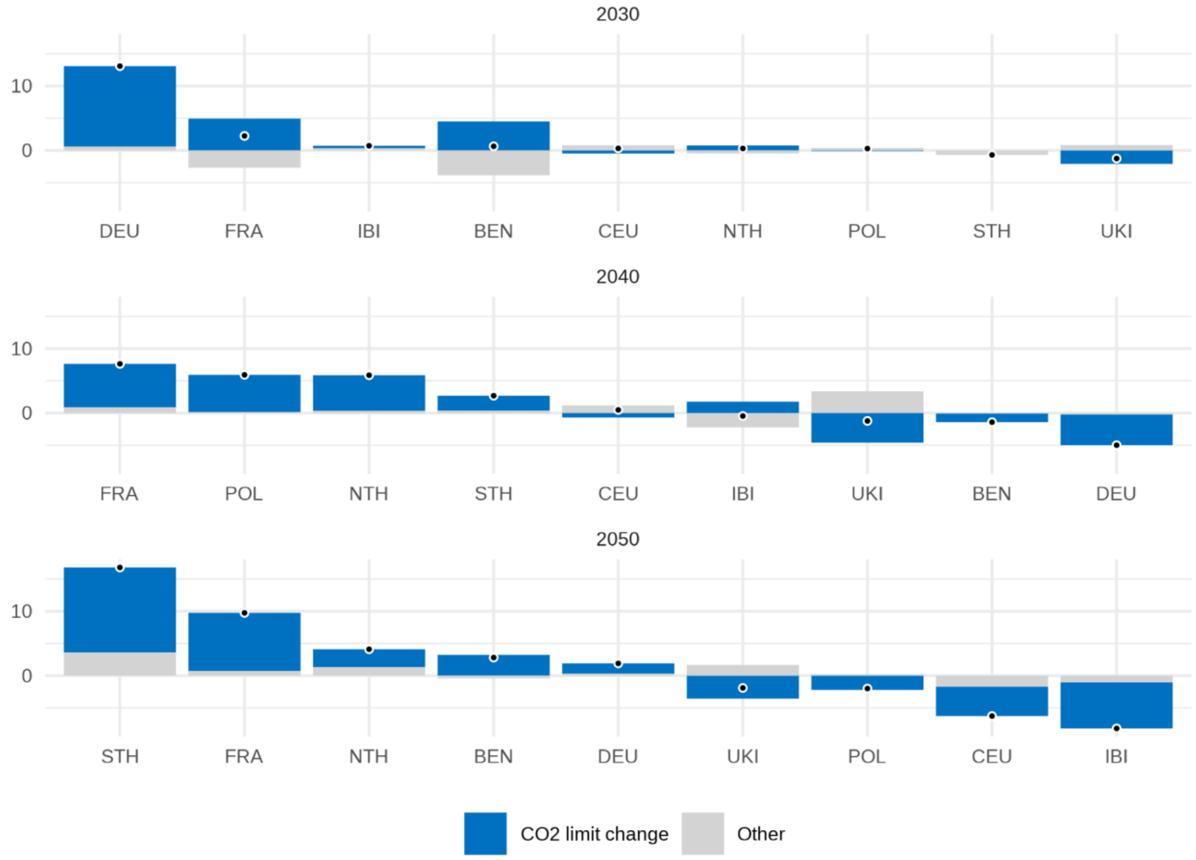
Source: CAKE/KOBiZE

119. It is difficult to identify a clear pattern of consumption changes. A single region might benefit from the reform in one year but lose in another year. However, we find in this case that simulated changes in consumption are highly correlated with the shock size itself. In specific, simulation results can be reproduced with a high degree of accuracy using the following equation:

$$\Delta Consumption_{r,t} = 1.05 \cdot \Delta Limit_{r,t}(D) \cdot \overline{CarbonPrice}_{r,t}(D)$$

This equation explains 91% of the variability of simulation results (concerning consumption change) across regions and years. Even though we focus on the results for 2030, 2040 and 2050, the equation and its fit relates to years 2030, 2035, 2040, 2045 and 2050. The same relates to similar equations in subsequent sections. Variable $\Delta Limit_{r,t}(D)$ represents a change in effective emission limit in the “narrow non-ETS” (segment D) in region r, year t, whereas $\overline{CarbonPrice}(D)$ is the carbon price (marginal abatement cost) in segment D in the reference (Fit55) scenario. The equation works particularly well in the years 2045 and 2050 in which carbon prices are high. The decomposition of consumption changes using the above formula is shown in (Figure 18). In this figure, the dot denotes actual consumption change obtained in the simulation, whereas the bars represent contributions to that change of factors (here – a single factor) distinguished on the right-hand side of the equation. The term “Other” relates to variability not explained using the above equation. Those unexplained changes stem from complex relations described by the full model and are not easily attributed to any universal rule.

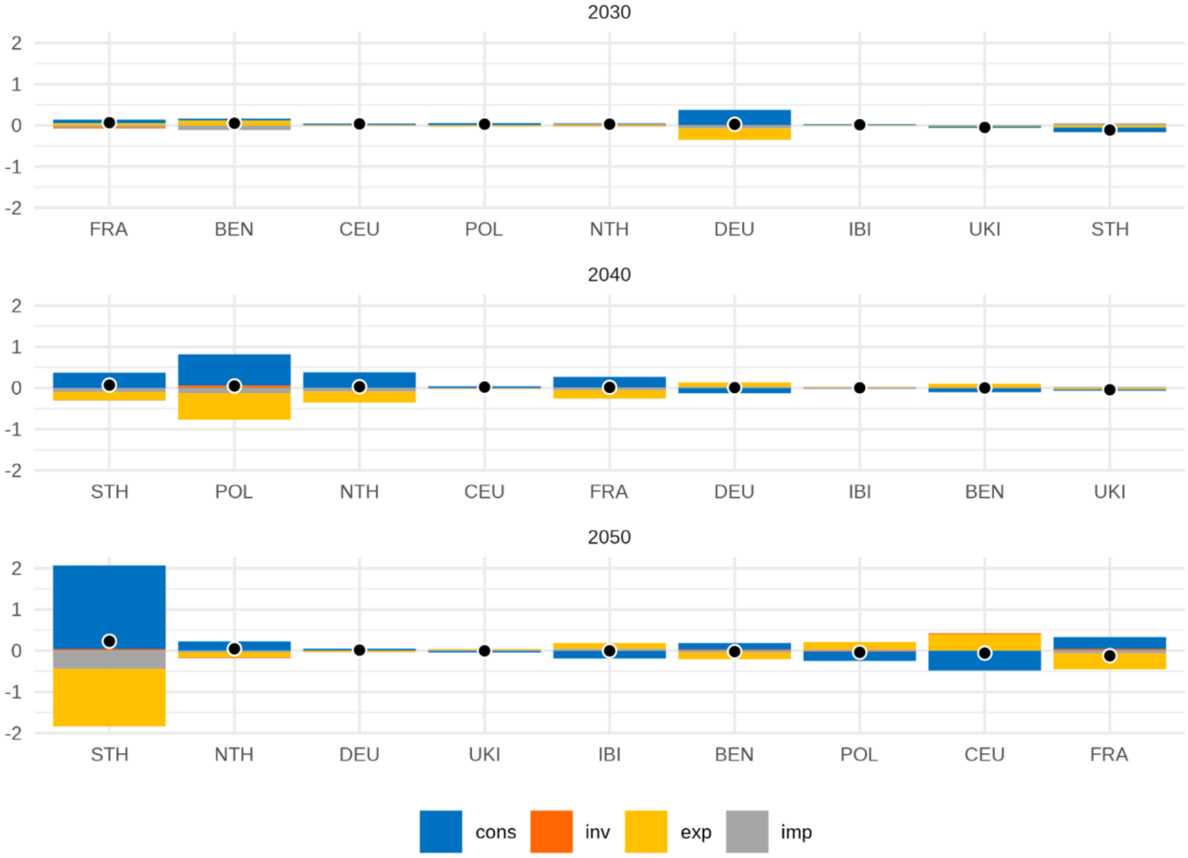
Figure 18. Step 1: Contributions to consumption change (in billion EUR'2015)



Source: CAKE/KOBiZE

120. The coefficient (1.05) implies that an increase in emission limit (by an increase we mean going from more to less ambitious limit) in value terms (evaluated at the carbon price from the reference scenario, here – Fit55) by EUR 1, leads to an increase in consumption of EUR 1.05. The excess over 1, i.e., 0.05, can be attributed to a variety of "general equilibrium" effects (second round effects), such as a decrease in carbon price upon raising the emission cap, an increase in exports followed by a reduction in emission cost, etc. In this case, these secondary effects are small, although note that the coefficient (1.05) is an approximate average across countries and years, so that actual effects may vary in specific regions or years.

Figure 19. Step 1: Decomposition of percentage changes in GDP



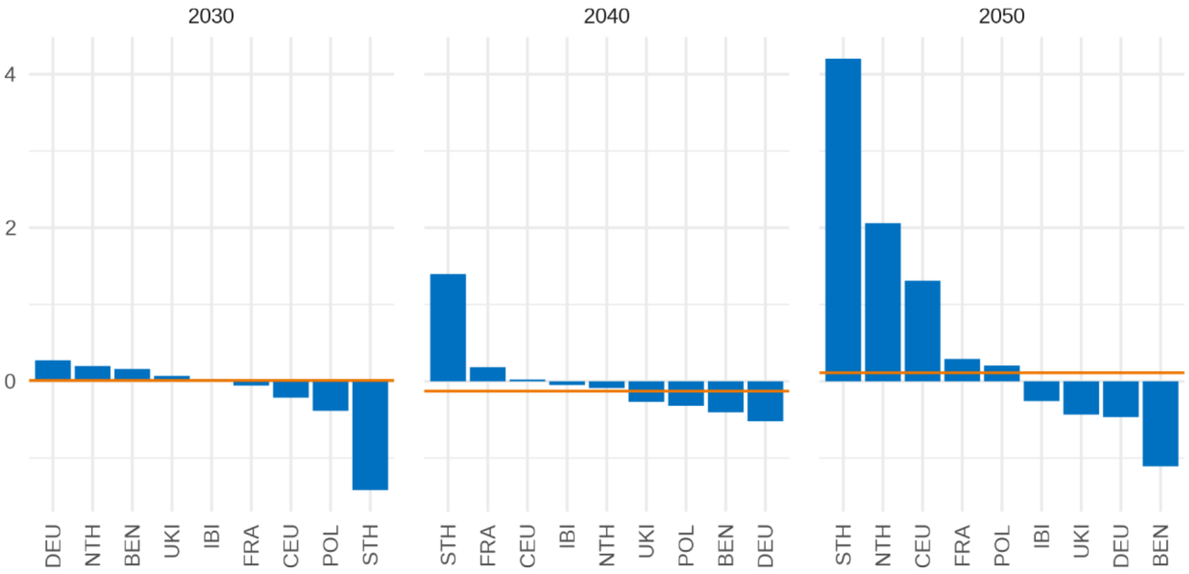
Source: CAKE/KOBiZE

121. From the demand-side GDP decomposition (Figure 19) we can conclude that changes in GDP (represented by the dots) are negligible, but they are often accompanied by relatively sizable changes in GDP structure (the bars show contributions of changes in demand-side GDP components to the GDP change). A common pattern is that a consumption increase is compensated by an export decrease (and vice versa). For example, in Southern Europe in 2050, increase in consumption is equivalent to around 2% of the GDP, whereas decrease in exports equals roughly 1.5% of the GDP, and increase in imports equals roughly 0.5% of the GDP. These contributions all add up to approximately zero, so that the GDP change is near zero.

7.3.3 Step 2 – linking BRT ETS and ETS systems

122. In this step, we move from ETS BRT nonETS to the Joint ETS+BRT scenario. Similar to the previous step, consumption changes are very small at the EU level, but the distributional effects across regions are much more pronounced.

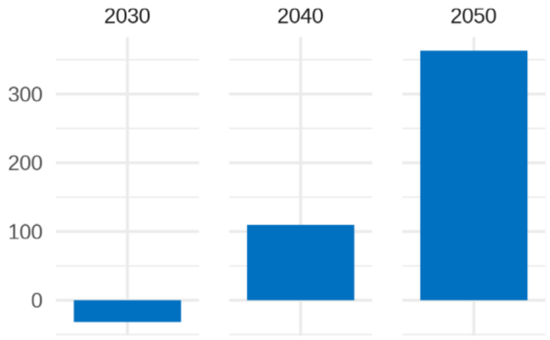
Figure 20. Step 2: Real consumption Joint ETS+BRT, deviations from ETS BRT nonETS [%]



Source: CAKE/KOBiZE

123. In this case, emission allowance allocations (EU ETS and BRT ETS), and emission limits ("narrow non-ETS", corresponding to segment D) do not change between the scenarios. However, linking between the BRT ETS and EU ETS leads to a substantial change in emission prices. From the perspective of EU ETS, carbon prices typically increase, as the system is expanded to include, i.a., transport, where emission abatement is more difficult and costly (Figure 21).

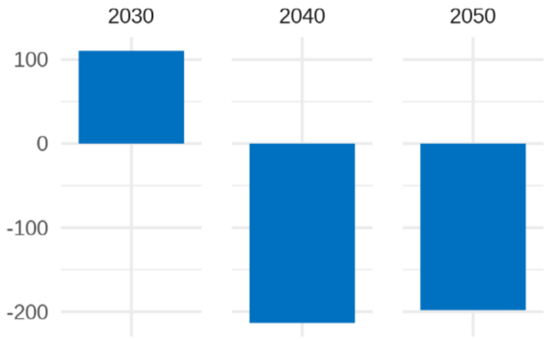
Figure 21. Step 2: Carbon price increase in EU ETS after merging with BRT ETS [EUR'2015/t CO_2 eq.]



Source: CAKE/KOBiZE

124. On the other hand, the buildings and transport sectors experience a decrease in emission prices in most years (except 2030 and 2035), as a result of merging with EU ETS (Figure 22).

Figure 22. Step 2: Buildings and transport sector experience price change after merging EU ETS and BRT ETS [EUR'2015/t CO_2 eq.]



Source: CAKE/KOBiZE

125. These changes in prices might lead to the following results:

- Income effect from revaluation of the balance of allowances. The balance of allowances of a region, in a given year, under a given cap and trade system is defined as:

$$Balance = Allocation - Emissions$$

  A positive balance means that a given region sells allowances to other regions (in net terms), while a negative balance means that a givengiven region buys allowances from other regions (in net terms). If, for example, the price of emissions falls, countries with a surplus of allowances will experience a fall in revenue from their sales abroad, i.e. a negative revenue effect (and vice versa).

- **Efficiency**. Merging of emission trading systems with different carbon prices should, in principle, lower the total cost of emission reduction, and thus lead to increased economic efficiency and higher output. This is because a unit increase in emissions in the system with a higher marginal abatement cost can be immediately offset by a unit reduction in emissions in the system with a lower marginal abatement cost, thus saving the difference between these marginal abatement costs for other uses in the economy.

- **Foreign trade**. Exports, as modelled in the CGE framework, are typically very sensitive to changes in production costs (export prices). Furthermore, we assume that the balance of payments (BoP) in each region is fixed, so that it does not change between scenarios. As our model does not include capital or financial flows, the BoP is equivalent to the current account, i.e., it consists of the difference between the value of exports and imports of goods and services, as well as the difference between the value of emission allowances sold to other regions and those bought from other regions. Consequently, an increase in the balance of emission allowances of a region will lead to a compensating effect on the trade balance – exports would decrease, and imports would increase. The latter effect is facilitated by an increase in relative prices of exports and imports, that is the terms of trade improvement. The opposite will be the case in regions which experience a decrease in the value of emission allowances balance.

126. We find that trade (terms of trade) effects dominate the results. There is hardly any efficiency gain seen in the results at the EU level – total consumption changes only negligibly (up or down). It is not to say that these gain do not exist but that they are overwhelmed by other effects. Linking EU ETS and BRT ETS , while creating an efficiency gain, also effectively increases the cost of EU ETS activities relative to the BRT ETS activities(this is the case in 2040 and 2050; in 2030 the effect is the opposite). Since EU ETS covers mostly energy and manufacturing industries, while BRT ETS covers mainly service or household activities, it tends to increase prices of domestically produced tradable goods (manufacturing goods) relative to non-tradable goods (a large part of services). This initially tends to worsen the trade balance (lower exports, higher imports), leading to a real depreciation and consumption decrease. In such a case we have two opposite effects in efficiency gain, counteracted by a deterioration of international competitiveness. Which of the two prevails is a question of the detailed composition of exports, the sensitivity of foreign demand to price changes, etc. It should also be remembered that on top of those two effects we have the "income effect" from the revaluation of the emission allowances balance which largely explains the variation of consumption outcomes across regions, as the following equation shows:

$$\Delta Consumption_{r,t} = 1.85 \cdot \Delta AllowancesBalanceValue_{r,t}$$

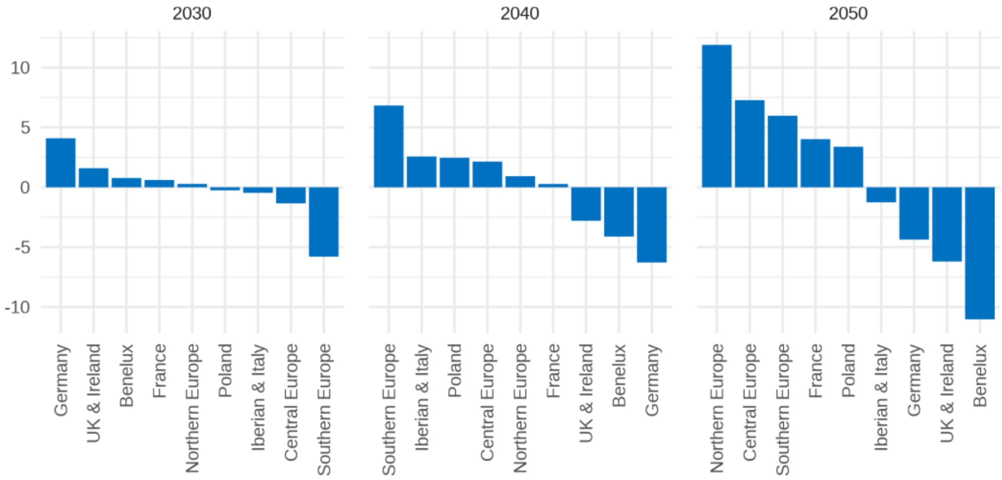
where:

$$\begin{aligned} &\Delta AllowancesBalanceValue_{r,t} = \\ &= \overline{AllowancesBalance_{r,t}}(A) \cdot \left(CarbonPrice_t(ABC) - \overline{CarbonPrice_t}(A)\right) + \\ &+ \overline{AllowancesBalance_{r,t}}(BC) \cdot \left(CarbonPrice_t(ABC) - \overline{CarbonPrice_t}(BC)\right) \end{aligned}$$

127. This equation explains 76% of the variability of consumption changes, across regions and years. It implies that in a region with an allowances surplus, an increase in the value of this surplus (caused by emission price increase) by EUR 1, induces a consumption increase by EUR 1.85. Whereas in a region with allowances shortage, an increase in allowance prices, leading to the increase in the value of the deficit by EUR 1, causes consumption to decrease by EUR 1.85. The "multiplier effect" (change in consumption

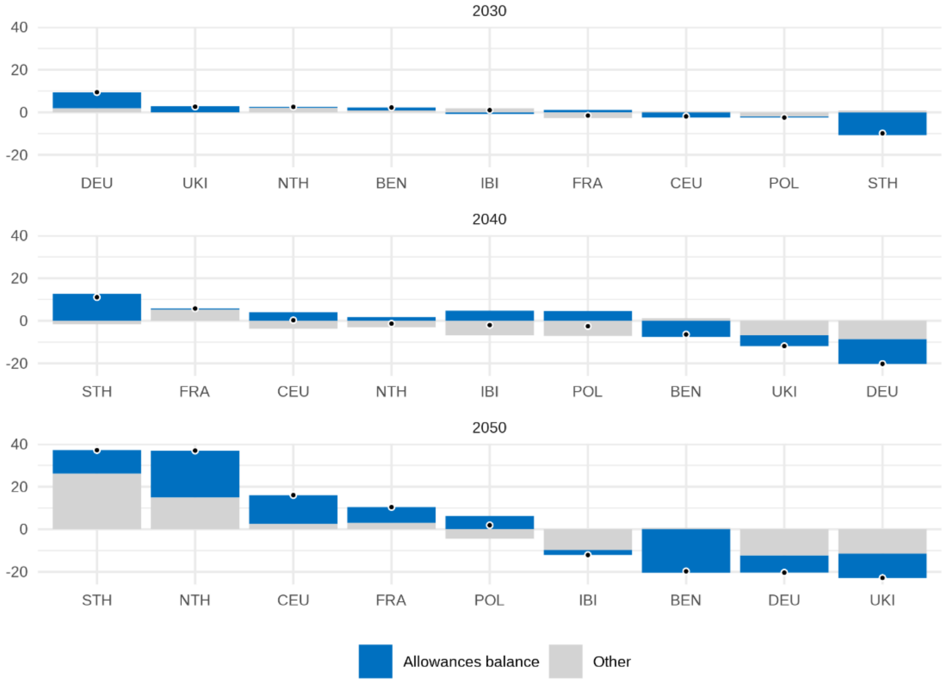
being 1.85 times higher than the initial income effect) is attributed to second-round effects, here mostly related to changes in the terms of trade. As can be seen in (Figure 24), consumption increases are typically accompanied by export decreases, and vice versa, so that changes in GDP are substantially smaller than changes in consumption.

Figure 23. Step 2: Balance of allowances in (total for EU ETS and BRT) before systems merge [Mt CO_2 eq.]



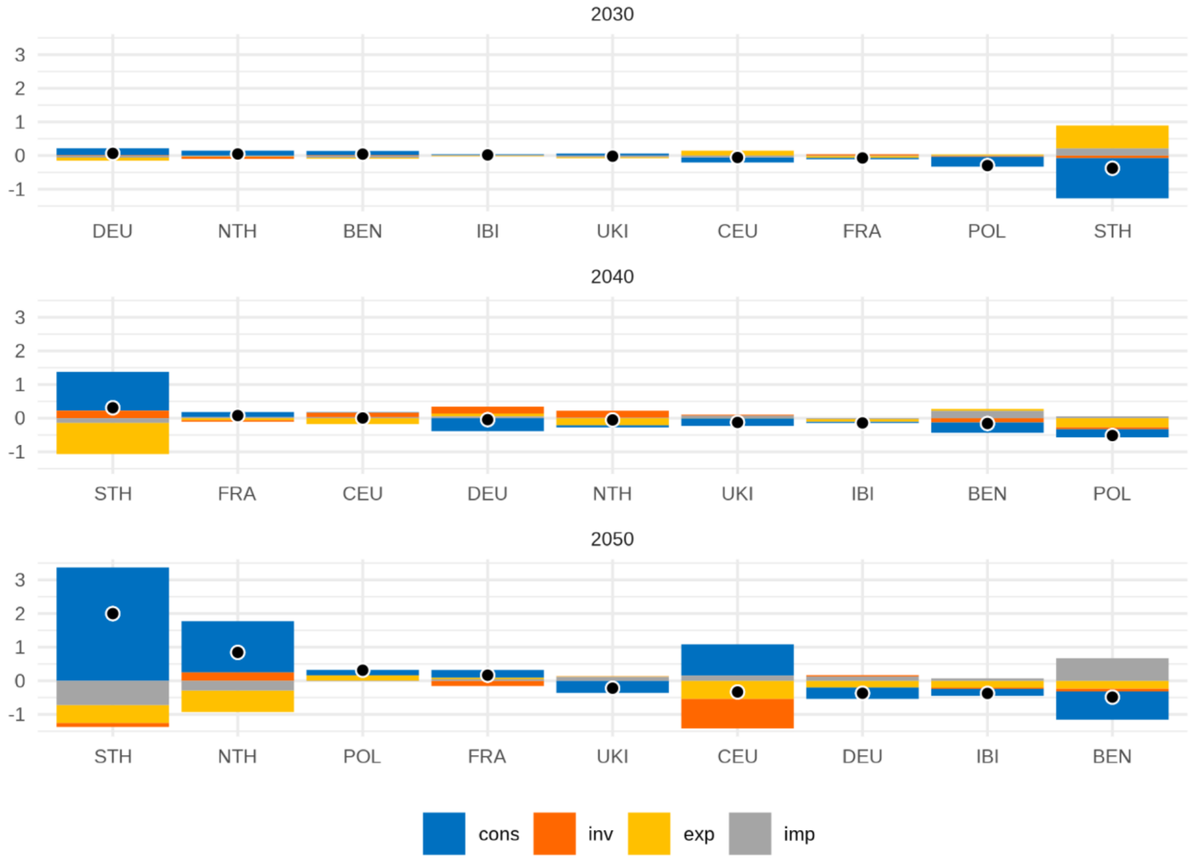
Source: *CAKE/KOBiZE*

Figure 24. Step 2: Contributions to consumption change [in billions of EUR'2015]



Source: *CAKE/KOBiZE*

Figure 25. Step 2: Decomposition of percentage changes in GDP



Source: CAKE/KOBiZE

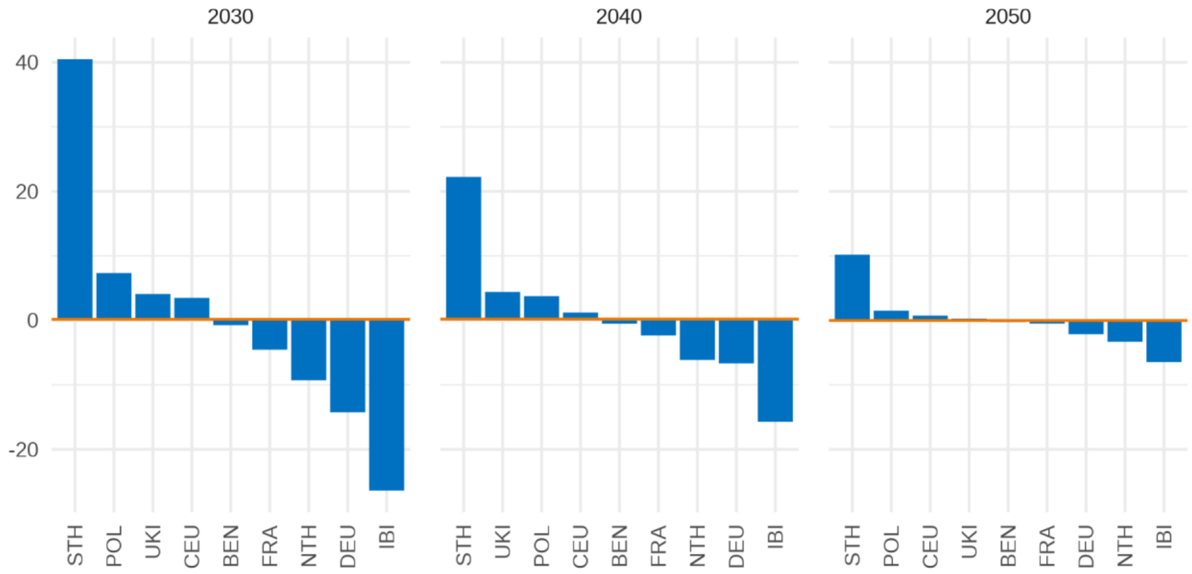
7.3.4 Step 2a – linking RT and ETS systems

128. This scenario is similar to Step 2, in that it assumes an extension of the EU ETS, but in this case only to road transport, with emissions from buildings being assigned to non-ETS. There are two additional aspects to this scenario:

- Moving buildings'emissions to non-ETS implies switching from emission pricing to command-and-control type policies – a point discussed in more detail in the next section.
- Moving buildings to non-ETS is accompanied by a change in the overall allocation of emissions to individual regions – in the form of allowances (EU ETS) and in the form of actual limits (non-ETS).

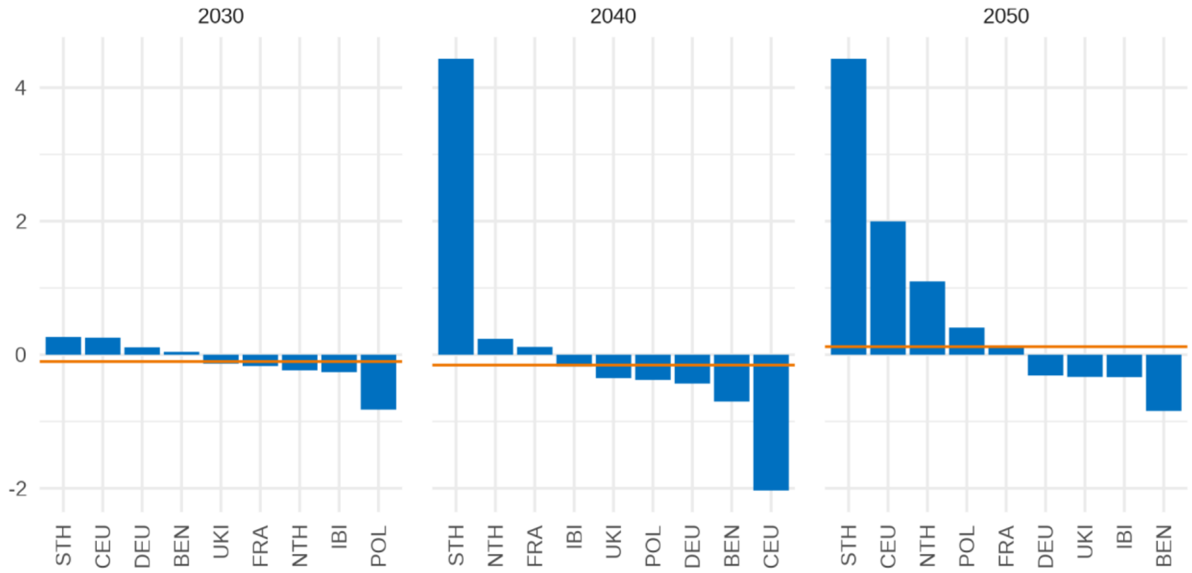
The latter point is illustrated in the following Figure 26.

Figure 26. Step 2a: Changes in total emission allocation by region [Mt CO_2 eq.]



Source: CAKE/KOBiZE

Figure 27. Step 2a: Change in real consumption [%]



Source: CAKE/KOBiZE

129. Even though, the impact on consumption is more difficult to track in this scenario, the revaluation of emission allowances balance and the change in total allocation/limit explain a substantial part (61%) of results variability between regions and years:

$$\Delta Consumption_{r,t} = 1.20 \cdot \Delta AllowancesBalanceValue_{r,t} + 1.02 \cdot \Delta TotalAllocationValue_{r,t}$$

where:

$$\begin{aligned}&\Delta AllowancesBalanceValue_{r,t} = \\ &= \overline{AllowancesBalance_{r,t}}(A) \cdot \left(CarbonPrice_t(AC) - \overline{CarbonPrice_t}(A)\right) + \\ &+ \overline{AllowancesBalance_{r,t}}(BC) \cdot \left(CarbonPrice_t(AC) - \overline{CarbonPrice_t}(BC)\right)\end{aligned}$$

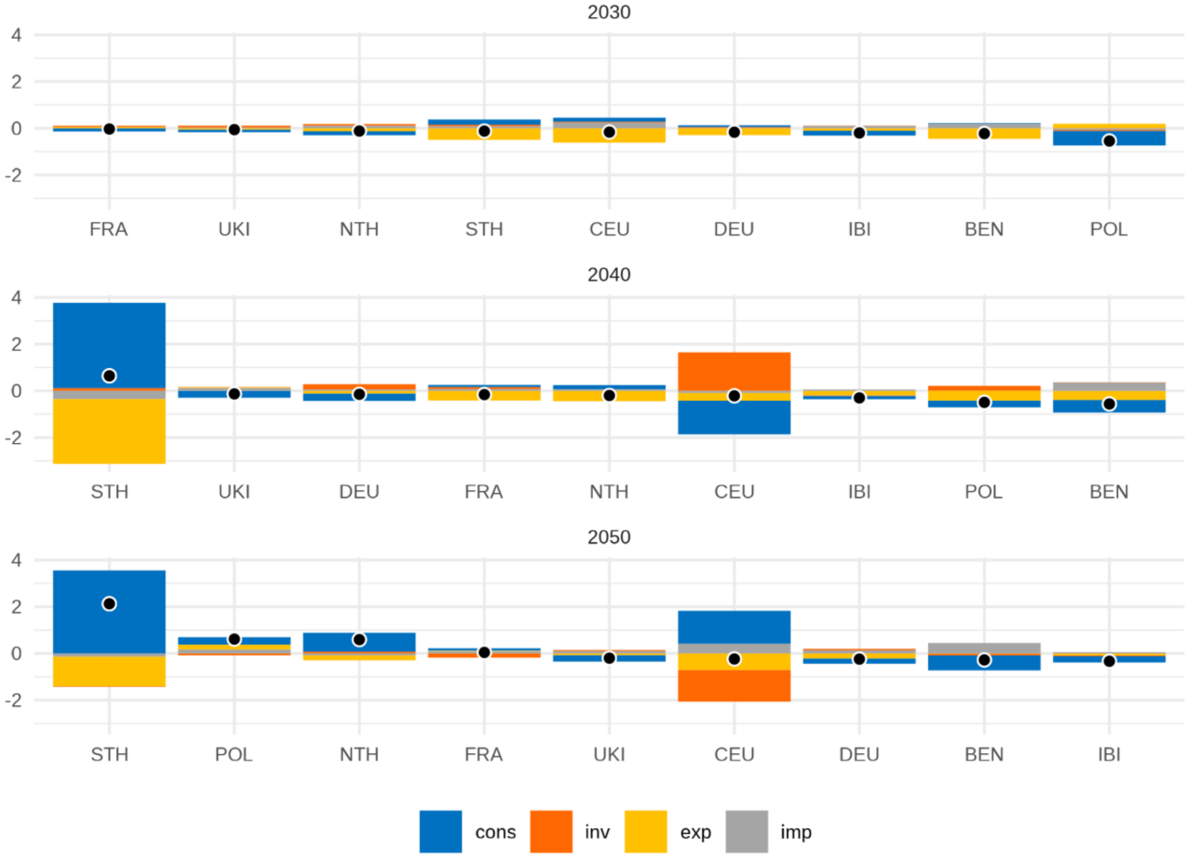
and:

$$\begin{aligned}&\Delta TotalAllocationValue_{r,t} = \\ &= \left(Alloc_{r,t}(AC) + Limit_{r,t}(BD) - \overline{Alloc_{r,t}}(A) - \overline{Alloc_{r,t}}(BC) - \overline{Limit_{r,t}}(D)\right) \\ &\qquad \cdot \overline{CarbonPrice_{r,t}}(D)\end{aligned}$$

Figure 28. Step 2a: Contributions to consumption change [in billions of EUR'2015]

Source: CAKE/KOBiZE

Figure 29. Step 2a: Decomposition of percentage changes in GDP



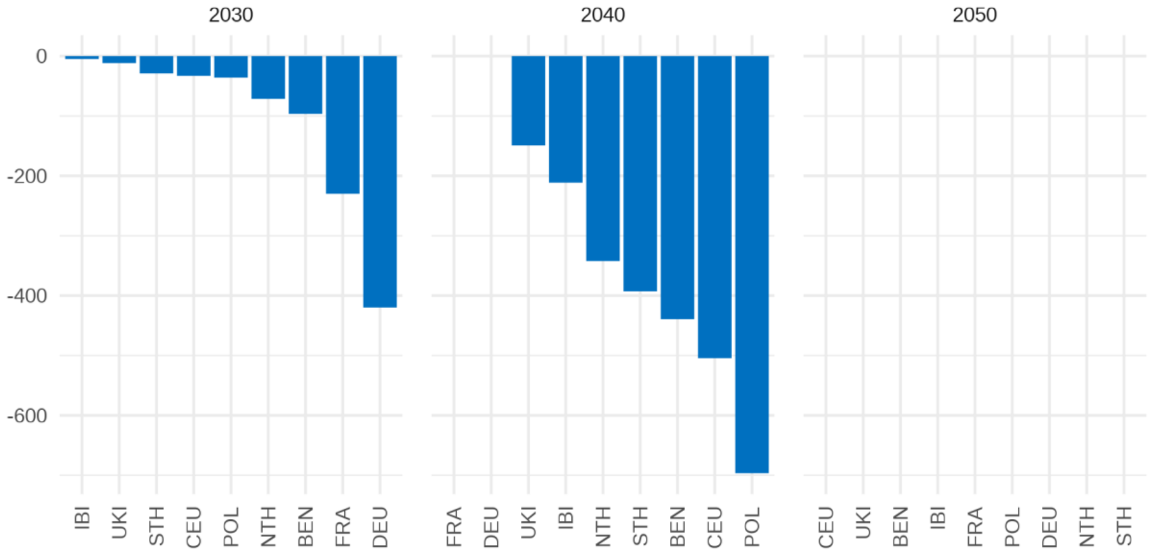
Source: *CAKE/KOBiZE*

7.3.5 Step 3 – from standards to carbon prices in "narrow non-ETS"

130. Both, command-and-control emission reduction policies and explicit carbon pricing can, in principle (in theory) yield the same marginal abatement cost. Yet, even with the same marginal abatement cost, the effects of these policies differ in an important aspect. Consider a production activity under carbon pricing. Given a carbon price of, say, EUR 100/t CO_2 eq., the producer faces incentives to take actions to reduce the emission intensity of production which cost up to EUR 100 per abated tonne of emissions. The same actions could, in principle, be invoked by command-and-control policies, e.g., by enforcing specific emission intensity standards for the production processes. In both cases, the marginal abatement cost is the same. However, in the case of a carbon tax, the remaining emissions are still subject to tax, so production cost is higher than in the case of command-and-control policies (here we abstract from administrative costs of these policies, as well as costs related to sub-optimal allocation of, e.g., emission standards to various sectors, due to imperfect information on the decision-makers side).

131. The higher production costs in the case of a carbon price, compared to command-and-control policies ensuring the same choice of production technique (and, consequently, the same marginal abatement cost), also implies that emission reductions are more strongly supported by demand-side adjustments. For example, some consumers might be willing to switch to less carbon-intensive goods or services with even a small price incentive. With command-and-control policies imposed on producers only, such opportunities will not be fully exploited, as consumer will not face the full carbon cost in the price o the consumed product or service. As a consequence, the total cost of a given emission reduction will also be higher. On the other hand, high prices of emission-intensive goods under carbon pricing may lead to adverse distributional as well as international competitiveness effects. In principle, the losses faced by specific (typically poorer) household groups or worker groups can be addressed by redistribution of carbon tax revenues, but redistribution itself can also be costly and policy-makers can also have limited information on the actual distribution of losses.

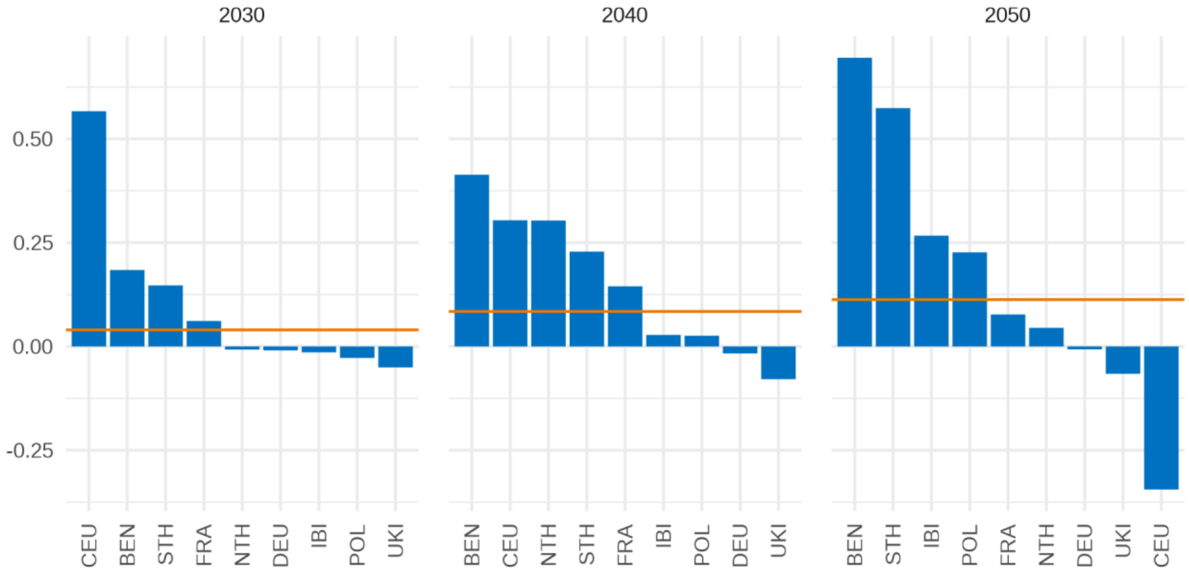
Figure 30. Step 3: Changes in non-ETS marginal abatement costs [EUR'2015/t CO_2eq.]



Source: CAKE/KOBiZE

132. Figure 30 shows that marginal abatement cost in the Joint ETS+BRT scenario drops significantly relative to the Joint ETS+BRTtax scenario – by as much as a few hundred EUR/t CO_2 eq. in some regions – in 2030 and 2040. In 2050 marginal abatement costs do not change as they hit the price cap of EUR 1000 in both scenarios. This does not mean that the scenarios are equivalent in 2050, as under a carbon tax the economies have to rely more on the backstop technology implemented in the model as a last resort abatement option, at a cost of EUR 1000/t CO_2 eq.

Figure 31. Step 3: Change in real consumption [%]

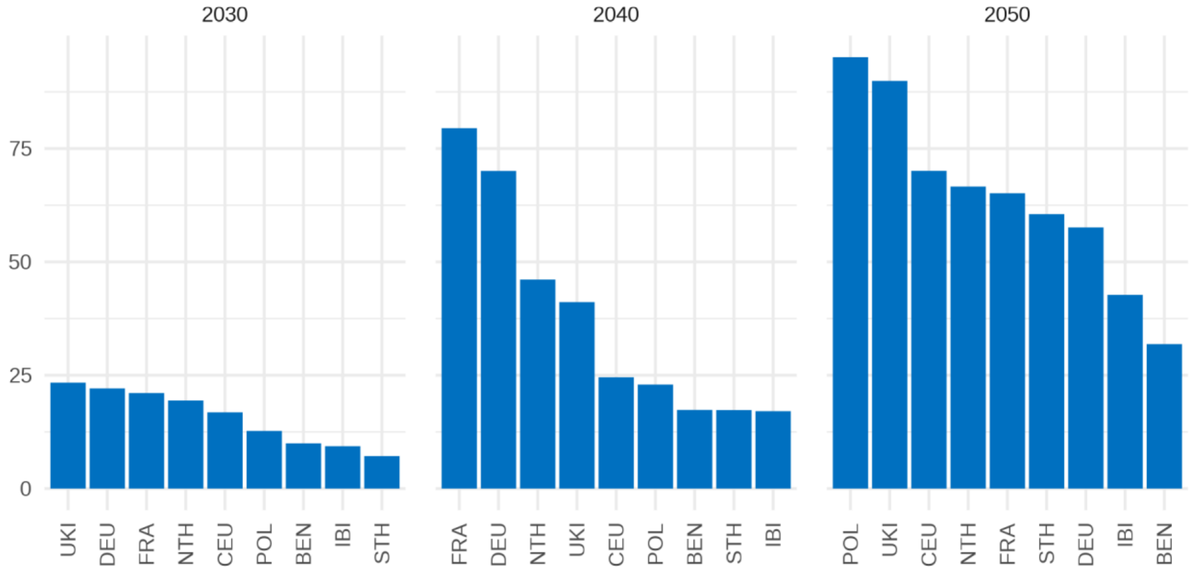


Source: CAKE/KOBiZE

133. Figure 31 shows that aggregate consumption increases slightly at the EU level, as well as in most regions individually, as a result of the shift from command-and-control policies to the carbon tax. The decrease in the consumption in Central Europe in 2050 is mainly due to the postponement of some investments in the energy sector from the earlier years to 2050.

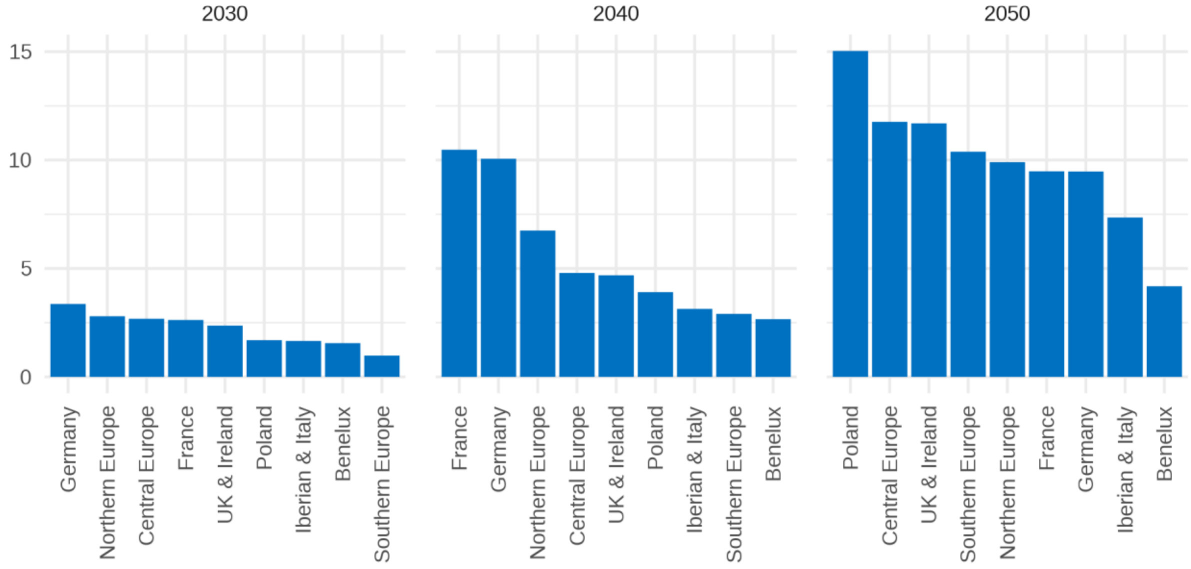
134. However, consumption gains come at a cost of much higher prices of agricultural and food products. This is a result of carbon pricing in agriculture – a sector characterized by a high share of unavoidable emissions. The price difference between the scenarios reaches up to 60-80% in 2050 for agricultural products in most regions. This difference further translates to the prices of food products.

Figure 32. Step 3: Changes in prices of domestic agricultural products relative to a basket of consumption goods [%]



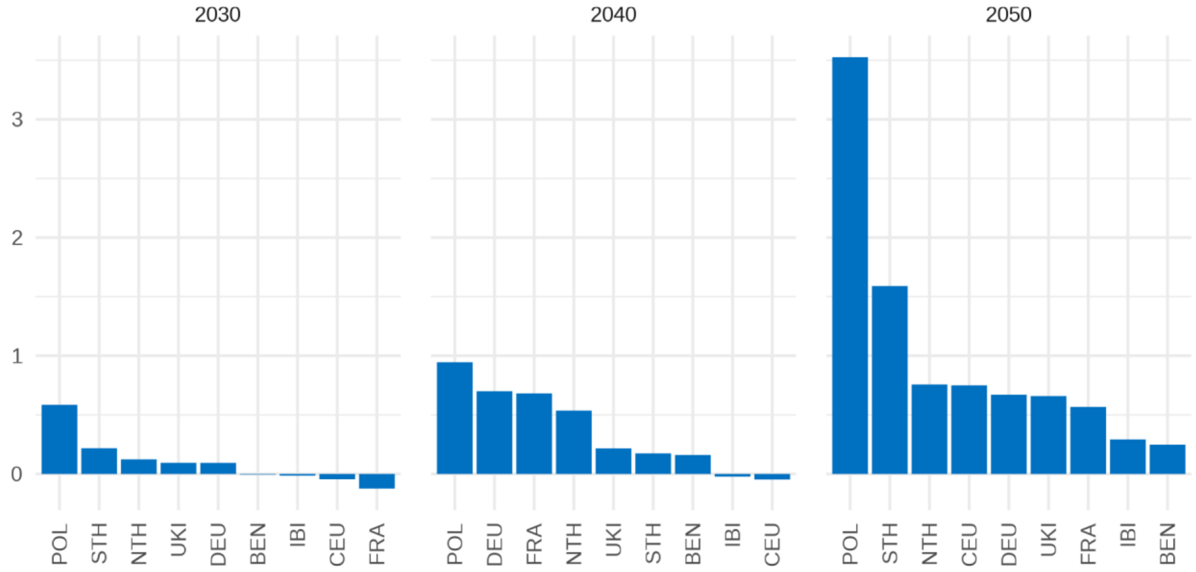
Source: CAKE/KOBiZE

Figure 33. Step 3: Changes in prices of domestic food products relative to a basket of consumption goods [%]



Source: CAKE/KOBiZE

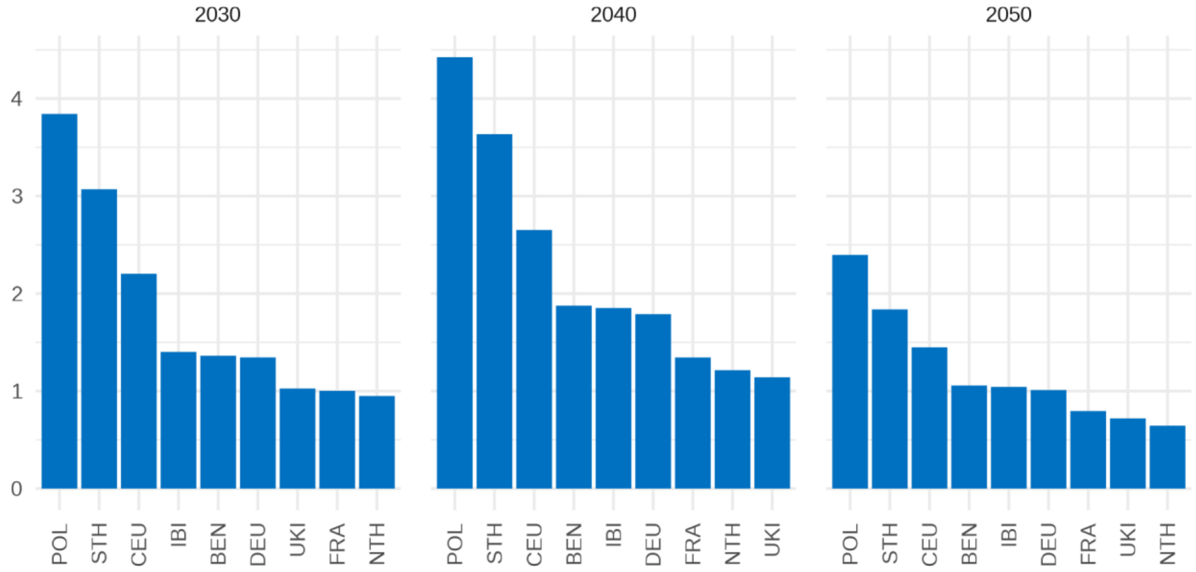
Figure 34. Step 3: Changes in prices of (household) consumption goods relative to world prices [%]



Source: CAKE/KOBiZE

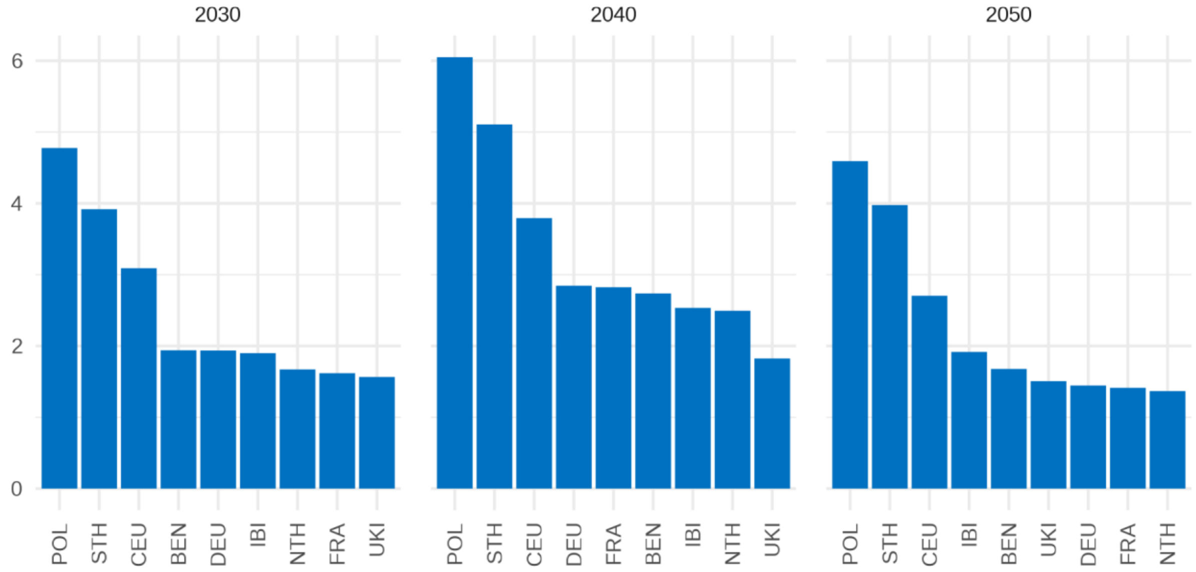
135. How to reconcile the seemingly paradoxical result – increases in real consumption accompanied by an increase in the cost of consumption, in particular sharp increases in agriculture and food prices? The answer lies in the increased government transfers. The shift from command-and-control policies to carbon prices boosts government revenues, some of which are then transferred back to households. This is the assumption of our models, but in the real world, it would require an active redistribution policy. Figures 35 and 36 show the share of government revenues from carbon pricing in the GDP before and after the switch to carbon pricing in the non-ETS.

Figure 35. Step 3: Share of government revenues from carbon pricing in the GDP [%] – Joint ETS+BRT scenario



Source: CAKE/KOBiZE

Figure 36. Step 3: Share of government revenues from carbon pricing in the GDP [%] – Joint ETS+BRTtax scenario



Source: CAKE/KOBiZE

136. A general conclusion is that carbon pricing, as opposed to command-and-control policies, might yield significant distributional effects when applied to consumer goods and services. This is because carbon prices tend to increase the prices of emission-intensive goods. In particular, high food prices would negatively affect lower-income households.

Therefore carbon pricing should be combined with an active and targeted redistribution policy (e.g., transfers). On the other hand, carbon pricing is associated with lower total economic costs, at least in the case considered in our simulations. Note also, that our simulations do not consider administrative costs related to either of the policies.

Figure 37. Step 3: Decomposition of percentage changes in GDP

Source: CAKE/KOBiZE

7.3.6 Step 4 – merging "narrow non-ETS" with EU ETS into one cap and trade system

137. In this final step of the analysis, we merge all carbon pricing systems into a single One ETS system. This is similar to step 2, where the the BRT ETS was merged with the EU ETS. Accordingly, we can identify three main channels of impact on the economy:

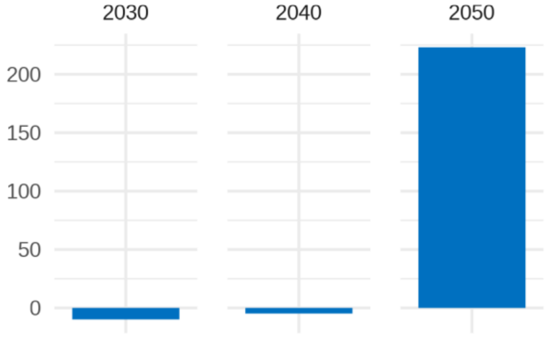
- Efficiency gains related to cheaper overall abatement under a single economy-wide carbon price.
- Income effects related to the change in the value of the allowance surplus or deficit, and the corresponding adjustment in the balance of trade in goods and services.

- Foreign trade adjustments related to a change in international competitiveness.

138. However, there is another important aspect that was not present in the other scenarios. Non-ETS was based on individual country targets, whereas moving non-ETS activities to an EU-wide cap and trade system allows for exploitation of inter-regional flexibility in the allocation of abatement efforts. Countries with cheaper abatement options will be able to trade their allowances, to countries with lower abatement potential.

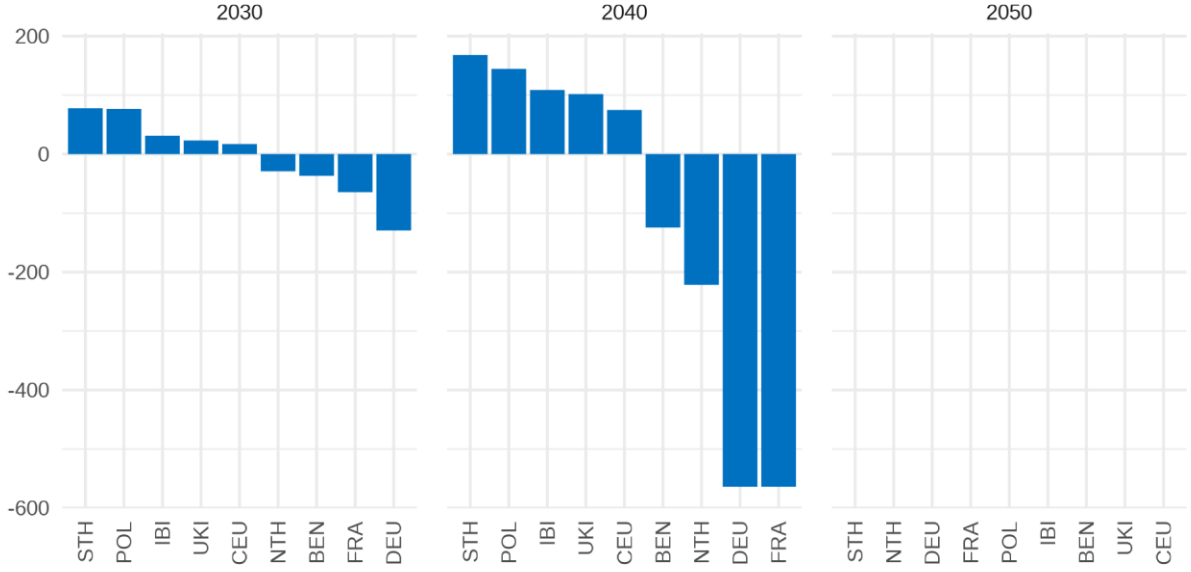
139. Merging the systems affects carbon prices in the EU ETS and in the former "narrow non-ETS" covered segment D (Figures 38, 39 and 40). In 2050, the price of emissions in the EU ETS increases by more than EUR 200/t CO_2 eq., whereas in earlier years changes are negligible. From the perspective of sectors originally covered by the "narrow non-ETS", prices do not change in 2050, as they were already at their maximum level (EUR 1000/t CO_2 eq.). In the years 2030 and 2040, prices change significantly in individual regions, although not much on average.

Figure 38. Step 4: Changes in carbon prices in the EU ETS [EUR'2015/t CO_2 eq.]



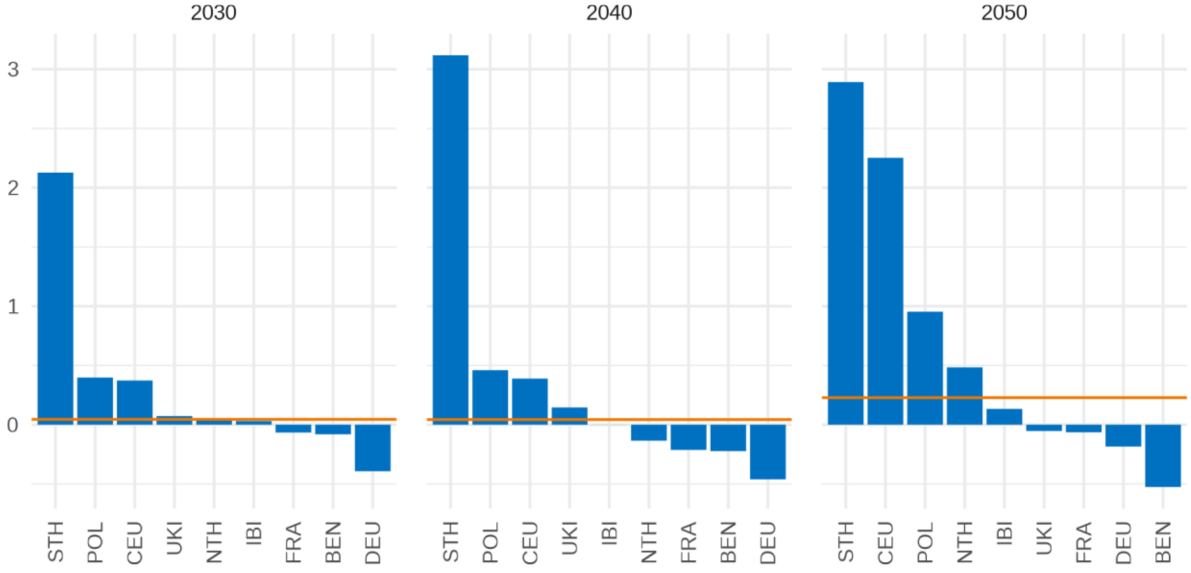
Source: CAKE/KOBiZE

Figure 39. Step 4: Changes in carbon prices in the "narrow non-ETS" [EUR'2015/t CO$_2$ eq.]



Source: CAKE/KOBiZE

Figure 40. Step 4: Changes in real consumption [%]

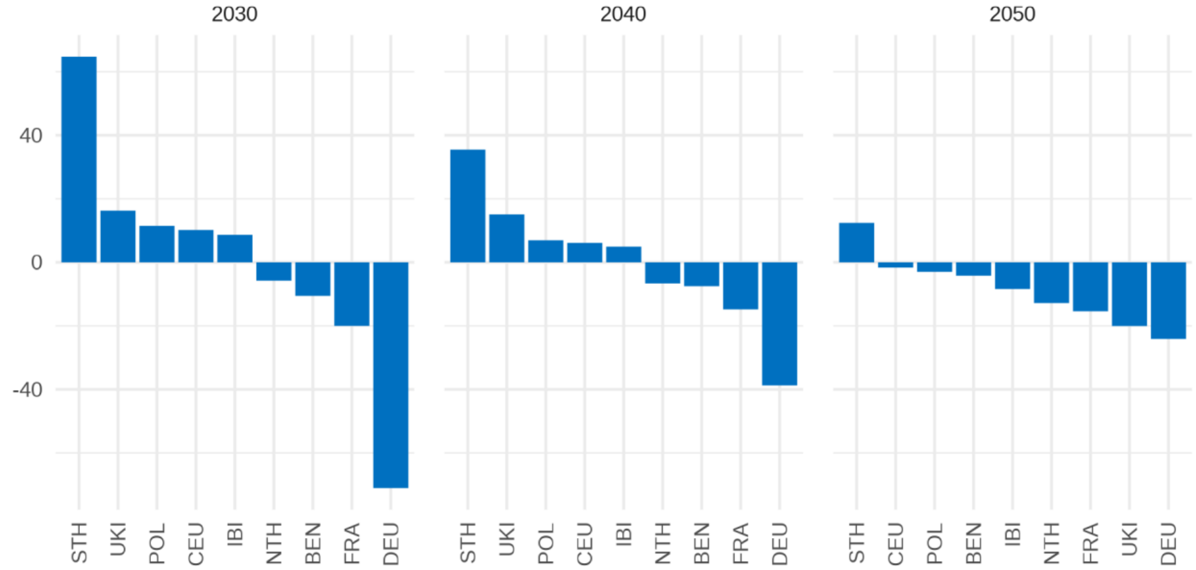


Source: CAKE/KOBiZE

140. Efficiency gains from linking the systems are barely visible in the results, except perhaps in 2050 where there is a small increase in consumption at the EU level (around 0.25%). However, as in the previous scenarios, the aggregate EU outcomes are much smaller than the effects for individual regions. In this case, relatively high consumption gains are observed in Southern Europe, Central Europe and Poland – that is, in regions that mostly cover the new EU Member States, while for the old Member States with more

developed economies, small consumption losses are observed. This variability is highly correlated with the changes in trading patterns in emission allowances. Figure 41 shows the net change in the sale of emission allowances to other regions, as a result of the systems' merger.

Figure 41. Changes in "exports" of emission allowances [Mt CO_2 eq.]



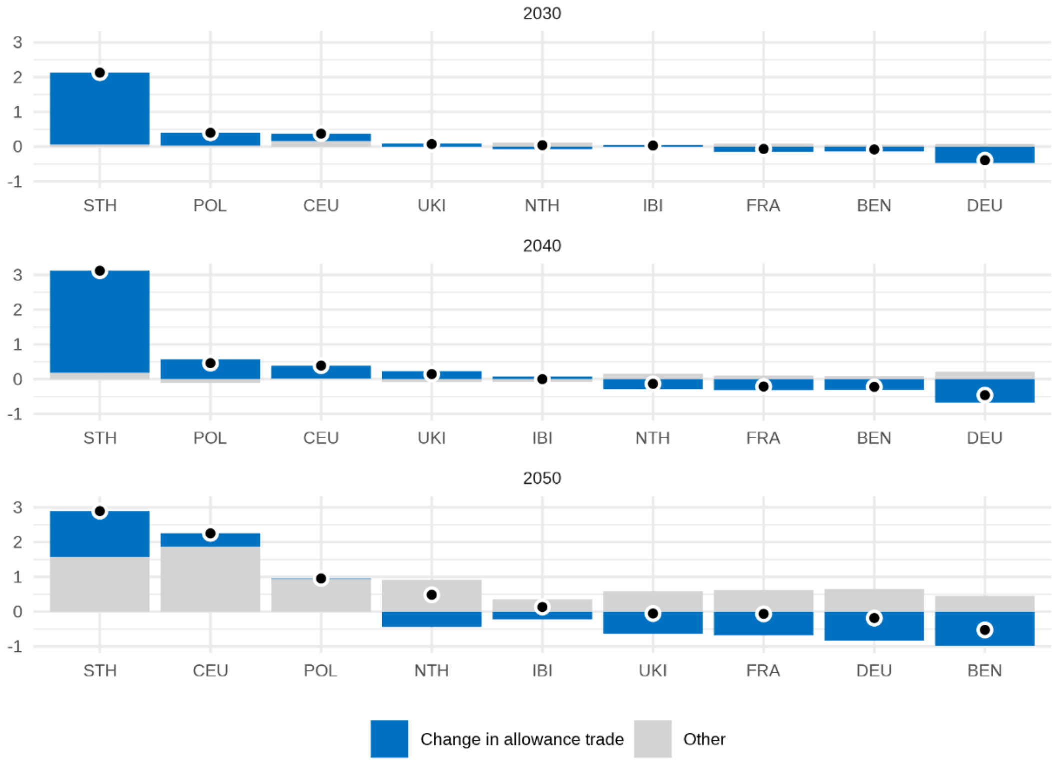
Source: CAKE/KOBiZE

141. The following formula explains 75% of the variability in percentage changes of consumption across regions and years:

$$\Delta\%Consumption_{r,t} = 1.15 \cdot \Delta AllowancesNetExportsValueShare_{r,t}$$

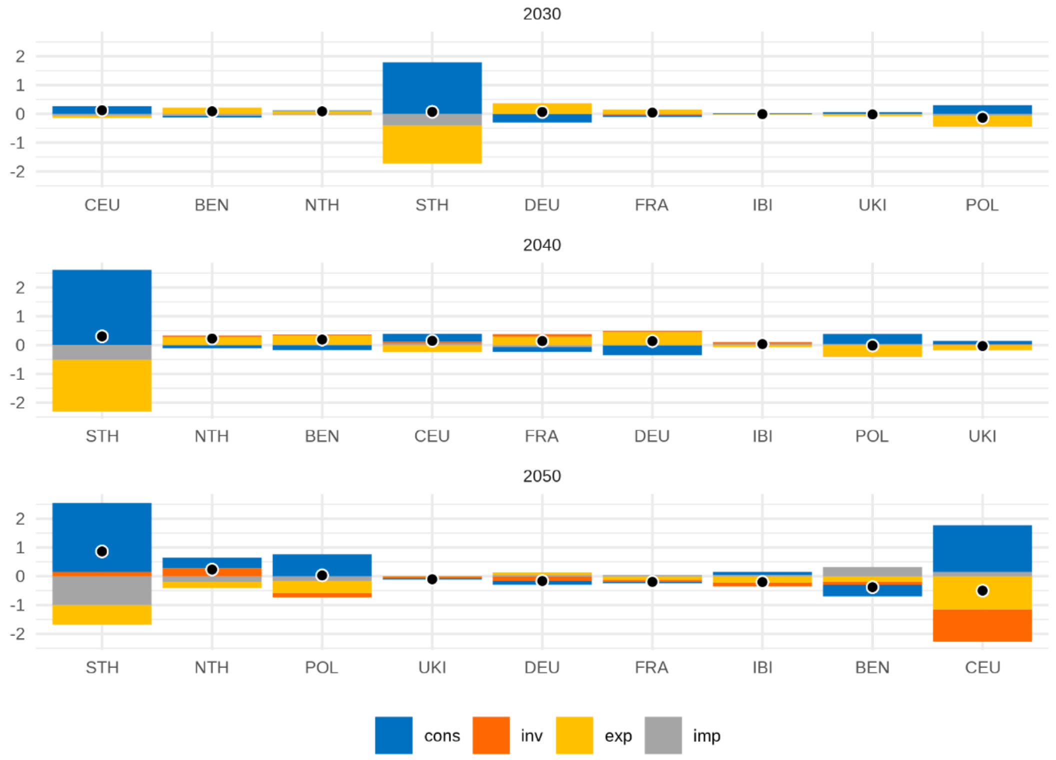
Where $AllowancesNetExportsValueShare$ is the percentage share of value (volume times a respective carbon price) of net exports of emission allowances in total consumption.
That is, consumption increases are observed in countries utilizing their relatively low-cost abatement potential. In addition, some incidental moves in consumption can be attributed to postponing energy sector investment (the case of Central Europe in 2040 and 2050), as well as additional revenue to BECCS installations (the case of Southern Europe in 2050).

Figure 42. Step 4: Contributions to percentage change in consumption [pp.]



Source: CAKE/KOBiZE

Figure 43. Step 4: Decomposition of percentage changes in GDP



Source: CAKE/KOBiZE

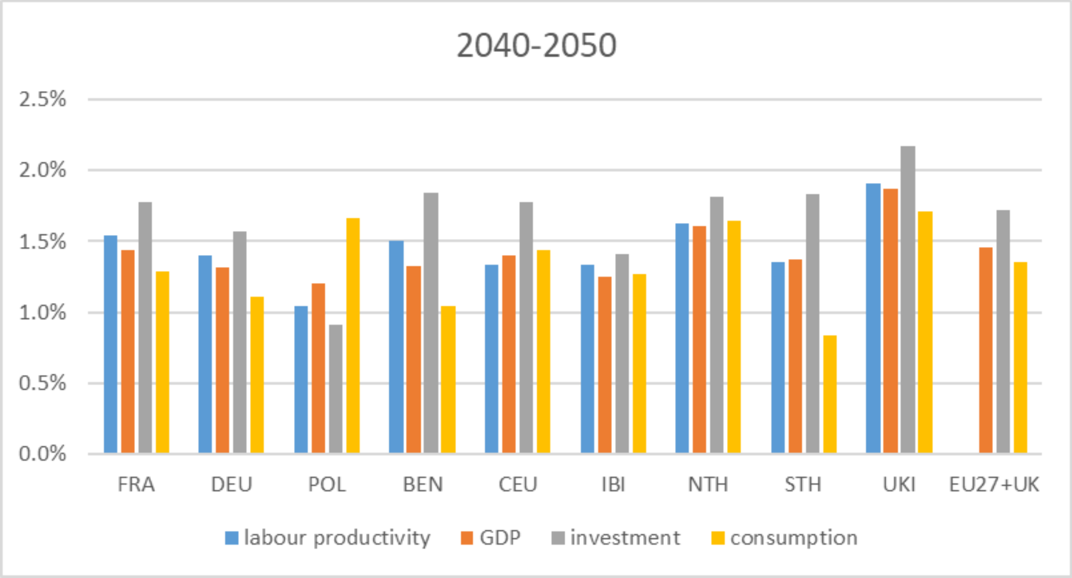
7.4 Macroeconomic results relative to Fit55 scenario

7.4.1 Impact on investments, GDP and consumption

7.4.1.1 Fit55 scenario

142. In the Fit55 scenario, GDP of EU27+UK economy grows at the rate of 1.7% per annum within the 2020-2030 period. The average annual growth rate in the 2030s is expected at 1.4% and at 1.5% during the 2040s, while it will differ significantly between the analysed regions (Figure 44). In the case of Poland, for instance, the average annual growth rate in the first analysed period (2020-2030) will be at 2.7%, slowing down to 2.2% in the second period (2030-2040) and to 1.2% in the third period (2040-2050).

Figure 44. Average annual growth rate of labour productivity, GDP, investment, and consumption in the Fit55 scenario



Source: CAKE/KOBiZE

143. The depicted growth rate is driven primarily by a continuous improvement in labour productivity. In theory, the growth could also be influenced by technological improvements in the energy and transport sector, autonomous energy efficiency improvement and targets limiting emissions. However, Figure 44 indicates that the net impact of these other factors is small and the final GDP growth rate is close to the productivity growth, with the differences between them below 0.3 p.p. in every region in the 2020s and below 0.2 p.p. in the 2030s and 2040s in every region except Poland. This result confirms the findings of IPCC (2022), showing that the impact of decarbonisation trends on macroeconomic variables is negligible. In Poland in the first analysed period the GDP growth lags behind productivity growth by approx. 0.2 p.p. annually. Interestingly, this effect is reversed in the 2030-2050 period: GDP in Poland should witness 0.4 p.p. and 0.2 p.p. faster growth of GDP compared to productivity growth in the periods of 2030-2040 and 2040-2050, respectively, suggesting that the distortionary impacts of climate policies will become weaker while the benefits of faster low-carbon technological progress will become stronger in this region.

144. Growth of investment is driven by the growth of GDP, although its growth rate is slightly higher than GDP growth in almost all regions. At EU27+UK level, the average annual investment growth is to reach 2.3% within 2020-2030, 1.5% in 2030-2040, and 1.7% in 2040-2050. In Poland, the growth rates during these three periods are expected to be at 3.2%, 2.2% and 0.9%, respectively.

145. The reason why investment grows faster than GDP is the additional demand for capital in the energy sector and capital required for energy-efficiency improvement in other sectors (i.e., capital that substitutes energy in other sectors' production functions). Again, an interesting exception is the period 2040-2050 in Poland, where the growth of

investment is ca. 0.3 p.p. slower than the GDP growth. This can be explained by the fact that in the first two periods of the analysis (that is in years 2020-2040) Poland will have particularly high investment needs in the power sector, and therefore, lower investment will be required in the subsequent period.

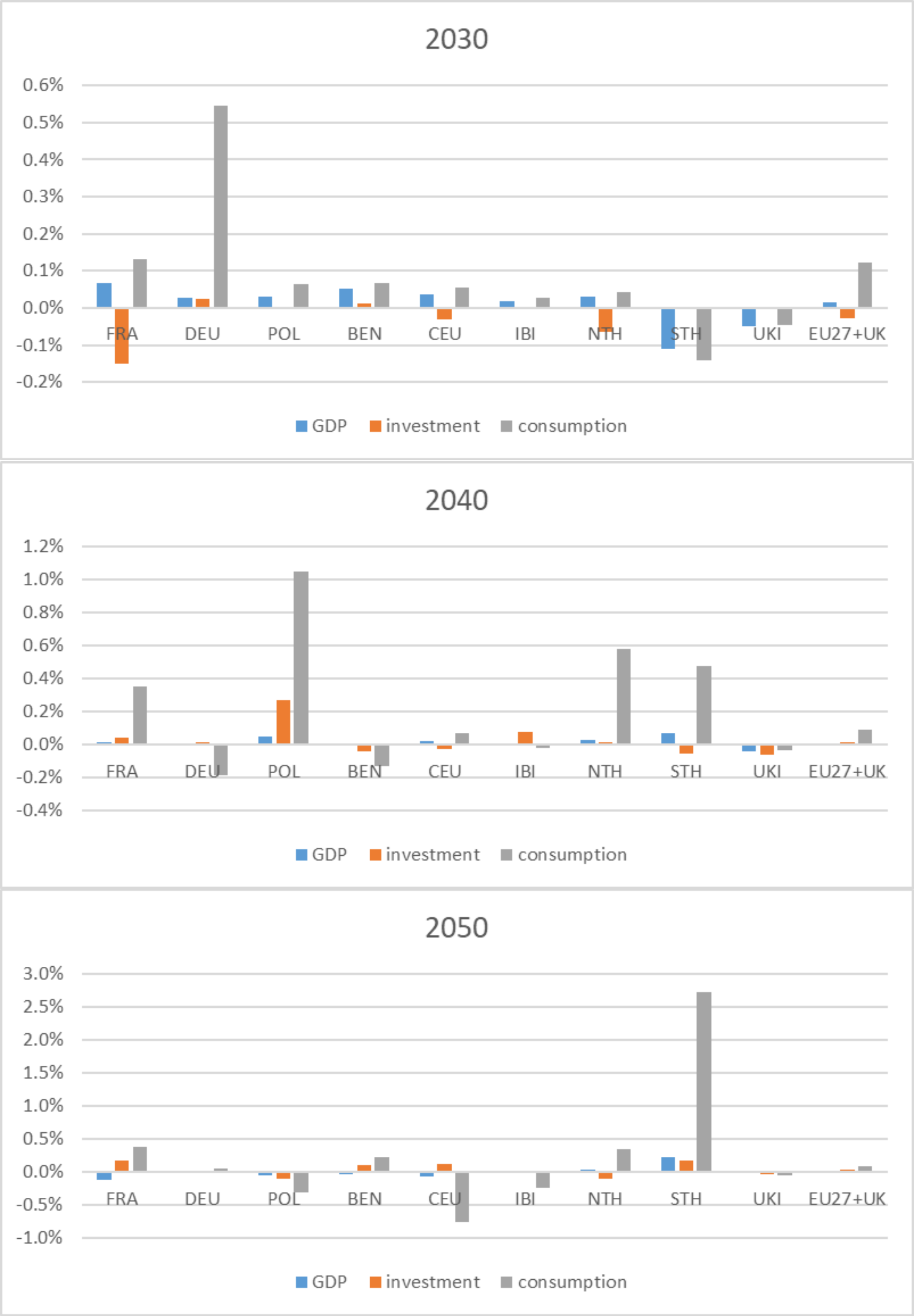
146. Growth of consumption is also mostly driven by the GDP increase, but its rate is slightly lower because of a growing share of GDP dedicated to investment. In the entire region of EU27+UK consumption grows at the rate of ca. 1.5% per annum within the entire analysis period. In Poland, consumption grows slower than GDP within 2020-2030 at 2.6% per annum. However, in contrast to the other EU regions, consumption will be the same or faster than the GDP growth rate in later periods, with an average annual growth of 2.2% in the period 2030-2040 and 1.7% during 2040-2050. Again, this latter result can be explained by the relatively low investment needs in the latter period of the analysis.

7.4.1.2 Comparison of scenarios

ETS BRT nonETS vs Fit55

147. According to simulations, the macroeconomic differences between the Fit55 scenario and the scenario with three separate systems (ETS BRT nonETS) are in general small. At the EU level, the differences in consumption, investment and GDP are negligible: ca. 0.1% in all periods analysed. Also at the regional level, GDP and investment growth rates are similar to the Fit55 scenario, as carbon prices driving companies' incentives are almost identical between the two scenarios. The only two exceptions are France in 2030, where lower prices in the non-ETS in this scenario lead to 0.2% lower investment, and Poland in 2040, where higher emission limits stimulates economic activity and leads to 0.3% higher investment. For the same reason, France and STH region witness 0.2% higher investment in 2050.

Figure 45. Comparison of macroeconomic variables between the ETS BRT nonETS and the Fit55 scenarios



Source: CAKE/KOBiZE

148. More substantial differences between the scenarios are revealed when looking at consumption at a regional level. Here the differences reflect the differences in allocations of non-ETS targets between the scenarios. In 2030 the main beneficiary of the separate

systems scenario is Germany which achieves 0.5% higher consumption than in the Fit55 scenario. On the other hand, the STH region loses 0.1%. In 2040, Poland is the country with the highest benefits: it achieves 1.1% higher consumption, compared to the Fit55 scenario. In addition, the NTH region gains 0.6% and the STH gains 0.5%. Germany loses 0.2% in this period. In 2050, the STH region is clearly, the main beneficiary, gainining 2.7% of consumption, while the CEU region loses 0.8%.

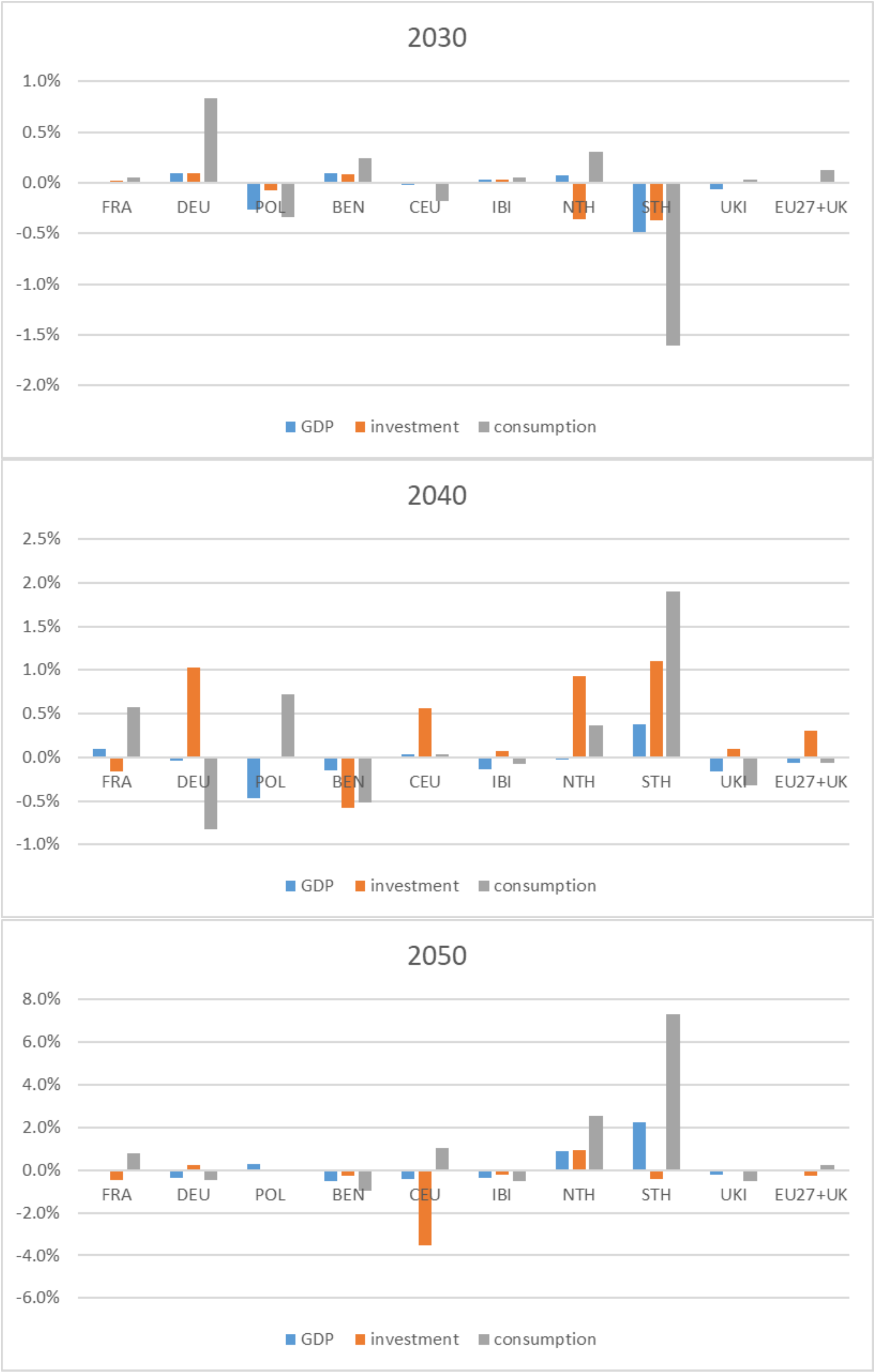
Joint ETS+BRT vs Fit55

149. Comparison between the Joint ETS+BRT and the Fit55 scenarios shares a lot of common features with the previous comparison between the ETS BRT nonETS and the Fit55. Both, ETS BRT nonETS and Joint ETS+BRT scenarios assume the same allocation in non-ETS sectors, so any effect resulting from the changes in the emission limits with respect to the assumptions made in the Fit55 and described before will be present in the current subsection as well.

150. However, the comparison between the Joint ETS+BRT and the Fit55 scenario must in addition take into account the impact of merging the current EU ETS with the BRT ETS. The change will result in higher efficiency of production, as in general, this development would allow shifting the emission allowances towards the sectors with high mitigation costs. However, the total effect on the economy differs across periods and regions. In the Fit55 scenario, the mitigation costs are higher in the BRT ETS compared to the EU ETS sectors in the 2040s and 2050s. Hence, merging the two systems in the Joint ETS+BRT scenario involves lower emission prices for the former sectors (BRT) and higher prices for the latter sectors (EU ETS). Countries that had a surplus of emission allowances in the EU ETS will benefit and those with a deficit will not. Similarly, countries with a surplus of BRT ETS emission allowances will lose and those with a deficit will benefit from merging the sectors. Finally, while interpreting the results it is useful to notice that higher prices in the EU ETS will increase the price of electricity which will stimulate additional investments dedicated to improving energy efficiency.

151. At the EU level, the results are very similar to those described in the previous section (Figure 46). Macroeconomic differences between the Fit55 and Joint ETS+BRT scenario are small in general. The only noticeable difference is that investment in 2040 is 0.3% higher than in the Fit55 scenario, which is induced by higher emission prices for the power sector, higher electricity prices and higher incentives to invest in energy efficiency. Consumption in 2050 is 0.2% higher than in the Fit55 scenario, which is due to higher efficiency of the merged system.

Figure 46. Comparison of macroeconomic variables between the Joint ETS+BRT and the Fit55 scenarios



Source: CAKE/KOBiZE

152. In 2030, the main beneficiary is Germany, as in the comparison of the previous subsection, with a consumption increase of 0.8%. On the other hand, the STH region experiences a 1.6% decrease in consumption. The reason for this is that the STH region has a relatively large deficit of allowances in the BRT system, which in the Joint ETS+BRT scenario in 2030 has a higher price compared to the Fit55 scenario. A drop in income in this situation also drags down the GDP and investment in this region, but both effects are lower than 0.5%. In Poland, the impacts are relatively small. Consumption and GDP are 0.3% lower and investment is almost unchanged.

153. In 2040, the picture changes substantially. The price of emissions in the merged system is lower than the price in BRT ETS in the Fit55 scenario, which means that regions featuring a deficit of BRT ETS allowances in the Fit55 scenario will benefit from moving to the Joint ETS+BRT scenario. This is clearly visible in the case of the STH region, which now experiences a 1.9% increase in consumption. The second biggest beneficiary is Poland, that features a deficit of allowances in the BRT ETS in 2040. On the other hand, Germany, having a surplus of BRT ETS allowances, will suffer a decrease in consumption by 0.8%. The same situation applies to BEN and UKI regions which experience 0.5% and 0.3% loss in consumption, respectively. Another important observation is that in all regions investment in 2040 either does not change or increases relative to Fit55. This can be explained by an increase in the EU ETS price, which drives up electricity prices and stimulates investments in energy efficiency. An exception is the BEN region, where investment is dragged down by its higher price. GDP is not affected substantially. We observe a 0.4% increase in GDP in the STH region and a 0.5% decrease in Poland. This last result could be explained by a drop in the export of energy-intensive products due to an increase in the price of emissions in the EU ETS sectors.

154. In 2050, the picture is quite similar. The main beneficiary of the scenario remains the STH region, experiencing a 7.3% increase in consumption relative to the Fit55 scenario. Also, the NTH region experiences a 2.6% increase in consumption. In other regions, the deviation is relatively small. The difference in investment in that year is close to zero with an exception of the CEU region, where it is 3.5% lower in the Joint ETS+BRT scenario compared to the Fit55 scenario. In that region demand for capital may be lower due to faster accumulation in the previous periods.

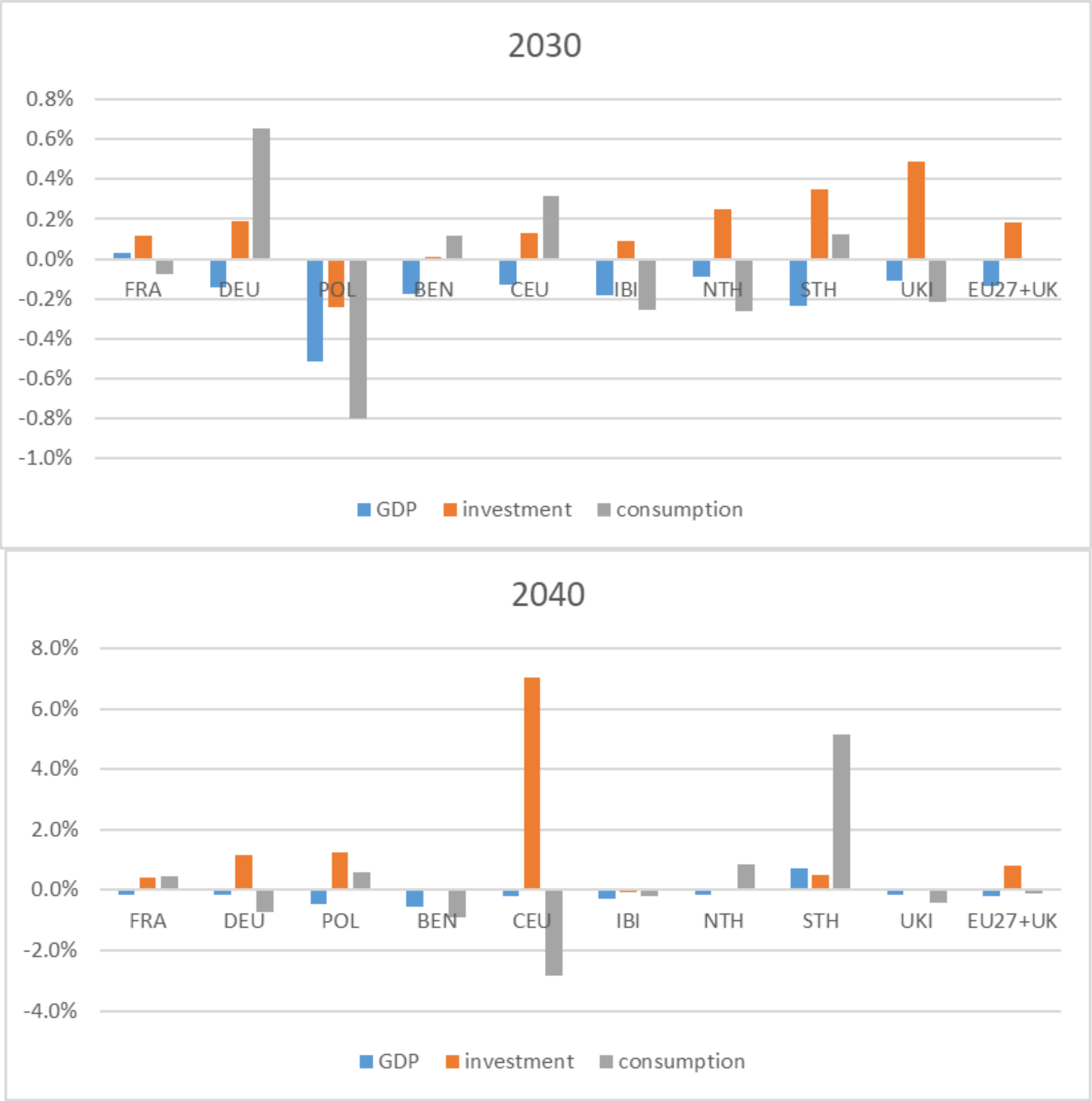
Joint ETS+RT vs Fit55

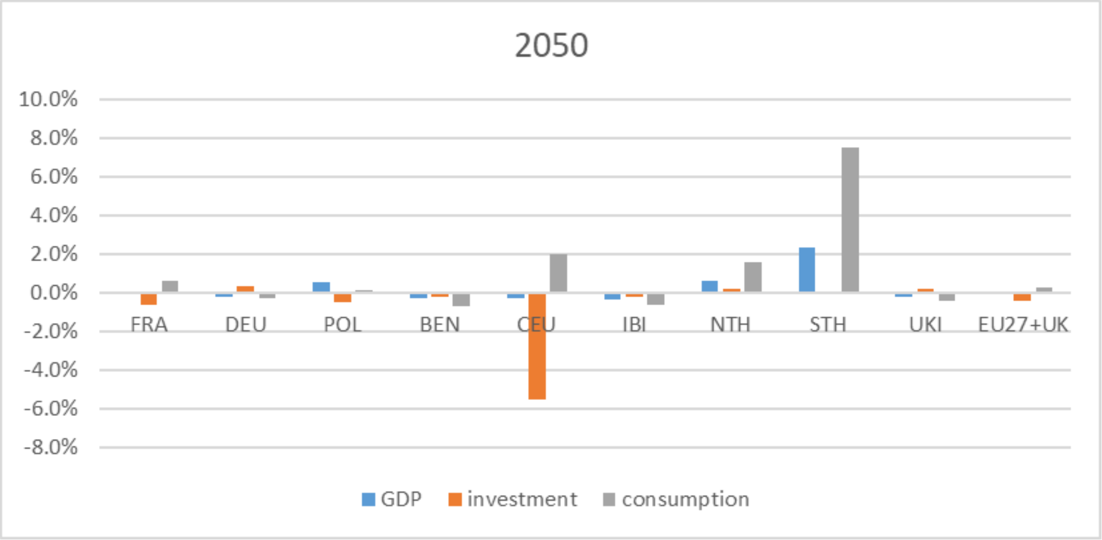
155. Next the Joint ETS+RT scenario is compared, where the EU ETS covers emissions from road transport (but not emissions from buildings) with the Fit55 scenario. In this scenario, the price in EU ETS is significantly higher than in the Fit55 starting from 2030. In 2040, the price is even higher than in the Joint ETS+BRT scenario. As a result, some of the effects described in the previous section are amplified. Most importantly, investment at the EU level in 2030 increases by 0.2% compared to the Fit55, and in 2040 it increases by 0.8%.

However, the differences in consumption and GDP are negligible. In 2050, all macroeconomic results are close to the values of the Fit55 scenario.

156. In Poland in the Joint ETS+RT scenario, the consumption, GDP and investment is experiencing a rather substantial drop, compared to the Fit55 in 2030, which is due to the high price in the EU ETS in that year. Consumption decreases by 0.8%, investment by 0.2% and GDP by 0.5%. In 2040, consumption increases by 0.6% and investment by 1.2%, while the GDP decreases by 0.4%. In 2050, consumption increases only by 0.2% and GDP by 0.6%, while investment decreases by 0.5%.

Figure 47. Comparison of macroeconomic variables between the Joint ETS+RT and the Fit55 scenarios





Source: CAKE/KOBiZE

Joint ETS+BRTtax vs Fit55

157. In the comparison of the Joint ETS+BRTtax scenario with the Fit55, the pattern of results is very similar to the one presented in the previous subsections. At the EU level, there are minor differences in macroeconomic variables in 2030 and 2040. In 2050, investment is lower by 0.5% compared to the Fit55. This is partly due to the relatively high price of emissions in the ETS system, which increases the price of commodities used in investment projects, and partly due to lower demand for capital in sectors in non-ETS, which produce less (as they now need to pay tax for emissions). A drop in investment allows an increase in consumption by 0.4%.

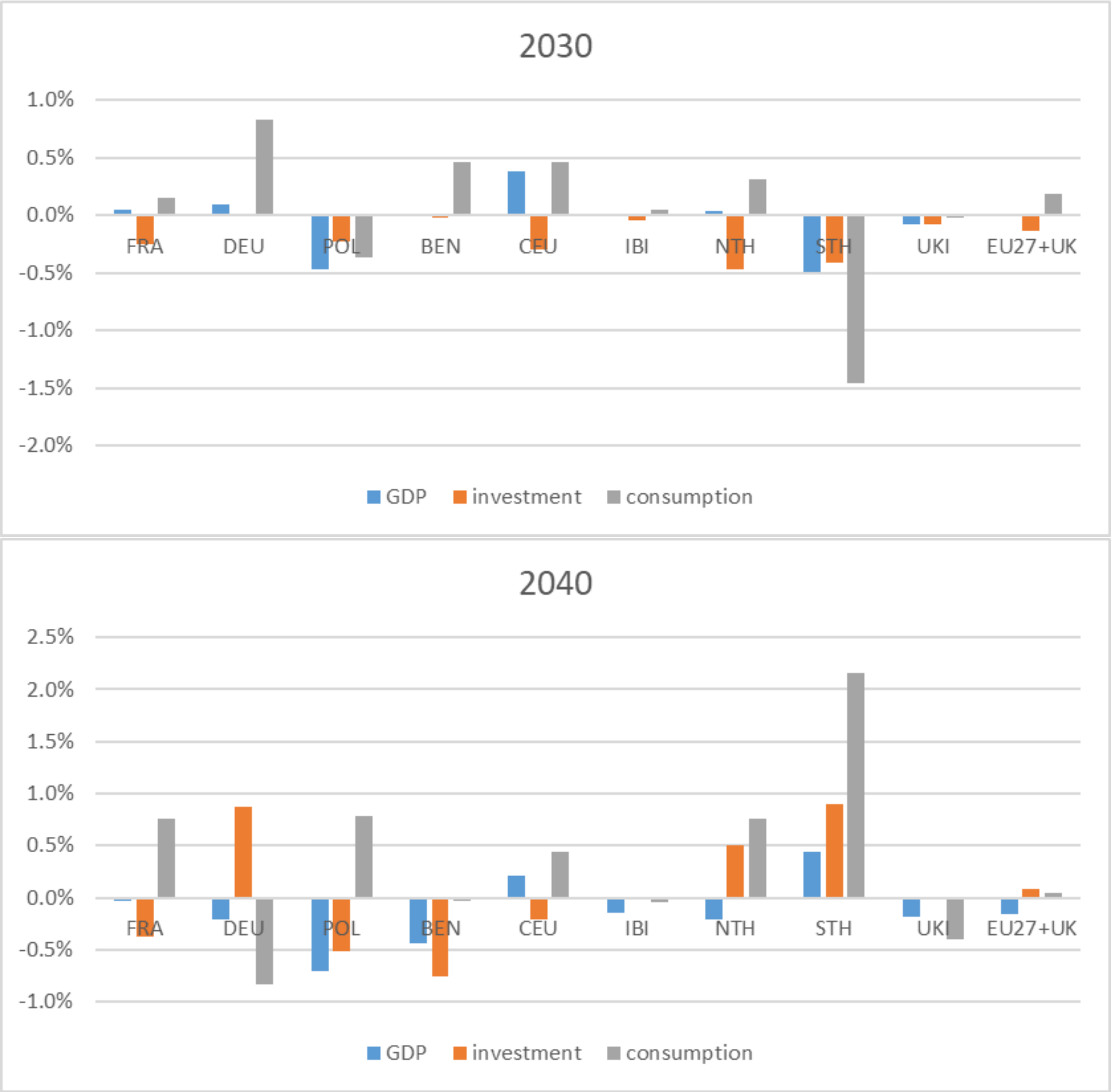
158. At the regional level, the most positive outcome in 2030 is that of Germany with a 0.8% increase in consumption, while the least favourable changes happen in the STH region with a 1.5% drop in consumption. Effects driving these differences are exactly the same as in the previous subsection – countries that have a deficit of allowances in BRT ETS sectors must purchase them at a higher price in the Joint ETS+BRTtax scenario, compared to the Fit55 scenario in 2030. In 2040, when the price of emission in BRT ETS sectors is lower under the Joint ETS+BRTtax scenario, the opposite is true: countries with deficit benefit. That year the STH region consumption increases by 2.2% and Germany's consumption decreases by 0.8%. In 2050, the benefits of the STH region reach a 8.0% gain in consumption.

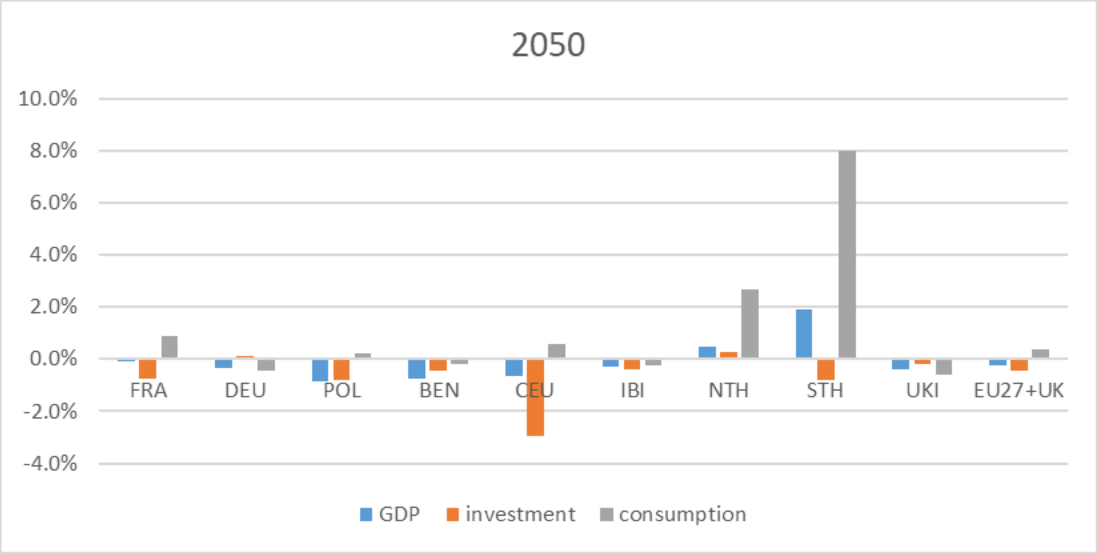
159. An interesting feature of results for the Joint ETS+BRTtax, which distinguishes this scenario from the Joint ETS+BRT examined in the previous section, is the lower economic activity in Poland. In 2030, the GDP in Poland is 0.5% lower than in the Fit55 scenario. In 2040, this loss is already equal to 0.7%, and in 2050 it reaches 0.9%. The reason is that in the Joint ETS+BRTtax scenario, the revenue from the non-ETS sectors is not returned to these sectors but instead goes to households. As a result, the price of output in the non-

ETS sectors increases and export of these sectors drops. In Poland, this effect is particularly sharp, because one of the key non-ETS sectors – agriculture – is responsible for a larger share of Polish exports (directly and indirectly, in the form of processed food).

160. The impact on consumption is different than the impact on GDP due to trade effects. For instance, in Poland, an increase in the price of agricultural goods reduces exports and increases imports of this commodity, so that the changes in consumption in the 2040s and 2050s take the opposite direction to the changes in GDP.

Figure 48. Comparison of macroeconomic variables between the Joint ETS+BRTtax and the Fit55 scenarios





Source: CAKE/KOBiZE

One ETS vs Fit55

161. In the One ETS scenario, when all sectors are covered by one economy-wide ETS system, macroeconomic results are close to the results for the scenario of Joint ETS+BRTtax with tax in non-ETS, described above. At the EU level, there are no significant differences with respect to the Fit55 scenario in 2030 and 2040. In 2050, simulations show a 1% lower investment, which is due to the high price of investment commodities, caused by the high price of emissions in the EU ETS. In fact, in 2050 this scenario has the highest emission allowance price in the EU ETS among all scenarios considered in this analysis. Among other variables, the GDP is lower in 2050 by 0.4%. One reason for this is a lower accumulation of capital (due to the higher price of investment). The second reason is linked to changes in the structure of trade: high price in the EU ETS in this scenario increases the costs of industrial goods, which results in a reduction of their exports. As a result, production factors are shifted from exporting sectors to other sectors, where these factors are less productive. Altogether, however, consumption for households increases in 2050 by 0.7% due to lower exports and lower investment.

162. At a regional level, the results are more diverse. Some regions could significantly benefit from the trade of emission allowances, which in other scenarios were reserved for the EU ETS and BRT ETS sectors. In 2030, the main beneficiaries (in terms of consumption gains) are the CEU and STH regions. In the Fit55 scenarios, the price of emissions in non-ETS in these regions was significantly lower than the analogous price in two large economies: Germany and France. When the trade of emission allowances in non-ETS is permitted[32], the CEU and STH regions can sell their allowances and devote additional

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[32] We assume that there is no trade of annual emission allocations in non-ETS between Member States (although the Effort Sharing Regulation allows for such trade) and it becomes possible only after the inclusion of non-ETS in the EU ETS.

income to increase their consumption. Poland could also benefit from this trade, although here the gain is much smaller due to effects described in the previous subsection.

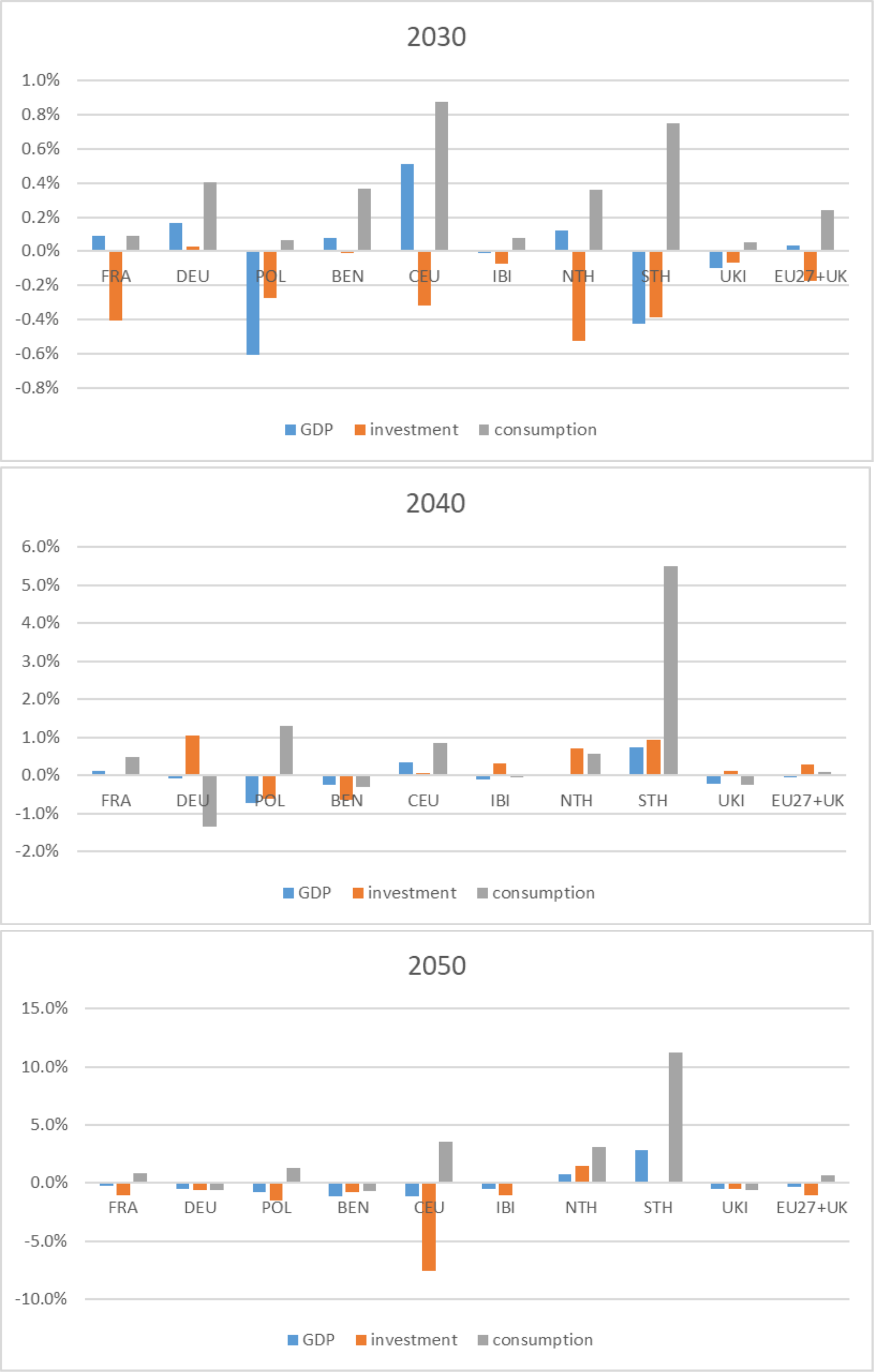
163. As described in the subsection above, GDP in Poland is low because in the One ETS scenario, in contrast to the Fit55 scenario, non-ETS sectors must pay tax on emissions, which increases the prices of output and decreases exports. This hurts the overall productivity and GDP. The same effect explains the low GDP levels in the STH region.

164. In 2040, the main beneficiary is the STH region, which witnesses an increase in consumption by 5.5% compared to the Fit55 scenario. The main costs are reported in Germany, where consumption is lower by 1.3%. The reasons for both, gain in STH and loss in Germany have been explained in the previous sections: the STH region must purchase allowances for BRT, which has a much lower price in the One ETS scenario, compared to the Fit55 scenario. For Germany, which sells allowances, the opposite is true. Other significant impacts on consumption are reported for Poland (an increase by 1.3%) and in the CEU region (an increase by 0.8%).

165. GDP differences in 2040 are relatively small. The only exception is Poland, where it decreases by 0.7% compared to the Fit55 scenario, due to lower exports. In the STH region, on the other hand, GDP increases by 0.7%. The pattern of investment is similar to the one described in the section on the Joint ETS+BRTtax scenario.

166. In 2050, the direction of economic changes is in general similar to those described above, yet now their strength is amplified. In the STH region, consumption grows by 11.3%. In the CEU and NTH regions and in Poland it grows by 3.5%, 3.1% and 1.3%, respectively. No region experiences a significant drop in consumption, confirming the prediction that a scenario with one ETS system allowing for free trade of allowances between sectors could result in the highest possible efficiency in the long run.

Figure 49. Comparison of macroeconomic variables between the One ETS and the Fit55 scenarios



Source: CAKE/KOBiZE

7.4.2 Impact on output by sector

167. Significant differences are not observed in the output of most economic sectors in EU27+UK area across the simulated scenarios. The difference between the average annual rate of growth of output within 2020-2050 between scenarios with the highest and lowest growth does not exceed 0.1[33] p.p. for the following sectors (which account for almost 80% of the entire economy): Forestry, Non-ferrous metals, Vehicles, Paper, Other Manufacturing, Construction and Services. These sectors are characterised by relatively low emissions and energy intensity.

168. Sectors more vulnerable to changes in the implementation of the emission pricing scheme are those that produce energy-related goods or emit higher volumes of greenhouse gases in the production process. The latter can be divided into three groups: agriculture and food, energy-intensive manufacturing, and transport. The largest inter-scenario variability in output can be observed for the agriculture and energy-intensive manufacturing, and the smallest – for transport. Furthermore, out of the different types of transport, only the output of the aviation sector differs significantly across the scenarios. Land transport, which is the dominant form, is fairly resilient to changes in the emission pricing system. The following analysis in this section shows the key relative changes in the level of output between the year 2020 and 2050 across regions and scenarios. Detailed results covering the changes within the three analysed decades (2020-2030, 2030-2040, and 2040-2050) are included in the Appendix.

169. At EU27+UK level, no drastic changes are predicted in the output of the Agriculture sector across the scenarios, with an exception of the One ETS scenario (Figure 50). Within this scenario, the predicted drop in agricultural output amounts to 22%, while in all other scenarios, the output is to remain at a roughly constant level. This scenario alone includes the agricultural sector in the ETS system, which results in a significant price increase in its output relative to the other analysed scenarios. The regions in which agriculture could face the largest contraction are BEN, CEU and NTH.

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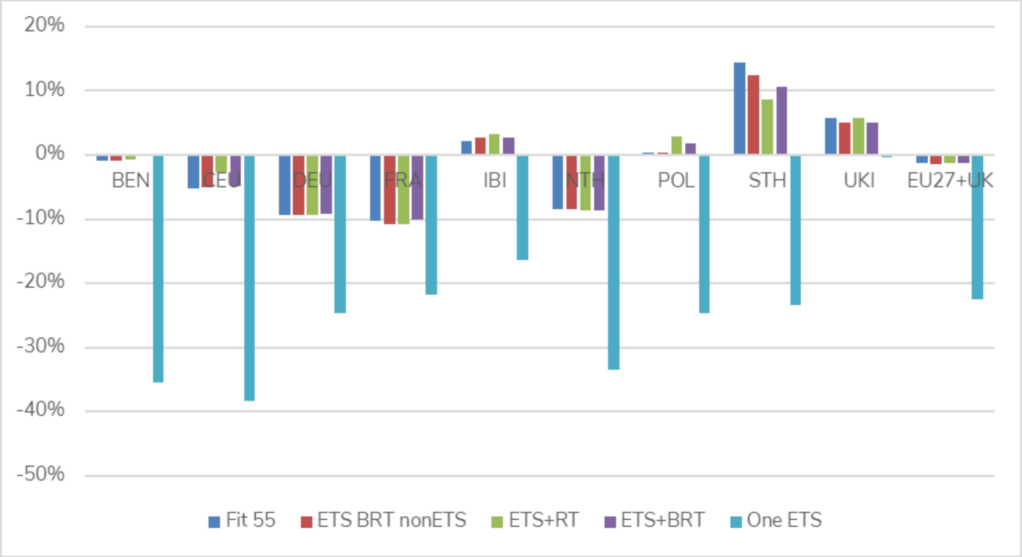
[33] The cumulative change in the level of output after 30 year does not exceed approx. 3%.

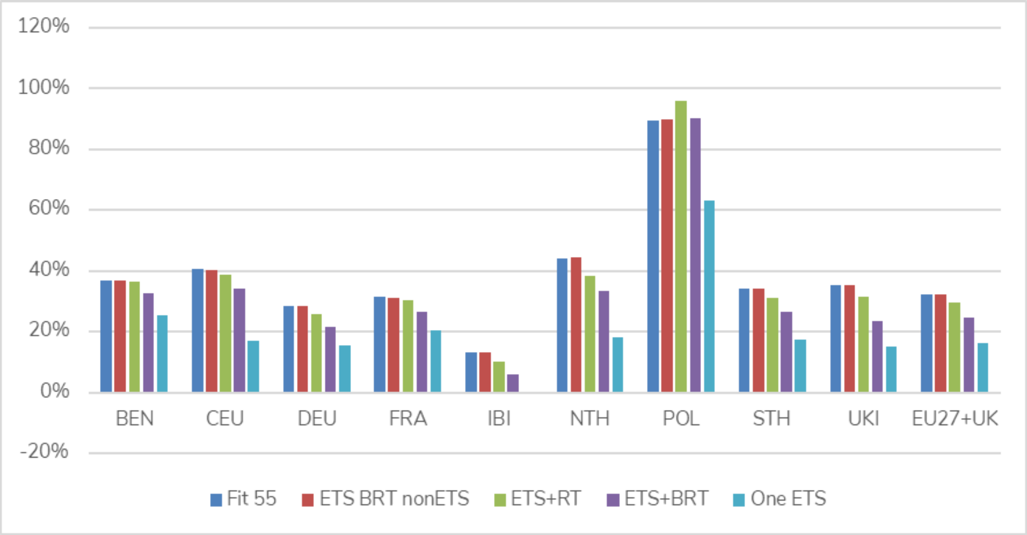
Figure 50. Total change in output of Agriculture between 2020 and 2050



Source: CAKE/KOBiZE

170. Figure 51 shows the average changes in output over the period 2020-2050 for the aviation sector. Its output is expected to grow by as much as 32% for the Fit55 and the ETS BRT non-ETS scenarios. On the other hand, if the cost of emissions for this sector is higher, which is the case for the remaining scenarios, the growth of output can be reduced to as little as 16%. The impact of different scenarios is quite similar across the analysed regions. The biggest outlier is Poland, where aviation is expected to grow significantly over the next couple of decades (an implicit assumption being that the capacity of Polish airlines will expand in line with the demand for all aviation). However, under the One ETS scenario, the growth of output could be reduced by almost 30 p.p. with respect to the remaining scenarios.

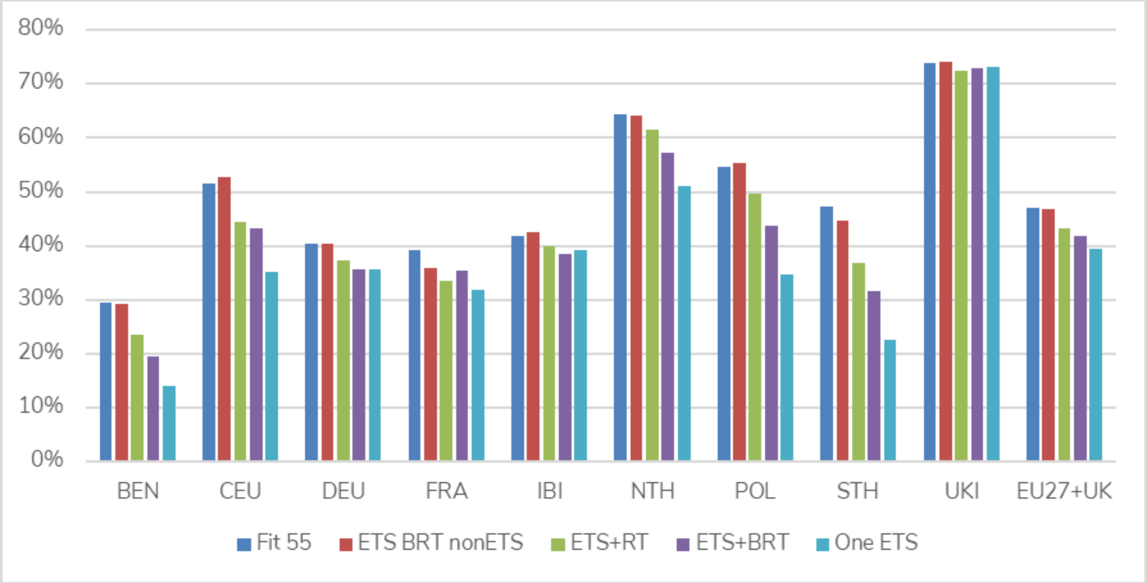
Figure 51. Total change in output of Aviation sector between 2020 and 2050



Source: CAKE/KOBiZE

171. Figure 52 shows the variability across scenarios and regions in the output of selected energy-intensive manufacturing sectors. The output of manufacturing could be highest within the Fit55 and the ETS BRT nonETS scenarios. Expanding the ETS by road transport, buildings and the remaining sectors leads to a decrease in the output of these sectors by 8% in 2050 for the entire EU area. The decrease in the output is not uniformly distributed across regions. The manufacturing in the BEN, CEU, POL and STH could face the biggest challenges to growth under the One ETS scenario.

Figure 52. Total change in output of Chemicals, Iron and Steel and Non-metallic minerals sectors between 2020 and 2050



Source: *CAKE/KOBiZE*

7.5 Energy, transport and agriculture – detailed results

7.5.1 Energy sector

7.5.1.1 The impact of extension EU ETS on energy sector

172. This chapter presents the results of analyses dedicated to energy sector. Various scenarios for the inclusion of new sectors in the emissions trading scheme and their impacts on the energy sector were analysed. The types of scenarios and their nomenclature were described in Chapter 5. For each scenario, a complete computational loop was run, taking into account all sectors of the economy and their impact on the future energy mix. Relevant comparisons were made, including in particular comparisons with the Fit55 scenario, which constitutes the main reference point for all analyses.

173. The energy sector proved low to be not very sensitive to various schemes of incorporating other sectors into the EU ETS. This is comprehensible, given that the entire energy sector is already operating under extremely stringent targets for GHG reductions

in the Fit55 scenario. Even in the scenario assuming a significant expansion of the EU ETS, the impact on the energy sector was very small. The main element differentiating the results in the analysed scenarios turned out to be the prices of emission as illustrated in Chapter 7.1. This, in turn, has had some, albeit limited, influence on the selection of technologies that cover demand determined by the CGE model, since the energy system is already highly decarbonised in the Fit55 scenario. It seems that changes in the cost of emission have a significant impact on the energy mix only up to a point, but at very high cost levels even large cost fluctuations have a limited impact.

7.5.1.2 Electricity demand (EU+[34], POL)

174. The starting point for any kind of analysis of energy sector development is energy demand projections. In this case, the source of this data are identified as the results of calculations performed within the d-PLACE economic model, supplemented by additional demand from the e-mobility sector and heat pump consumption originating from the MEESA model.

175. According to the results shown in Figure 53, the total electricity demand in the EU+ countries is increasing from approx. 2900 TWh in 2020 to 7200-7400 TWh in 2050. Total electricity demand in all scenarios is similar for the periods considered. The final electricity demand in each scenario is quite the same, the only difference pertains to electricity consumption for hydrogen production and e-mobility purposes. In scenarios assuming the inclusion of the transportation sector in the ETS or assuming the imposition of any costs related to CO_2 emissions, e-mobility development is a little bit higher.

176. Generally, the decarbonisation process taking place in the BRT sectors will have an impact on the operation of the electricity system by generating additional volumes of electricity consumption that will entail an increase in production at generating units. The difference created by various scheme of incorporating other sectors into EU ETS shows mainly different effectiveness of particular measure used, but doesn’t change overall targets, therefore has limited impact on energy the sector.

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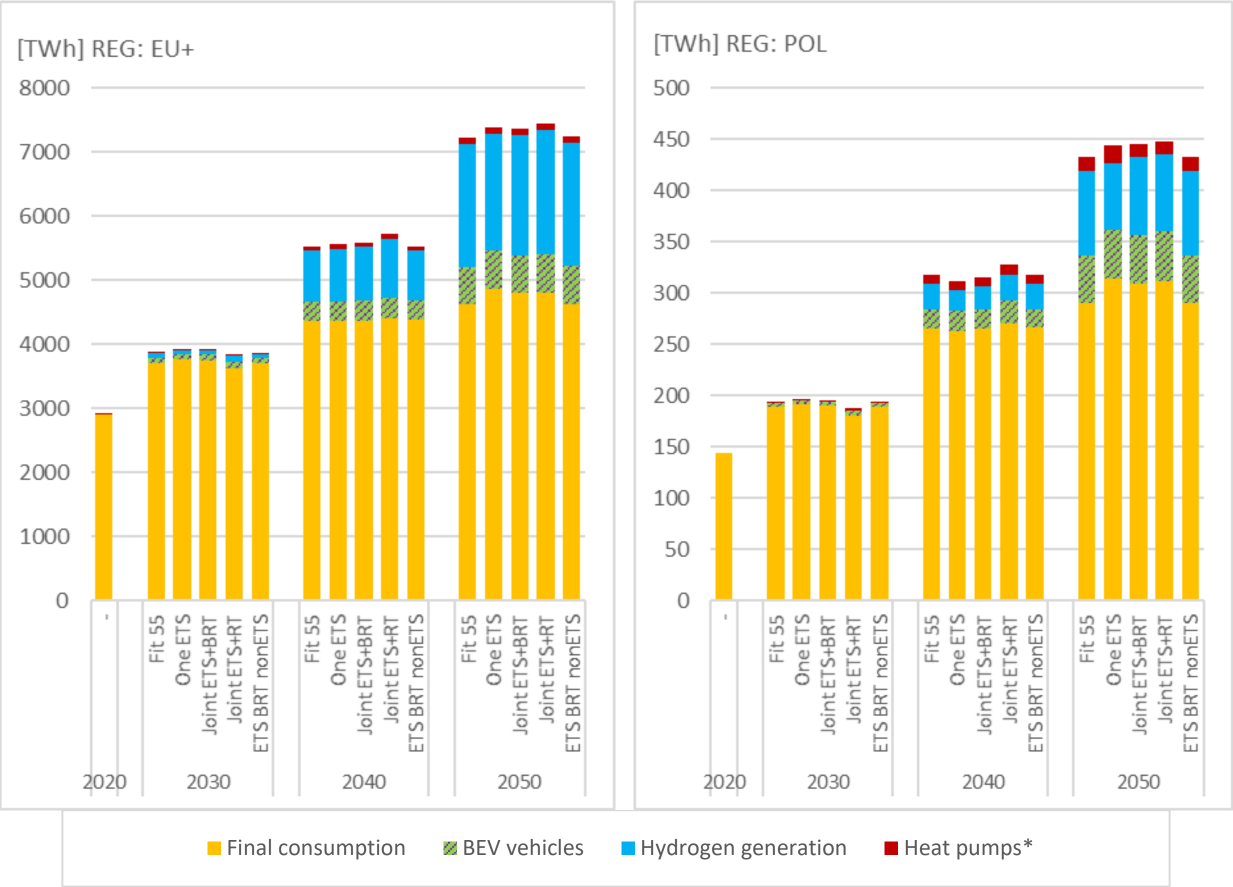
[34] Due to the significant impact of cross-border interconnections, the energy model, in addition to the EU27 countries and the UK, also includes Switzerland and Norway (this extended coverage is referred to as EU+ in this analysis).

Figure 53. Electricity demand in EU+ and in Poland within scenarios



Legend:

Final consumption	Final Electricity Consumption (including part of the energy sector - refineries, coking plants)
BEV vehicles	Electricity Consumption by Battery Energy Vehicle
Hydrogen generation	Electricity Consumption for Green Hydrogen Production
Heat pumps*	Electricity Consumption in Heat pumps (system heat pumps and heat pumps replacing district heating)

Source: CAKE/KOBiZE

177. As for the projections of electricity demand for Poland (Figure 53), they indicate an increase in demand from nearly 140 TWh in 2020 to ca. 425-445 TWh in 2050, depending on the scenario. Presented projections show a very strong pro-growth trend in all considered scenarios. It is mainly due to the process of electrification of the industry, heating and transport.

178. The lowest consumption is noted within the Fit55 and the ETS BRT nonETS scenarios (ca. 425 TWh). The other three scenarios have slightly higher energy demand at around 440 TWh. The differences between the scenarios are minor and result from the slightly higher rates of electrification in other economic sectors. A more visible impact concerns electricity consumption on hydrogen generation – this aspect is discussed in more detail in Chapter 7.5.1.8.

7.5.1.3 Electricity production (EU+, POL)

179. Calculation results obtained for the power sector indicate far-reaching changes in the electricity generation structure. Gradual decarbonisation of the electric power sector will lead to its complete remodelling in the perspective of 2050. Modernisation of the sector will be stimulated by the rapidly rising costs of emission reductions and increasing availability of renewable energy sources. These technologies will be competitive already in the Fit55 scenario, therefore further increase in emission cost does not change the overall picture – RES will be the dominant technologies in all scenarios (primarily onshore wind farms, offshore wind farms and PV). In the energy system with a significant penetration of intermittent RES, the role of energy storage systems providing elastic load is crucial to secure the system reliability. In periods of significant surplus of energy from RES, the use of electrolysers will enable the production of hydrogen for the needs of other sectors of the economy, while acting as a long-term energy store.

180. Achieving the ambitious emission reduction targets in the whole economy is difficult because not all industrial processes can be completely decarbonised - so it is necessary to achieve the highest possible reductions (or even negative emissions) in those areas where it is possible to do so at a reasonable cost. Results of simulations on the combined models have shown that energy sector is one of those where deep reductions (and even achievement of negative emissions) are possible. To reach the net-zero target on the EU scale, a development of a wide range of energy technologies to reduce emissions is needed - both RES and nuclear power plants, as well as BECCS. There will be a significant role for BECCS (biomass-based technologies with the ability for capturing and storage of CO_2), primarily due to the fact that by removing CO_2 from the atmosphere, they reduce the need to curb emissions in those sectors where the marginal costs of reduction are very high.

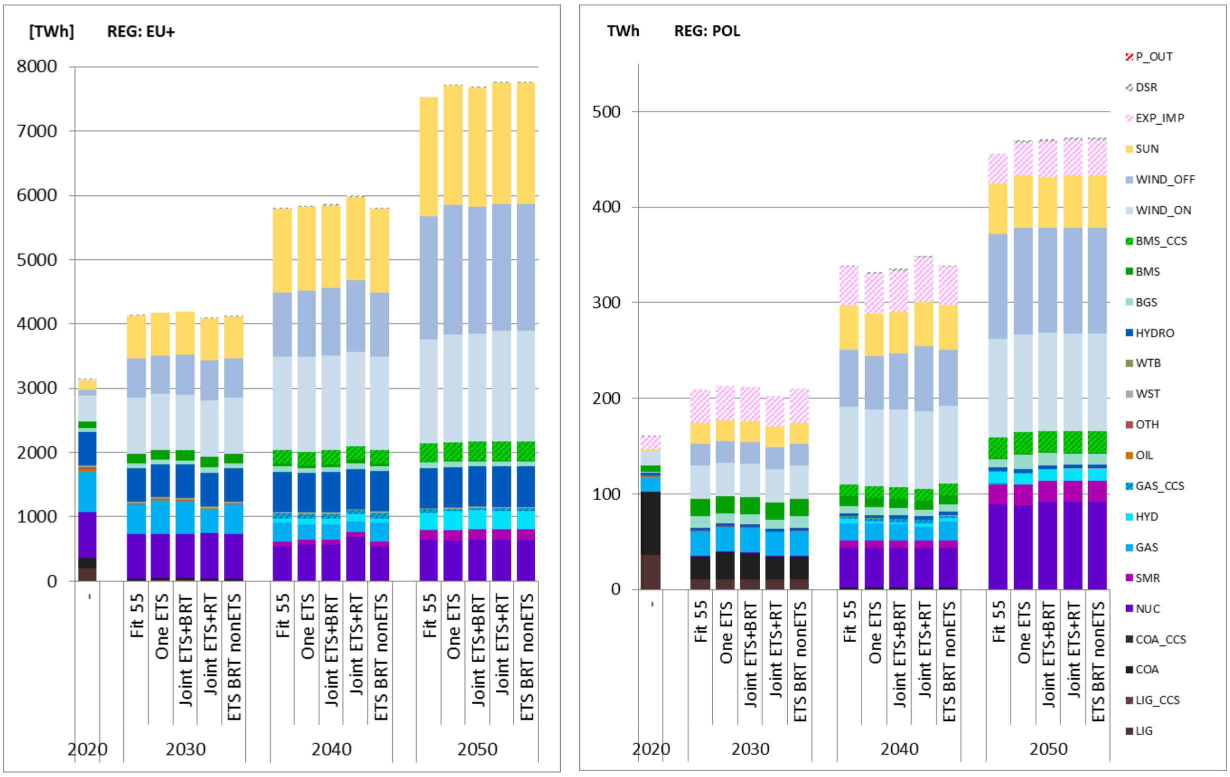
181. Results of the MEESA model for electricity generation capacity development in Poland indicate that the reduction targets assumed in each scenario will also force significant changes in the Polish energy mix, involving the replacement of carbon-based technologies with zero- or low-carbon technologies. Poland, compared to the EU as a whole, has one of the most difficult tasks to accomplish, and the process of transforming the energy sector is a great challenge, due to the large share of fossil fuels (especially coal).

182. In Poland, changes in the structure of generation will not just involve the development of just RES sources with intermittent operation. In the new energy system, an important role will be played by nuclear power plants, which are one of the few sources that provide a stable supply of electricity, without greenhouse gas emissions, and at a moderate cost. In addition, by supplying a large amount of energy in the load base, nuclear power plants will create conditions for the use of surplus RES production for hydrogen production,

significantly influencing the stabilisation of electricity prices, as well as increasing the potential for green hydrogen.

183. Electricity production of particular generating units is derived from the total installed power capacity structure. Figure 54 shows the volume of electricity production in each group of generating units in the period 2020-2050 for the whole EU and for Poland. This allows to illustrate changes in the use of each technology in the energy transition process.

Figure 54. Electricity production in the EU+ and in Poland



Legend:

DSR	Demand Side Response	OTH	Other sources
EXP_IMP	Net Export-Import Balance	OIL	Oil
SUN	PV_Large and PV_Small	GAS_CCS	Natural Gas with CCS
WIND_OFF	Wind Offshore	HYD	Green Hydrogen Co-firing
WIND_ON	Wind Onshore	GAS	Natural Gas
BMS_CCS	Biomass with CCS	SMR	Small Modular Reactor
BMS	Biomass	NUC	Nuclear (large-scale)
BGS	Biogas	COA_CCS	Hard Coal with CCS
HYDRO	Hydro	COA	Hard Coal
WSB	Biomass Waste	LIG_CCS	Lignite with CCS
WST	Non-Biomass Waste	LIG	Lignite

Source: CAKE/KOBiZE

184. Higher gas prices, as well as restrictions on gas imports to the EU resulting from the conflict in Ukraine, will contribute to a lower than previously assumed use of natural gas in the energy sector. Natural gas will play a role as a transitional fuel for transformation to a much lesser extent. This deficit will be partly compensated by longer maintenance of

existing units and a slightly faster development of the potential of renewable technologies, hydrogen and energy storage technologies. The role of natural gas is gradually being reduced, and replaced by hydrogen.

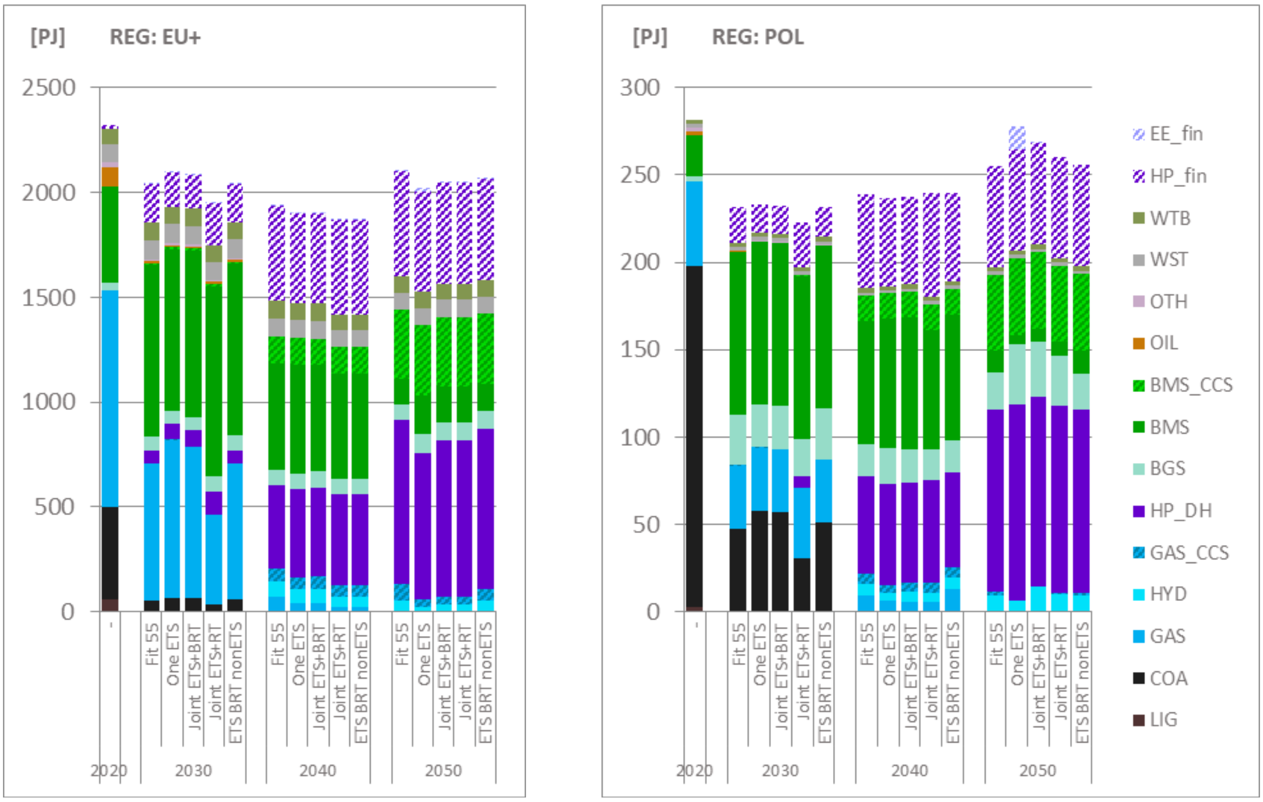
185. When it comes to the structure of electricity production in Poland, it is worth mentioning that in the scenarios assuming the implementation of the Fit for 55 package, coal is completely phased out of use in the electricity sector in 2040. It is replaced by nuclear power and RES. Meeting ambitious decarbonisation goals requires the development of all types of zero and low-emission sources – RES and nuclear, without exception.

186. A positive export-import balance has been maintained throughout the period under consideration. This shows that in the neighbouring countries, mainly Germany, energy is cheaper due to the lower burden associated with the cost of purchasing CO_2 emission allowances. This is especially true in the period before 2030, when Poland maintains a relatively high share of coal in electricity production.

7.5.1.4 District heat production (EU+, POL)

187. District heat demand projections are an equally important element that determines the operation of the energy sector. According to the results obtained via the iteration process, the demand for district heating is quite similar in all scenarios considered. However, some differences exist in the way this demand is being covered. In all of the scenarios, both for the entire EU and Poland, the demand for district heat decreases significantly. This decline is a consequence of energy efficiency improvement as well as the increase in the cost of district heating, and the popularisation of alternative forms of heating, such as heat pumps, which are becoming one of the main technologies for covering the demand for heat over time. Note that in Figure 55, the development of heat pumps in individual heating sources is marked in light purple (HP_fin). All other technologies included in the figure, are sources of heat entered into district heating networks. One can clearly see a strong increase in the share of heat production in individual heat pumps, affecting the reduction of production in technologies operating in centralised heating systems. The development of the residential and non-residential heat pump market will be supported by the development of photovoltaics, as it will increase the profitability of investments in the electrification of heating systems through heat pumps or electric boilers. One can observe also a strong increase in the share of heat production in centralised heat pumps (marked in dark purple on the graph, HP_DH), affecting the reduction of production in other technologies operating for district heating.

Figure 55. District heat production in the EU+ and in Poland



Legend:

EE_fin	Electricity (in electric heaters)	BGS	Biogas
HP_fin	Small Heat pumps (replacing district heating)	HP_DH	System Heat pumps
WTB	Biomass Waste	GAS_CCS	Natural Gas with CCS
WST	Non- Biomass Waste	HYD	Green Hydrogen Co-firing
OTH	Other sources of district heating	GAS	Natural Gas
OIL	Oil	COA	Hard Coal
BMS_CCS	Biomass with CCS	LIG	Lignite
BMS	Biomass		

Source: CAKE/KOBiZE

188. Results for Poland show similar trends as seen for the EU as a whole. Heat pumps in both individual and centralised district heating systems are expected to play a key role in the transformation of district heating. Assumptions of the EU energy and climate policy enforce the necessity of the complete elimination of coal from the heating sector already in 2040. This will be an extremely difficult task for Poland, taking into account the fact that currently more than 70% of production is based on coal.

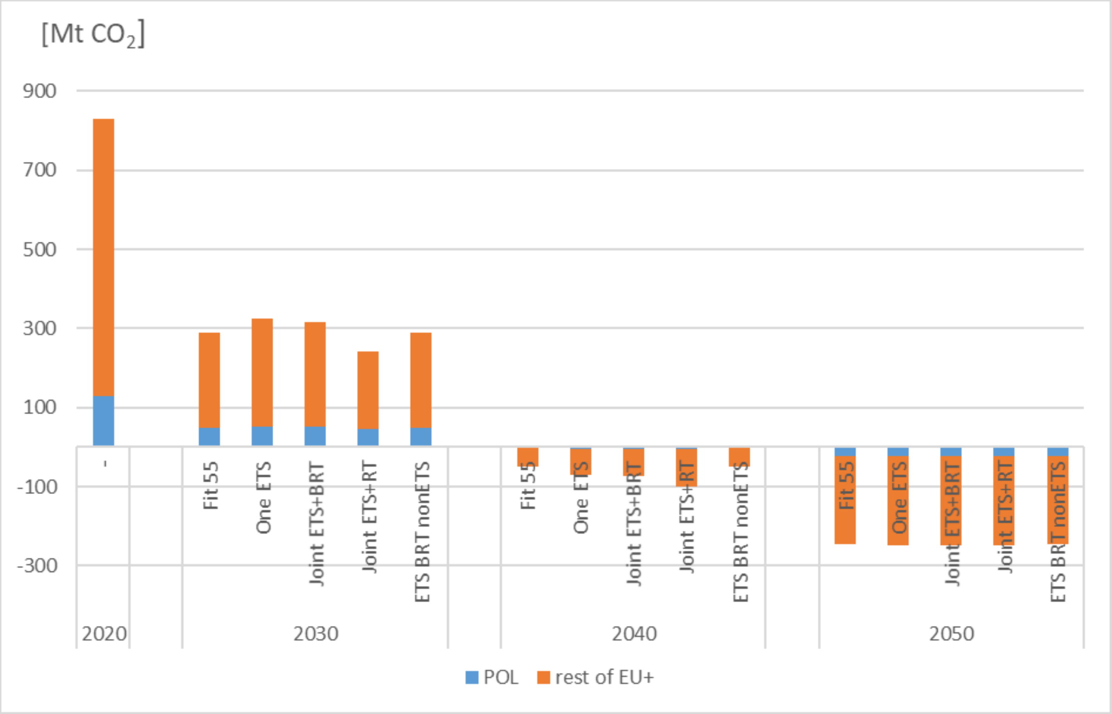
189. The question arises whether it is possible to make such a rapid transformation in this sector and replace practically all production from coal and gas with heat pumps by 2040. The model shows that this would be the optimal solution under given conditions, but in this type of modelling, it is assumed that everything is going according to the plan. In real life, technical or regulatory obstacles may change the pace of development of a given technology. In addition to this, the difficult financial situation of most district heating

companies makes it impossible to carry out any investment efforts. Also, the rising cost of heat supply from fossil fuel-based sources will cause the number of network heat consumers to decline in the future and their conversion to individual heating systems, which will make the situation of heat producers even worse.

7.5.1.5 GHG emissions in the energy sector (EU+, POL)

190. Figure 56 presents the modelling results of GHG emissions in the energy sector for Poland and other EU+ countries in all analysed scenarios. For 2050, they are almost identical, presented graph shows negative values (-250 million tonnes) in all scenarios for the whole EU+ and ca. -23 million tonnes for Poland. As mentioned earlier, the energy sector is the one where reduction is the easiest, moreover, negative emissions can be achieved by the use of BECCS technology. Without negative emissions obtained in the energy sector, achieving a net-zero economy is practically impossible, or at least very costly. Some differences in emission levels for analysed scenarios for the years 2030 and 2040 result from different paths of emission prices in these periods (see Figure 12). However, in 2050, even for the Fit55 scenario, with the lowest carbon price, the energy system practically reaches the limit of technical reduction possibilities; therefore, no further emission reduction takes place despite very high emission prices in other scenarios.

Figure 56. GHG emissions of the energy sector in Poland and the rest of EU+



Source: CAKE/KOBiZE

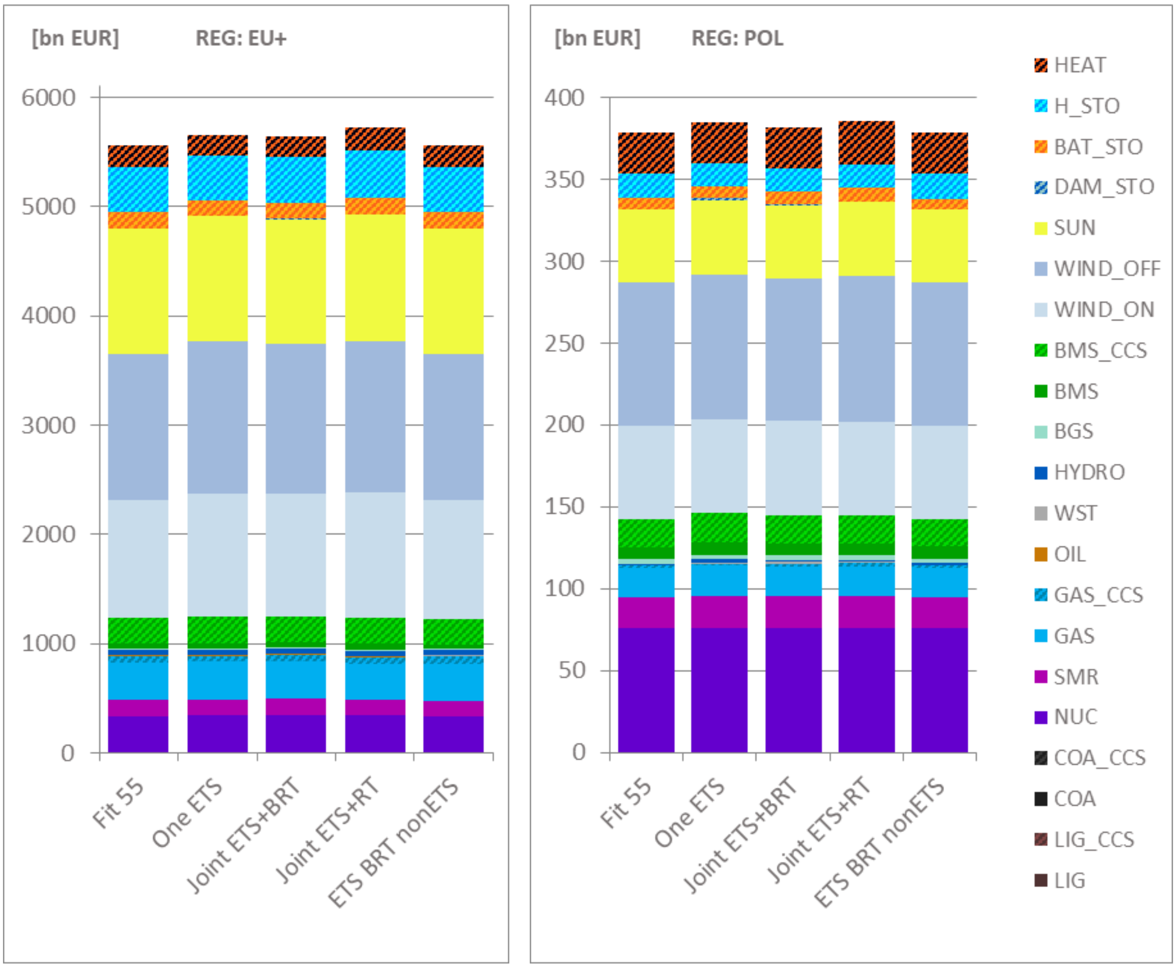
7.5.1.6 Investment expenditures

191. Figure 57 shows the cumulative capital expenditures within 2021-2050 for different scenarios in the EU+. In the Fit55 scenario, they amount to EUR 5500 billion. The vast majority of investments are related to the development of renewable energy sources, but there is also a significant share of nuclear power, district heat and investments related to hydrogen production and storage. The structure and level of expenditures in the analysed scenario are very similar (as is the energy mix).

192. The capital expenditures presented in this subsection include only investments in new generating units and energy storage (battery and hydrogen). They do not include expenditures related to the modernisation of existing generating units and the expansion and modernisation of the transmission and distribution network (both electric power and district heating). Especially the latter aspect will be important under conditions of growing electricity consumption, development of RES (including offshore wind power, offshore wind power, prosumer power) and nuclear power, and will entail the need for large investments in transmission and distribution infrastructure. Given the current state of the networks, especially for the distribution networks, the lack of investment would be a major constraint on the energy transition process. Unfortunately, the MEESA model used for the calculations does not take into account these kinds of expenditures and the potential impact of these investments on increased costs for end users.

193. Expenditures related to the development of hydrogen production infrastructure were estimated at EUR 410 billion to EUR 432 billion. It should be noted that these expenditures apply both to the use of hydrogen as energy storage and balancing of the electricity grids and for the use in the transportation, industry and heating sectors. Expenditures for the development of hydrogen production infrastructure are significant, but necessary if climate neutrality goals are to be met.

Figure 57. Investment expenditures in the EU+ and Poland within 2021-2050



Legend:

HEAT	Heat Plants	WST	Waste CHP (Biomass and Non-Biomass)
H_STO	Electrolysers	OIL	Oil PP_CHP
BAT_STO	Batteries	GAS_CCS	Gas PP_CHP with CCS
DAM_STO	Hydro-Pumped Storage PP	GAS	Gas PP_CHP
SUN	PV_Large and PV_Small	SMR	Small Modular Reactor PP
WIND_OFF	Wind Offshore	NUC	Nuclear (large-scale) PP
WIND_ON	Wind Onshore	COA_CCS	Hard Coal PP_CHP with CCS
BMS_CCS	Biomass PP_CHP with CCS	COA	Hard Coal PP_CHP
BMS	Biomass PP_CHP	LIG_CCS	Lignite PP with CCS
BGS	Biogas CHP	LIG	Lignite PP
HYDRO	Hydro PP		

Source: CAKE/KOBiZE

194. Investment expenditures for various scenarios have been estimated for Poland at just over EUR 370 billion. The largest part of these investments is related to the RES development (ca. 57% of the total expenditure) and construction of nuclear power plants (25% of total expenditure). This observation applies to all scenarios considered.

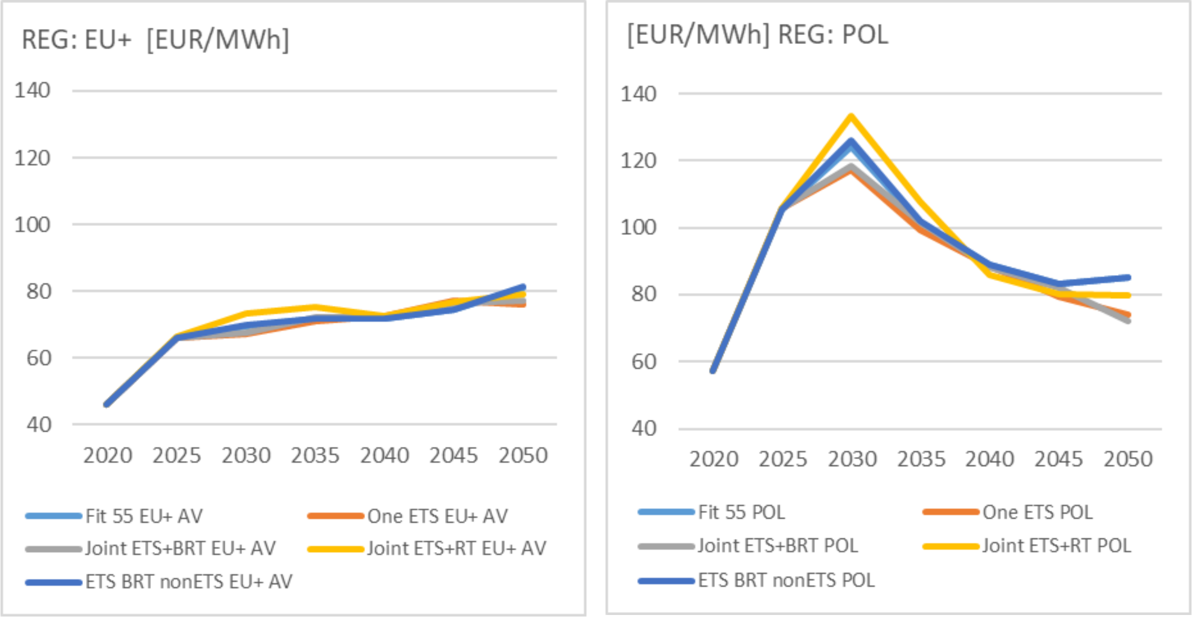
195. Investment expenditures on the development of hydrogen production infrastructure for Poland are estimated at EUR 15 billion (Fit55 scenario), EUR 13.6 billion (One ETS scenario) and EUR 14.6 billion (Joint ETS+BRT and Joint ETS+RT scenarios).

The development of hydrogen power requires significant external financial support, especially in the initial period. For now, green hydrogen is not competitive both in the application of this technology for energy storage (battery storage systems are cheaper) and for transportation purposes (electric-powered vehicles are cheaper), but in the future, with the growing energy supply from RES sources, it should become real competition for natural gas.

7.5.1.7 Average electricity generation costs

196. Implementation of the climate policy is associated with a significant increase in the costs of electricity generation. The increase is particularly notable for the period up to 2030, and is driven by the rising cost of purchasing CO_2 emission allowances (Figure 12).

Figure 58. Average electricity generating costs in the EU+ and in Poland



Source: CAKE/KOBiZE

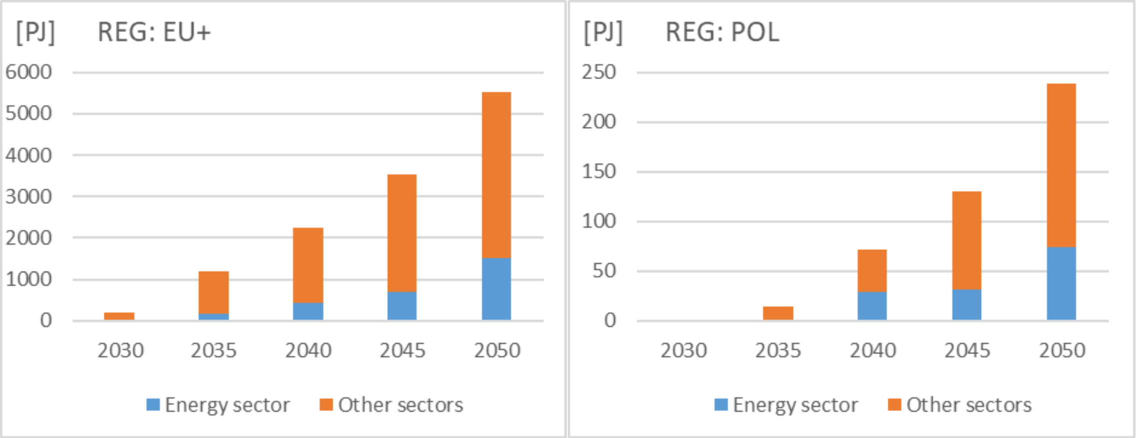
197. For most of the EU countries, the average cost of electricity will increase more or less steadily, but in case of Poland the electricity costs are expected to increase rapidly until 2030. During this period, the Polish electricity system will still rely heavily on fossil fuels, and emission cost will be a significant part of the total generation cost. A higher rate of phasing out the coal-fired sources and replacing them with low-emission technologies is unlikely. In addition, the high rate of transformation with significant investment needs will affect energy prices. It is only from 2035 that a change in this trend could be expected, production costs in Poland will gradually decrease and finally around 2050 they will reach levels close to the average in the EU.

198. Results also show some differences in average energy prices in 2050 between the scenarios. This is worth commenting on, as it may not be very intuitive, since scenarios with higher CO_2 cost show lower energy prices. This effect is caused by BECCS technologies (which are highly competitive with high CO_2 prices) and the model assumption that additional incomes for negative emissions in BECCS are directly used to lower energy prices (and not treated as excess profits).

7.5.1.8 Green hydrogen production

199. Green hydrogen will be an important factor on the way to achieve ambitious emission targets for 2050. Results show that for the Fit55 scenario by 2050, hydrogen production will reach 5530 PJ for the entire EU+ and almost 240 PJ for Poland. About 30% of hydrogen production is used by the power sector itself for electricity and district heat generation - as a sort of long-term energy storage. However, the vast majority of hydrogen is used in other sectors – mainly in industry and transport. This hydrogen consumption may reach as much as 20% of the final electricity consumption for the EU (not taking into account hydrogen consumption in the electricity sector), which shows the importance of this energy carrier.

Figure 59. Development of hydrogen consumption for the Fit55 scenario in the EU+ and Poland

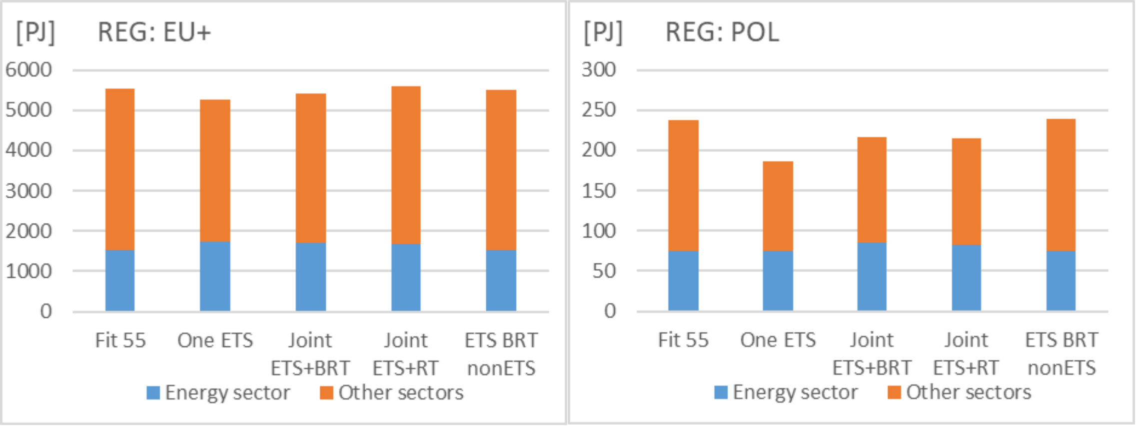


Source: CAKE/KOBiZE

200. Green hydrogen production starts to increase in the whole EU after 2030, both in the final consumption and energy sector, along with the development of renewable energy sources and increasing need for energy storage. In Poland, this process is a bit slower, but even there the green hydrogen becomes highly important after 2040.

201. Figure 60 shows differences in green hydrogen use in particular scenarios in comparison to the Fit55 scenario.

Figure 60. Green hydrogen consumption for different scenarios in comparison to the Fit55 scenario in EU+ and Poland in 2050



Source: CAKE/KOBiZE

202. All scenarios show similar total green hydrogen consumption in the entire EU. In the case of Poland, the green hydrogen consumption is significantly lower in the One ETS scenario, probably as an effect of increased electricity demand in industrial sectors and lower electricity prices. Interestingly, higher hydrogen consumption in the power sector occurs in scenarios with lower final hydrogen demand in industry and transport, possibly due to a larger energy surplus from renewable electricity generation, which can be effectively converted to hydrogen as long-term energy storage. Nevertheless, from the energy sector perspective, differences between considered scenarios are rather not significant.

7.5.2 Transport sector

7.5.2.1 Deployment of the zero-emission fleet in EU27+UK and Poland

203. The development of the composition of the fleet of vehicles in the EU will be determined by new legislation concerning new cars and emission pricing. The legislation includes the European Commission's Fit for 55 package, which proposed a ban on sales of internal combustion engine (ICE) passenger cars and light-duty vehicles from the year 2035. At the end of March 2023, the European Council adopted new CO_2 emission regulations for new cars and vans. According to them, CO_2 emission standards for passenger cars and vans in the years 2030-2034 will be reduced by 55% and 50%, respectively, compared to 2021. In 2035, CO_2 emission reductions for both new cars and vans will be completely reduced[35]. This measure will gradually reduce the share of new

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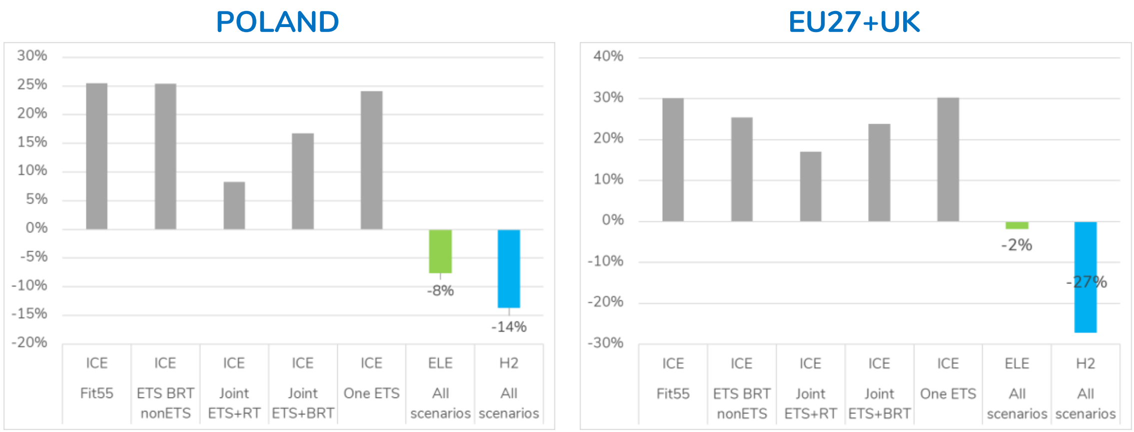
[35] https://www.consilium.europa.eu/en/press/press-releases/2023/03/28/fit-for-55-council-adopts-regulation-on-co2-emissions-for-new-cars-and-vans/

ICE vehicles appearing on our roads. However, they will not disappear completely. It will be possible to purchase them until 2035, and after this date, it will be possible to import used ICE vehicles from the remaining EU countries, as well as from outside the EU. Taking this into account, it is almost certain that some fossil fuel-powered cars will still be in operation in the year 2050.

204. The EU is also planning to put a price on emissions in the road transport sector, which will increase the cost of driving fossil fuel-powered vehicles. The cost of driving fossil fuel-powered vehicles will increase due to put a price on emissions in the road transport sector in the EU. The increase in the operating costs of vehicles resulting from pricing emissions will vary depending on the exact way in which the transport sector is included in an emission trading scheme. In Figure 61, the rise in the total operating cost of ICE cars in the scenarios was presented, which is considered against the drop in the cost to operate zero-emission vehicles (ZEVs). In EU27+UK in the period between 2030 and 2050, operating ICE cars will become up to average 30% more expensive, whereas the cost to operate battery and hydrogen powered cars will drop by 2% and 27% respectively. There is no doubt that these changes will vary at the country level. In the case of Poland in the period between 2030 and 2050 operating ICE cars will become up to 25% more expensive, whereas the cost to operate battery and hydrogen-powered cars will drop by 8% and 14% respectively.

Figure 61. Changes in cost per mile for cars between 2030 and 2050



Source: CAKE/KOBiZE

205. According to our simulations, the share of zero-emission passenger vehicles in the EU27+UK will be approx. 14% in 2030, while in Poland it will be lower by 5 p.p. The main reason for a lower adoption of these vehicles in Poland is their relatively high prices and limited infrastructure for charging or hydrogen refuelling[36]. In the decades following 2030,

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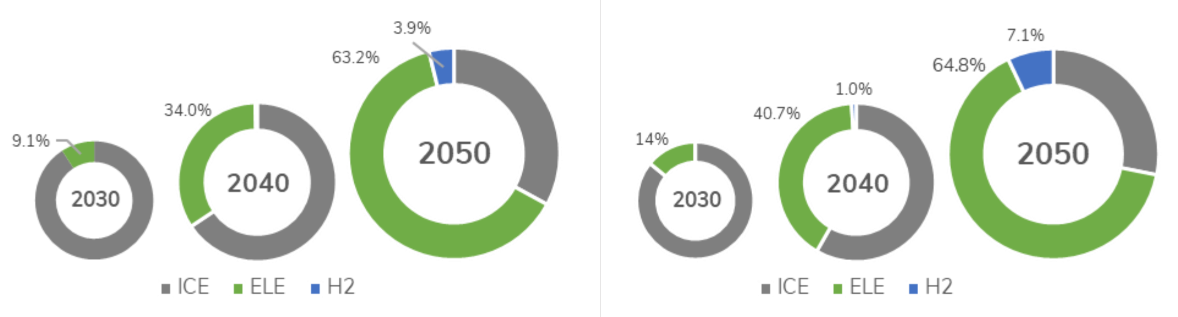
[36] According to the https://pspa.com.pl/research/licznik-elektromobilnosci the number of electric vehicles in Poland at the end of 2022 was approx. 32 thousand, with approx. 2.5 thousand charging stations. At the same time, in the Netherlands the number of BEV was approx. 300 thousand. https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/netherlands/vehicles-and-fleet .

the total cost of ownership (TCO) of zero-emission cars will decrease as a result of technological improvements, economies of scale and lower maintenance costs. As a result, such vehicles will gradually begin to crowd-out internal combustion engine vehicles from the market, whose operation costs will rise along with rising fossil fuel taxes. In 2050, the share of zero-emission vehicles in the EU27+UK will be equal to approx. 72%, and in Poland it will be equal to approx. 67%.

Figure 62. Shares of zero-emissions cars in Poland in 2030 and 2050 – comparison with the average share for EU27+UK

POLAND | **EU27+UK (average share)**

CARS – ETS BRT nonETS scenario



CARS - other scenarios

		POLAND				EU27+UK (average share)			
		Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS	Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS
2030	**ICE**	90.9%	90.9%	90.5%	90.6%	86.0%	85.5%	85.7%	85.6%
	ELE	9.1%	9.1%	9.5%	9.4%	14.0%	14.5%	14.3%	14.4%
	H2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	**ICE**	65.6%	65.6%	63.1%	64.4%	58.4%	55.5%	57.0%	57.2%
	ELE	34.0%	34.0%	36.5%	35.3%	40.7%	43.5%	42.0%	41.9%
	H2	0.4%	0.4%	0.4%	0.4%	1.0%	1.0%	0.9%	0.9%
2050	**ICE**	32.9%	33.0%	33.4%	34.0%	28.2%	27.9%	28.5%	28.1%
	ELE	63.2%	63.2%	63.1%	62.5%	64.7%	65.5%	64.9%	65.1%
	H2	3.9%	3.9%	3.5%	3.5%	7.1%	6.6%	6.6%	6.8%

Source: CAKE/KOBiZE

206. In all, the scenarios that we consider, the share of zero-emission buses will reach 6% in Poland in 2030, with an EU27+UK average of 8%. In the 2 following decades, this share will continue to increase. The pace of increase will be quicker in Poland, where we expect the share of zero-emission buses in 2050 to be equal to 76%, against a value of 65% for the EU27+UK.

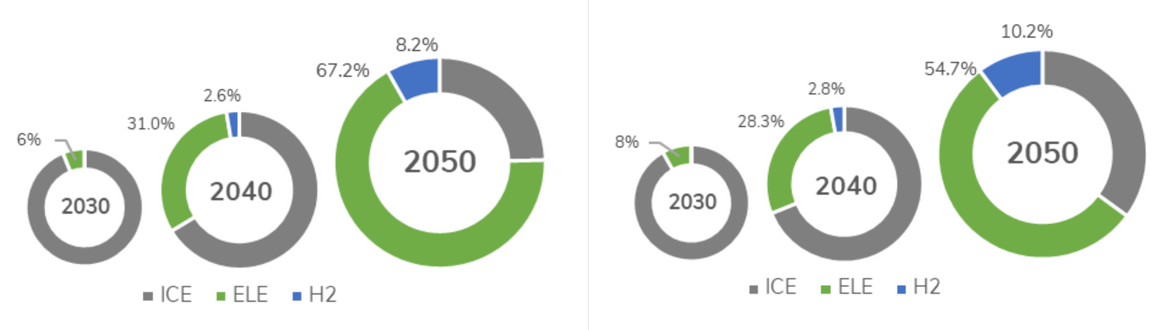
207. The transformation towards a zero-emission bus fleet will take place gradually and will begin in the sector of urban public transport. There is a huge potential for the rapid

replacement of diesel buses with battery and hydrogen-powered counterparts and this process has already begun in many European cities, including those in Poland. Furthermore, this process is highly beneficial for the Polish economy, since this country is a leading producer of electric buses in the EU. In 2020, exports of electric buses from Poland accounted for 40% of EU-wide exports of these buses.

Figure 63. Share of zero-emissions buses in Poland in 2030 and 2050 – comparison with the average share for EU27+UK

POLAND **EU27+UK (average share)**

BUSES – ETS BRT nonETS scenario



BUSES - other scenarios

		POLAND				EU27+UK (average share)			
		Fit55	**Joint ETS+RT**	**Joint ETS+BRT**	**One ETS**	**Fit55**	**Joint ETS+RT**	**Joint ETS+BRT**	**One ETS**
2030	**ICE**	94.0%	93.7%	94.0%	94.1%	91.9%	92.0%	92.0%	92.1%
	ELE	6.0%	6.3%	6.0%	5.9%	8.1%	8.0%	8.0%	7.9%
	H2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	**ICE**	66.4%	64.1%	68.1%	70.1%	68.9%	66.1%	68.6%	69.6%
	ELE	31.0%	33.1%	29.1%	27.1%	28.3%	30.7%	28.3%	27.4%
	H2	2.6%	2.8%	2.8%	2.8%	2.8%	3.2%	3.0%	3.0%
2050	**ICE**	24.6%	28.1%	31.5%	33.8%	35.1%	38.3%	40.2%	41.1%
	ELE	67.2%	63.6%	58.7%	55.3%	54.7%	51.5%	49.2%	47.6%
	H2	8.2%	8.3%	9.8%	10.9%	10.2%	10.2%	10.5%	11.3%

Source: CAKE/KOBiZE

208. Hydrogen technologies will also play a crucial part in the zero-emission transformation. The Polish hydrogen strategy assumes that by 2030, there will be approx. 800-1000 hydrogen-powered buses in operation in Poland and by 2025 the number will be equal

to 250[37]. Furthermore, it is expected that by 2030 the urban transport fleet in cities exceeding 100 000 inhabitants will consist solely of zero-emission vehicles[38]. This corresponds to the current proposals of the European Commission regarding 2030 zero-emissions target for new city buses and 90% emissions reductions for new trucks by 2040[39].

209. Long-distance road transport is a more difficult challenge than urban transport due to issues related to limited reach of vehicles and the need to develop charging infrastructure. For these reasons investment in rail infrastructure allowing the substitution of the road with rail transport will be crucial. Additionally, the latter mode of transport reduces congestion and is much safer, thereby reducing negative external costs in the transport sector. With improvements in battery technology and infrastructure, the use of buses on long-distance routes will also increase.

210. We expect a rapid process of electrification of light-duty vehicles (LDV), which is largely driven by relatively low total costs of ownership, (TCO). According to our assumptions, the TCO of electric LDV teaches the same level as for diesel the powered counterpart. These vehicles usually travel short distances, and hence they do not require large batteries and a highly developed charging infrastructure. Furthermore, these vehicles can be used as energy storage technology.

211. In 2030 we expect the share of zero-emission vehicles (ZEV) to account for only 4% of the entire fleet. However, after that year, we will see a rapid replacement of the fleet, especially since the sale of new fossil fuel-powered LDV is expected to be banned[40] after 2035. The total replacement of the LDV fleet takes place much faster than is the case for passenger vehicles, since the average lifespan of LDVs is much shorter and is usually less than 10 years. In 2050 almost the entire fleet of LDVs will consist of zero-emission vehicles. The share of hydrogen-powered LDVs crucially depends on the price of electricity. For Fit55, ETS BRT nonETS and Joint ETS+RT scenarios the share of hydrogen LDVs could reach approx. 10%. However, interesting threshold effects arise for the Joint ETS+BRT and One ETS scenarios. In these two scenarios, the price of electricity is slightly lower in 2050, which results in hydrogen LDVs completely losing their competitiveness against battery-powered counterparts.

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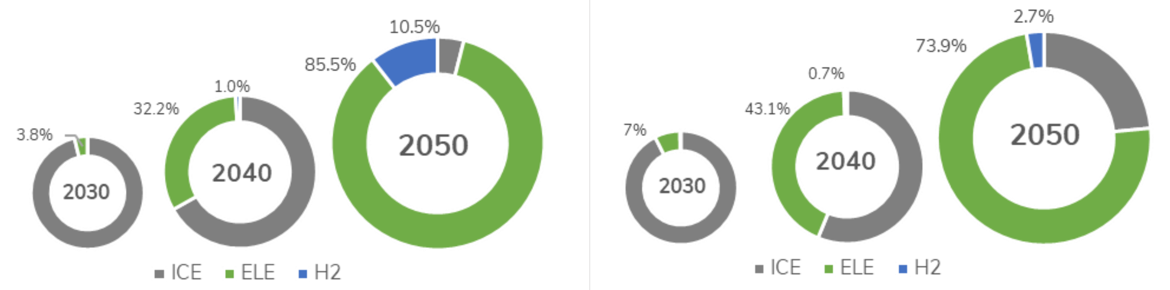
[40] Pending the agreement in trialogue between the EC, the Parliament and the Council

Figure 64. Share of zero-emission light-duty vehicles in Poland in 2030 and 2050 – comparison with the average share for the EU27+UK

POLAND | **EU27+UK (average share)**

LDV - ETS BRT nonETS scenario



LDV - Other scenarios

		Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS	Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS
2030	**ICE**	96.2%	95.6%	95.9%	95.9%	92.5%	91.7%	92.0%	92.0%
	ELE	3.8%	4.4%	4.1%	4.1%	7.3%	8.0%	7.7%	7.7%
	H2	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.2%	0.2%
2040	**ICE**	66.9%	50.1%	66.5%	66.6%	56.3%	51.7%	55.0%	54.9%
	ELE	32.2%	48.3%	32.6%	32.5%	43.0%	47.6%	44.3%	44.4%
	H2	1.0%	1.6%	0.9%	0.9%	0.7%	0.7%	0.7%	0.7%
2050	**ICE**	4.0%	1.3%	4.1%	4.0%	23.5%	24.2%	24.7%	23.9%
	ELE	85.5%	88.4%	95.8%	95.9%	73.8%	73.3%	73.1%	73.8%
	H2	10.5%	10.3%	0.2%	0.2%	2.7%	2.5%	2.2%	2.2%

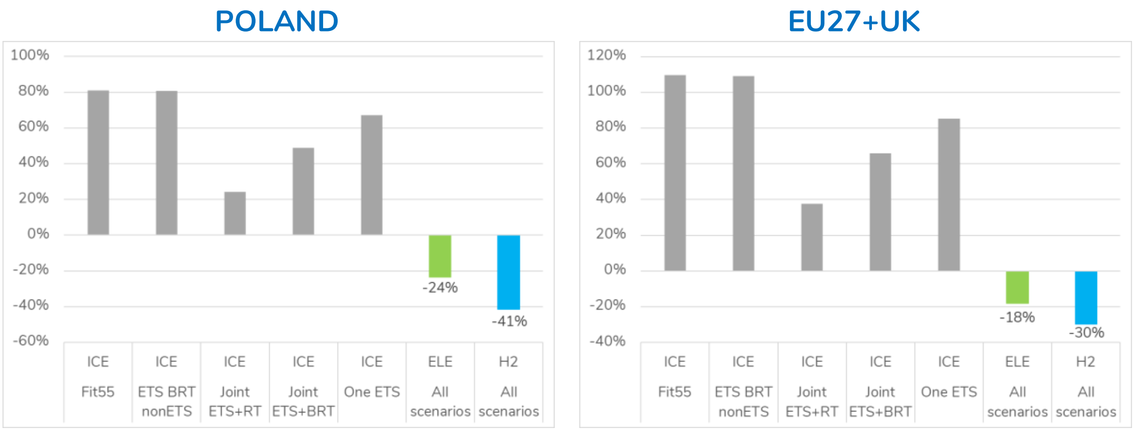
Source: CAKE/KOBiZE

212. Generally the inclusion of transport in an emission pricing scheme will have a greater cost impact on freight transport, especially HDVs, than on passenger transport. This is clearly visible when we compare the change in the cost per mile for HDVs in Figure 65 with the equivalent change for passenger cars shown in Figure 61. The percentage change over the period 2030-2050 is noticeably higher in all scenarios considered at both EU27+UK and on the case of Poland.

213. The replacement of the fleet of heavy-duty vehicles (HDV) with zero-emission vehicles will initially be hampered by a combination of high costs related to both charging infrastructure and the purchase of new vehicles. We expect that the structure of the fleet will start to change only after 2040. In the case of domestic transport, there is some potential for the deployment of hydrogen technologies. Such vehicles are characterised by the longer ranges and are able to reach areas with poorer charging infrastructure. The

simulations conducted for the Fit55 scenario suggest that in 2050 hydrogen-powered HDVs could cover approx. 80% of domestic transport. This share is additionally driven by significant decreases in the price of hydrogen, which is due to drop by 60% between 2030 and 2050. In the case of international transport, the use of hydrogen will also be widespread, however battery-powered HDVs will also be utilised. This will require the development of sufficient pan-European charging infrastructure, as part of the TEN-T (Trans-European Transport Network).

Figure 65. Change of CPM within 2030-2050 in HDV transport

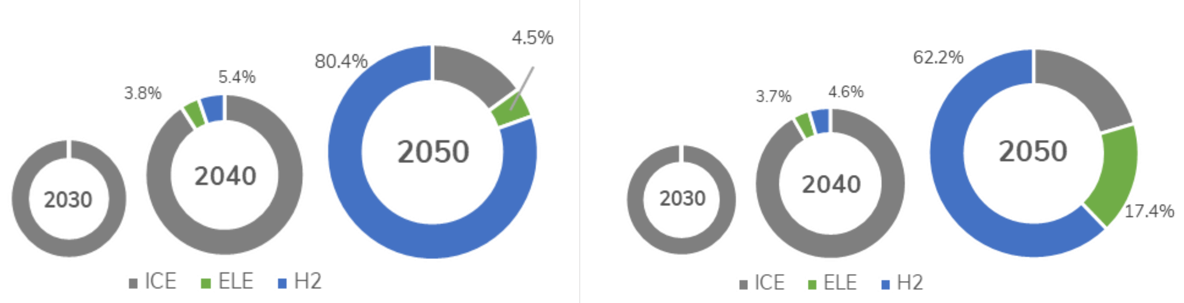


Source: CAKE/KOBiZE

Figure 66. Share of zero-emissions heavy duty vehicle (HDV) in Poland in 2030 and 2050 – comparison with the average share for the EU27+UK

POLAND **EU27+UK (average share)**

HDV - ETS BRT nonETS scenario



HDV - Other scenarios

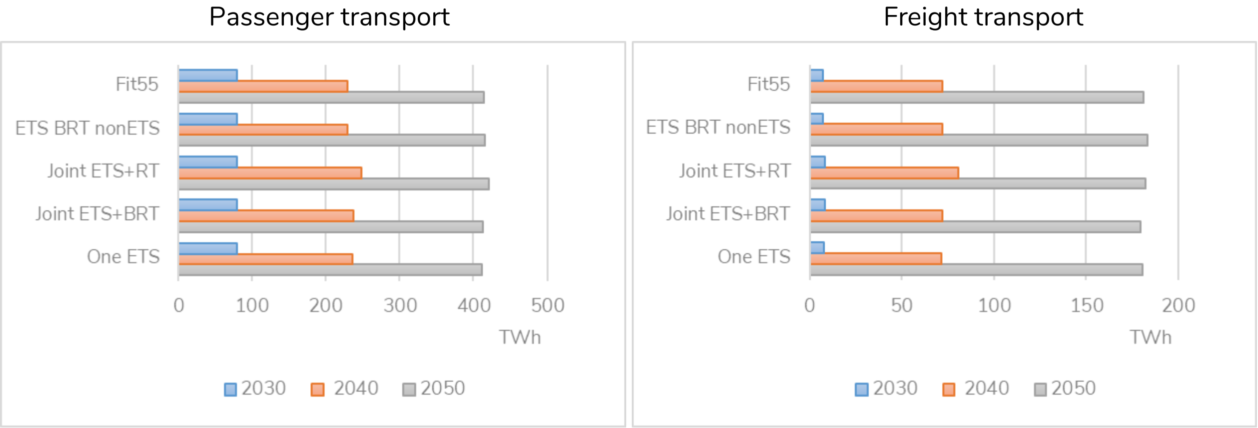
		Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS	Fit55	Joint ETS+RT	Joint ETS+BRT	One ETS
2030	**ICE**	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	ELE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	H2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2040	**ICE**	90.8%	79.4%	88.8%	89.4%	91.8%	89.3%	91.1%	91.4%
	ELE	3.8%	7.8%	4.6%	4.5%	3.6%	4.7%	3.9%	3.8%
	H2	5.3%	12.7%	6.5%	6.1%	4.6%	6.0%	5.0%	4.8%
2050	**ICE**	15.1%	16.3%	18.9%	18.8%	20.5%	21.5%	23.2%	23.9%
	ELE	4.5%	19.8%	18.2%	18.9%	17.1%	22.1%	21.2%	20.5%
	H2	80.4%	63.9%	62.9%	62.2%	62.4%	56.4%	55.6%	55.6%

Source: CAKE/KOBiZE

7.5.2.2 Energy demand in EU27+UK and Poland

214. One of the effects of the widespread development of electromobility in road transport will be a growing demand for electricity. In the EU27+UK demand for electricity in 2040 will reach 236 TWh in passenger transport and 74 TWh in freight transport. In 2050 the demand will increase to 415 TWh and 180 TWh respectively. In the case of the Joint ETS+RT scenario in 2040, the demand for electricity is slightly higher than in the other scenarios – by approx. 10%, while in 2050 these differences are negligible.

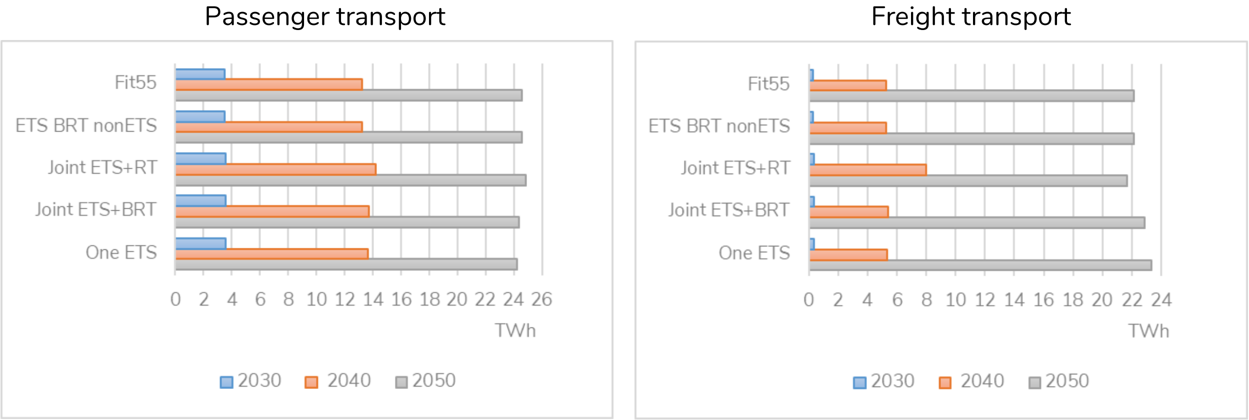
Figure 67. Demand for electricity in road transport in EU27+UK in 2030, 2040 and 2050 according to analysed scenarios [TWh]



Source: CAKE/KOBiZE

215. In the case of Poland by the year 2030, we expect passenger vehicles to consume approx. 4 TWh of electricity, with this number set to triple by 2040 and reach 24 TWh by the middle of the century. For the road freight transport, the replacement of the fleet with battery-powered vehicles concerns mainly light-duty vehicles (LDV). This pattern holds for all analysed scenarios. In the period 2020-2040, demand for electricity for freight transport mainly concerns these vehicles (100% in 2030 and 80% in 2040). In Poland we expect that the entire fleet of LDVs will be battery-powered. On the other hand, the use of battery technologies in heavy-duty vehicles (HDV) is lower due to technical issues such as range, battery weight and high capital costs. We expect that in 2050 energy demand from the freight transport sector will be on the same level then from passenger – between 22 TWh (in Joint ETS+RT scenario) and 24 (in One ETS scenario). Meanwhile, for EU27+UK, electricity demand for passenger transport is more than 2 times higher than for freight transport.

Figure 68. Demand for electricity in road transport in Poland in 2030, 2040 and 2050 according to analysed scenarios [TWh]

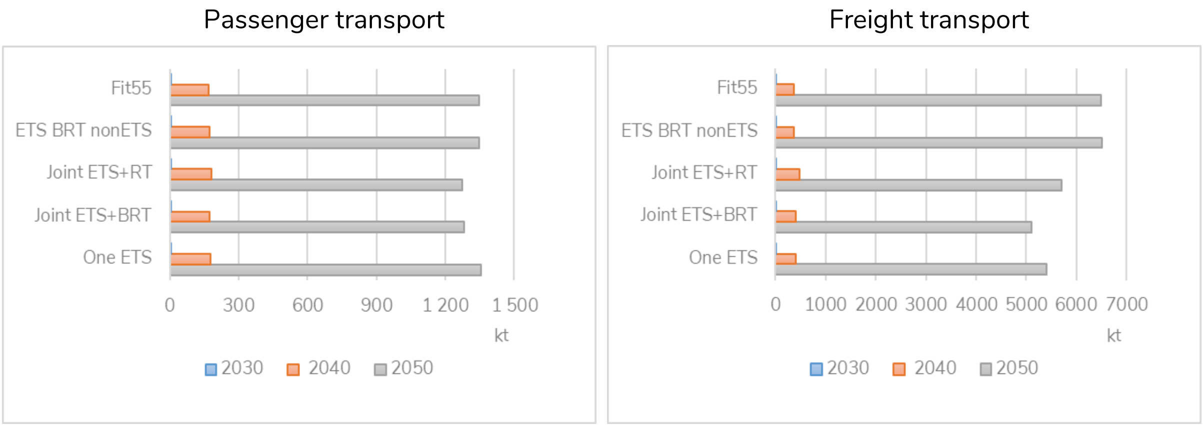


Source: CAKE/KOBiZE

216. Hydrogen technologies will most probably also play a crucial role in the decarbonisation of road transport. However, until 2030 their use in EU27+UK (and also in Poland) will be rather low due to high costs and insufficient refuelling infrastructure. In passenger transport, hydrogen will mainly be used in public transport rather than in individual. The share of hydrogen buses in the entire fleet might reach 10% in 2050 for EU27+UK and Poland. The lowest share is observed in Fit55 and ETS BRT nonETS scenarios and the highest level is in One ETS scenario. Meanwhile the share of hydrogen-powered cars in the vehicle fleet in Poland will be 2 times lower than in EU27+UK in 2050 (3.5-4% in Poland and 7.8% in EU27+UK). In all the analysed scenarios, hydrogen demand in passenger transport reaches 175 kt in EU27+UK and 10 kt in 2040 in Poland. After this date, the technology becomes more widespread due to decreasing costs which results in a sharp increase in the demand for hydrogen. In 2050, we expect that it might reach 1300 kt in EU27+UK and 60 kt in Poland.

217. There is considerable potential to use hydrogen in freight transport as well, in particular for heavy-duty vehicles. In contrast to battery-powered HDVs, the use of hydrogen allows for much higher range and quicker refuelling time, which might incentivise transport firms to choose this technology. The assumptions in our model regarding the development of hydrogen technologies results in growing adoption of such vehicles after 2035. The speed of this process is heavily influenced by the cost of hydrogen fuel, the availability of this technology and the costs levied on the operators of fossil fuel vehicles. As shown in Figure 69 and Figure 70, the demand for hydrogen in EU27+UK in 2050 will vary between 5000 kt (in Joint ETS+BRT scenario) and 6500 kt (in Fit55 and ETS BRT nonETS scenarios). In Poland this demand is from 450 in One ETS scenario to 750 kt in Fit55 and ETS BRT nonETS scenarios in 2050.

Figure 69. Demand for hydrogen in road transport in EU27+UK in 2030, 2040 and 2050 according to scenarios [in kt]



Source: CAKE/KOBiZE

Figure 70. Demand for hydrogen in road transport in Poland in 2030, 2040 and 2050 according to scenarios [in kt]

Source: CAKE/KOBiZE

7.5.2.3 Emission reductions in EU27+UK and Poland

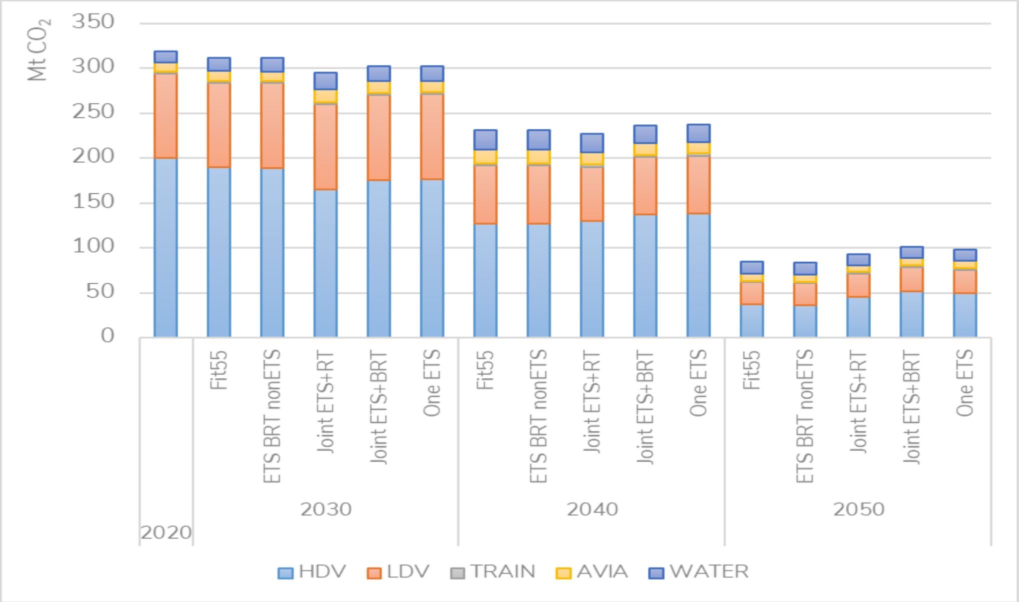
218. At EU27+UK level, the inclusion of the transport sector in the EU ETS leads to a reduction of emissions by 42% in 2040 and 70% in 2050 compared to 2020. In passenger transport, emissions fall to the level of approx. 300 Mt CO_2 in 2040 and approx. 190 Mt CO_2 in 2050, which is a reduction by 50% in 2040 and 69% in 2050 compared to 2020. The emissions in 2050 in passenger transport will consist of 40% emissions from passenger cars and 46% from aviation. Aggregated emission results for EU27+UK do not significantly differ between the analysed scenarios.

Figure 71. Emissions reduction in the passenger transport sector in EU27+UK in 2020-2050 within analysed scenarios

Source: CAKE/KOBiZE

219. By 2040, at EU27+UK level, freight transport will have reduced emissions to a lesser extent than passenger transport. These reductions amount to approx. 27% compared to 2020. A significant reduction in emissions in freight transport is achieved only after 2040. In 2050, in the EU27+UK, emissions in freight transport amount to approx. 85 Mt CO_2, which implies a 73% reduction compared to 2020. Significant reductions in freight transport are achieved a decade later than in passenger transport. This results from the fact that it will take significantly longer for zero-emission freight technologies to become cost competitive relative to fossil fuel vehicles.

Figure 72. Emissions reduction in the freight transport sector in EU27+UK in 2020-2050 within analysed scenarios



Source: CAKE/KOBiZE

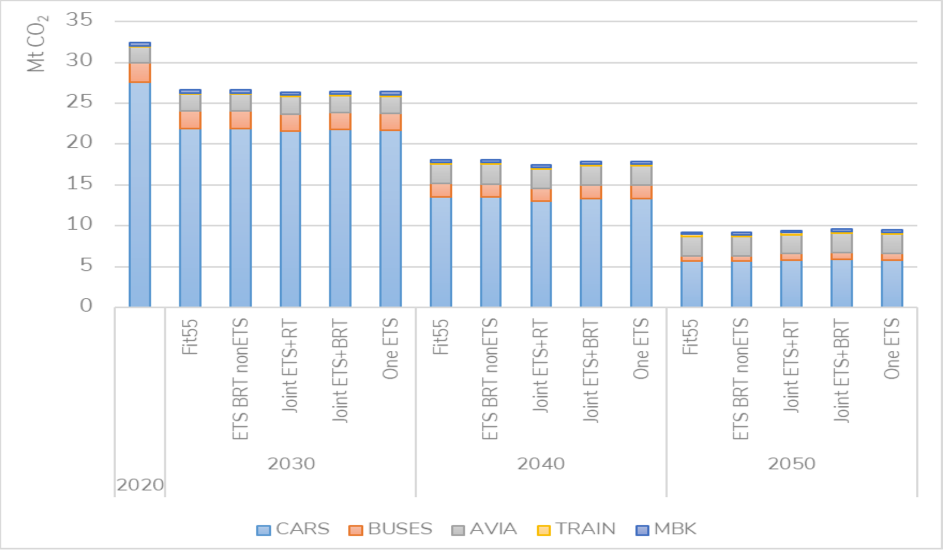
220. We can observe significant emission reductions in the transport sector in Poland across all considered scenarios. Under the Fit55 scenario, total emissions drop from 56.9 Mt CO_2 in 2020 to 13.0 Mt CO_2 in 2050, which amounts to a reduction of 77% (7 p.p. deeper reduction then EU27+UK). The reduction dynamic differs when passenger and freight transport are analysed separately. Emissions in Poland in the former gradually drop every 5 years by a value of between 2.8 and 4.9 Mt CO_2, with higher reductions taking place closer to the year 2050. On the other hand, freight transport continues to emit over 20 Mt CO_2 per year until 2040, with sharp decreases in emissions taking place in the last decade. This trajectory of emissions is driven by increases in the cost of reduction for the transport sector and the increasing availability and cost competitiveness of zero-emission technologies. The availability issue is particularly relevant for the freight transport sector, which inhibits reductions of emissions early on despite the growing cost of reduction. For freight transport, zero-emission vehicles become widely available only after the year 2035.

In the year 2050, we expect emissions from passenger transport to be approx. 9.2 Mt CO_2 emissions and 3.8 Mt CO_2 for freight transport.

221. For EU27+UK our simulations suggest that the lowest emissions in the year 2050 equal to 274.0 Mt CO_2 are associated with the Fit55 and the ETS BRT nonETS scenarios (in the case of Poland emissions are equal to 13.0 Mt CO_2). The scenarios in which we assume the extended EU ETS system are likely to be associated with higher levels of emissions. In the Joint ETS+RT scenario emissions reach 284.0 Mt CO_2 for EU27+UK and 14.9 Mt CO_2 in the case of Poland in 2050. For the scenario which additionally includes buildings in the ETS system and unified single ETS system for the entire economy results in emissions are the similar level – 290.0 Mt CO_2 in EU27+UK and 16.0 CO_2 Mt for Poland. On the other hand, the differences in cumulative emissions for the period 2020-2050 between the scenarios are smaller than the level of emissions in 2050. This is due to the fact that the cost of reductions for the latter scenarios is higher in the 2030s, leading to lower emissions in this period.

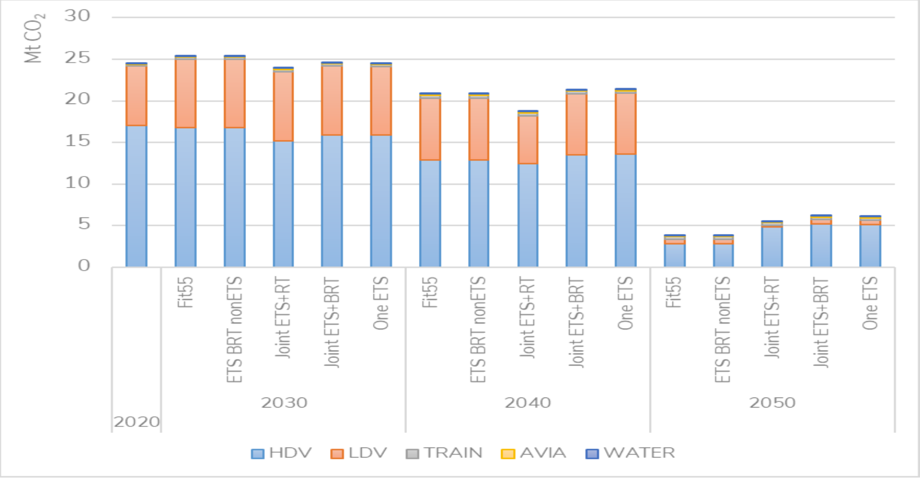
222. The differences between scenarios are larger for freight than for passenger transport. In the case of passenger transport (Figure 71, Figure 73), emission reductions in 2050 relative to 2020 vary between 68.4% - 68.9% in EU27+UK and 70.4% - 71.7% in Poland. For freight (Figure 72, Figure 74) they range from 68.1% for the Joint ETS+BRT scenario to 73.8% for the ETS BRT nonETS scenario in EU27+UK (74.8% and 84.5% for Poland). This is due to the fact that the share of fuel costs in total operation costs is higher for freight vehicles than for passenger vehicles. It follows that an increase in the price of fuel due to increasing emission reduction costs is a much stronger incentive for freight firms to invest in zero-emission technologies, leading to much stronger movements in overall emissions.

Figure 73. Emissions reduction in the passenger transport sector in Poland in 2020-2050 within analysed scenarios



Source: CAKE/KOBiZE

Figure 74. Emissions reduction in the freight transport sector in Poland in 2020-2050 according to analysed scenarios



Source: CAKE/KOBiZE

7.5.3 Agriculture

223. Agricultural sector provides food, one of the most basic goods in the economy. However, technologies used in this sector are still closely related to the biological roots of all agricultural processes. This is one of the reasons of technological backwardness of agricultural sector compared to other sectors of the economy. Due to the use of relatively simple technology, the concentration, globalisation and technological progress in the agricultural sector are still lagging behind other sectors of the economy. To overcome this weakness, the production of food is strongly supported to provide adequate income for farmers. This makes agriculture highly vulnerable to climate policy changes, especially those connected with the additional economic burden. Among the analysed scenarios, it is easy to differentiate those affecting the agricultural sector the most. Joint EST+BRTtax and One ETS scenarios, which assume the introduction of the “emitter pays” rule, influence the GHG emissions from the agricultural sector the most and cause the biggest adjustments in the sector’s structure. One of the most visible changes resulting from taxing the emissions in the agricultural sector is a significant reduction of GHG emissions (Figure 75). Compared to the Fit55 scenario, the GHG emission in EU27+UK region drops by 20%, while in Poland the relative reduction is even greater, reaching 25%.

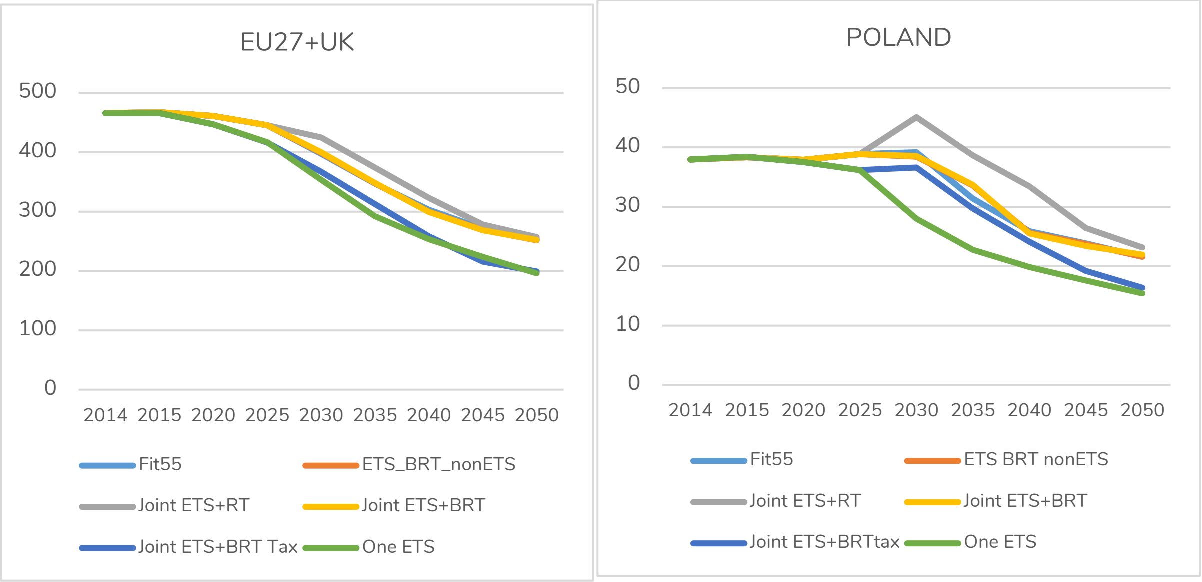
Figure 75. GHG emission form agricultural sector in EU27+UK and Poland in 2050 [Mt CO_2 eq.]*

*scope of GHG emissions according to GTAP10 including fossil fuels used in the agricultural sector.

Source: CAKE/KOBiZE

224. While the “final” effect of GHG emission reduction in considered scenarios in 2050 is very similar, the path to reach this point might be different (Figure 76). The differences in aggregated results for EU27+UK region are not very significant. As mentioned above, the biggest difference could be observed between the scenarios assuming taxation of the GHG emissions in the agricultural sector and other scenarios. In the case of Poland, reduction paths for analysed scenarios are much more differentiated. Under assumptions of the One ETS scenario, the reduction of GHG emissions from the agricultural sector will become significant by 2025, while in other scenarios, it could be observed only 5-10 years later. In 2040, the highest reduction rate could still be observed in the One ETS scenario, while in the Joint ETS+RT scenario, the reduction would be the lowest.

Figure 76. GHG emission reduction path in agricultural sector in EU27+UK and Poland within 2015-2050 [Mt CO_2 eq.]*

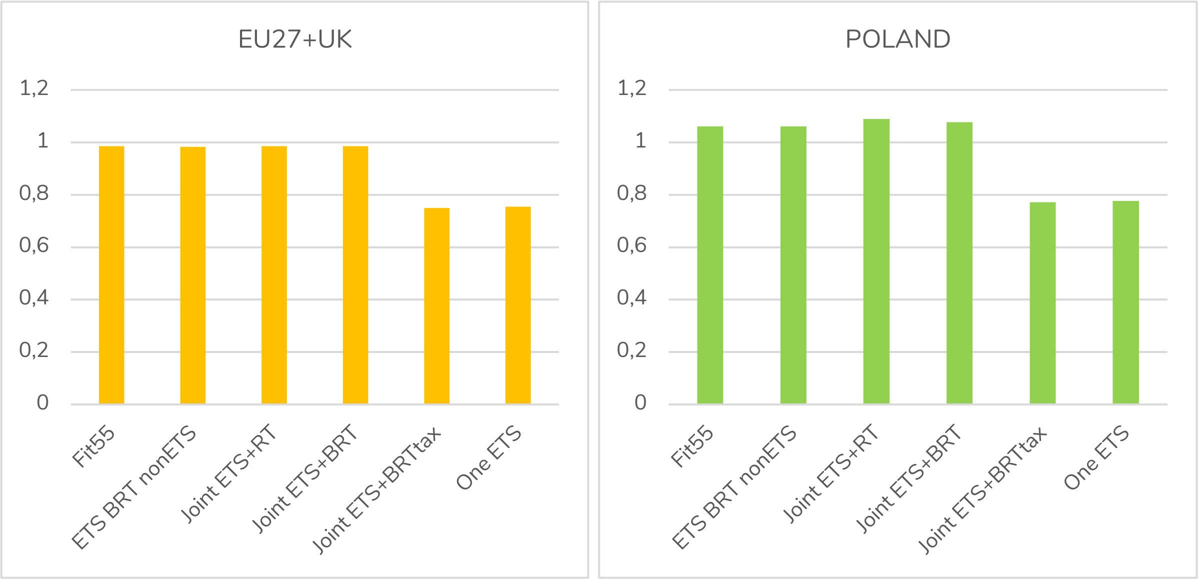


* GHG emissions in 2014 according to GTAP10 including fossil fuels used in the agricultural sector.

Source: CAKE/KOBiZE

225. However, the reduction of GHG emissions has side effects on the production output. Taxation of GHG emissions in the agricultural sector causes a severe reduction in the value of food output. It is especially visible in the case of Poland. In the Fit55 scenario, the agricultural production in Poland in 2050 is only slightly bigger than in the base year. This is the result of a lower initial intensity level, which leaves more space for adjustments to the new policy. This allows to compensate the drop in production in other EU countries with more intensive agriculture (Figure 77). However, in the case of the economic burden of the GHG emissions imposed on the agricultural sector, the drop in production value follows the drop in GHG emissions. Thus, even though the Joint ETS+BRT and the One ETS scenarios are the most effective in reducing GHG emissions from the agriculture sector (both in EU27+UK and in Poland), they are causing the biggest drop in the value of food production.

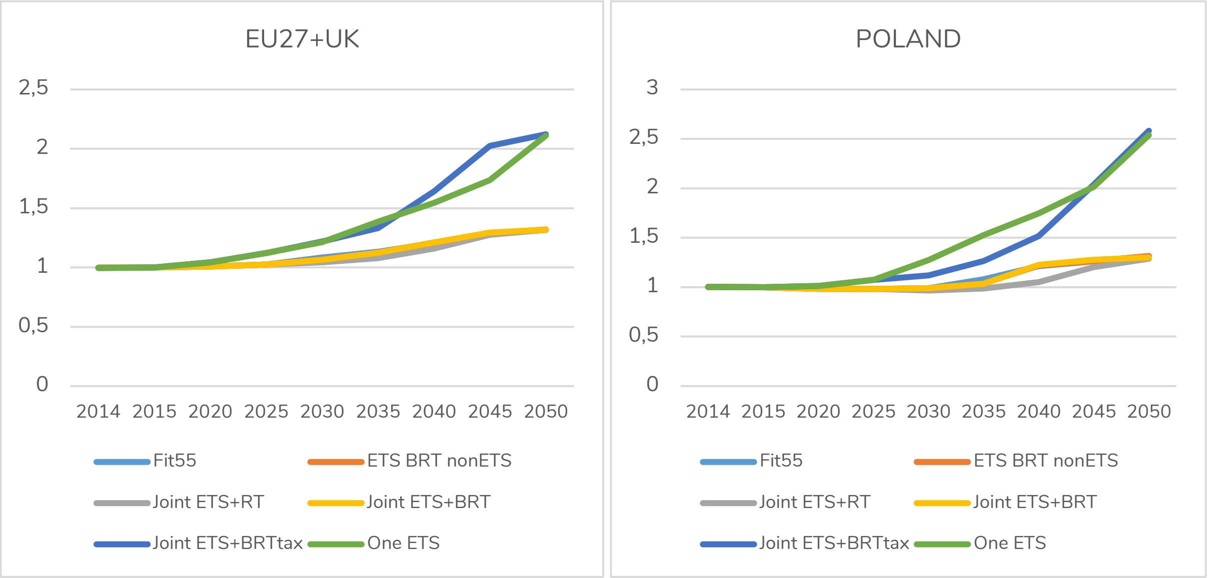
Figure 77. Index of agricultural production value in EU27+UK and Poland in 2050 [2015=1]



Source: CAKE/KOBiZE

226. A decrease in agricultural production explains the increase in prices for agricultural products (Figure 78). In relative terms, the average price increase is higher in Poland than in the EU. One of the main reasons is the lower initial price level of food products in the base year in Poland, comparing to average food prices in EU.

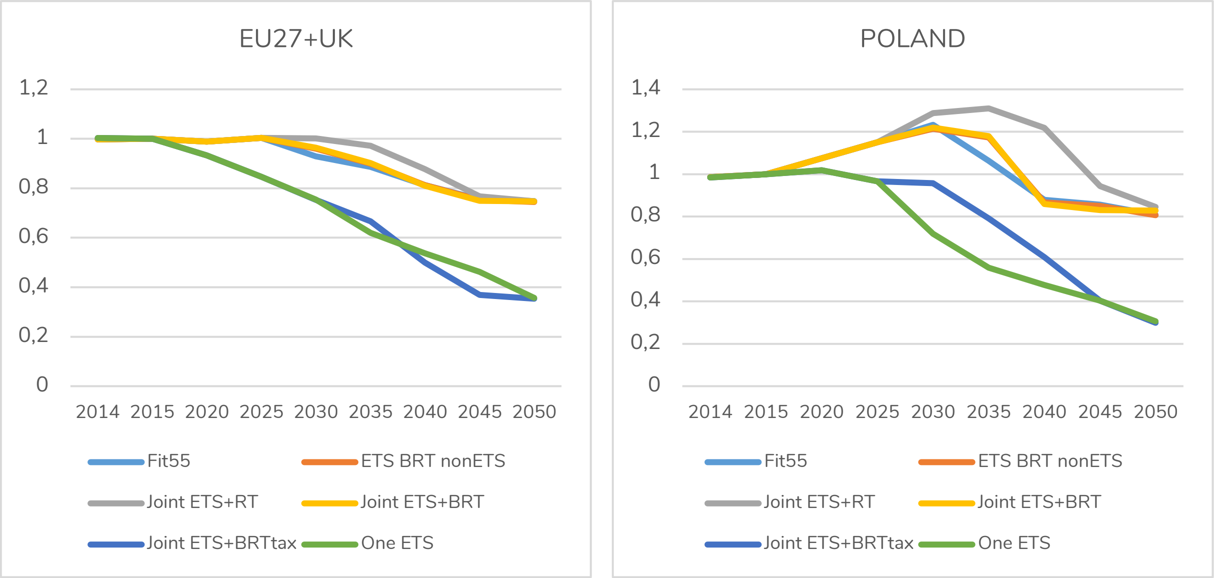
Figure 78. Price index of agricultural products in EU27+UK and Poland in 2050 [2015=1]



Source: CAKE/KOBiZE

227. The price index increase for agricultural products depends on the assumptions of particular scenarios. The introduction of payments for emissions (Joint ETS+BRTtax and One ETS) in the agricultural sector would cause a higher price increase than observed in other scenarios. The increase is even higher in Poland than in the EU, as the 2015 prices in Poland were a bit lower than the EU average. Taking into consideration the price increase of these products, the drop in the production quantity index (value index/price index) due to the assumed climate policy is even more significant (Figure 79).

Figure 79. Volume index of agricultural products in EU27+UK and Poland in 2050 [2015=1]



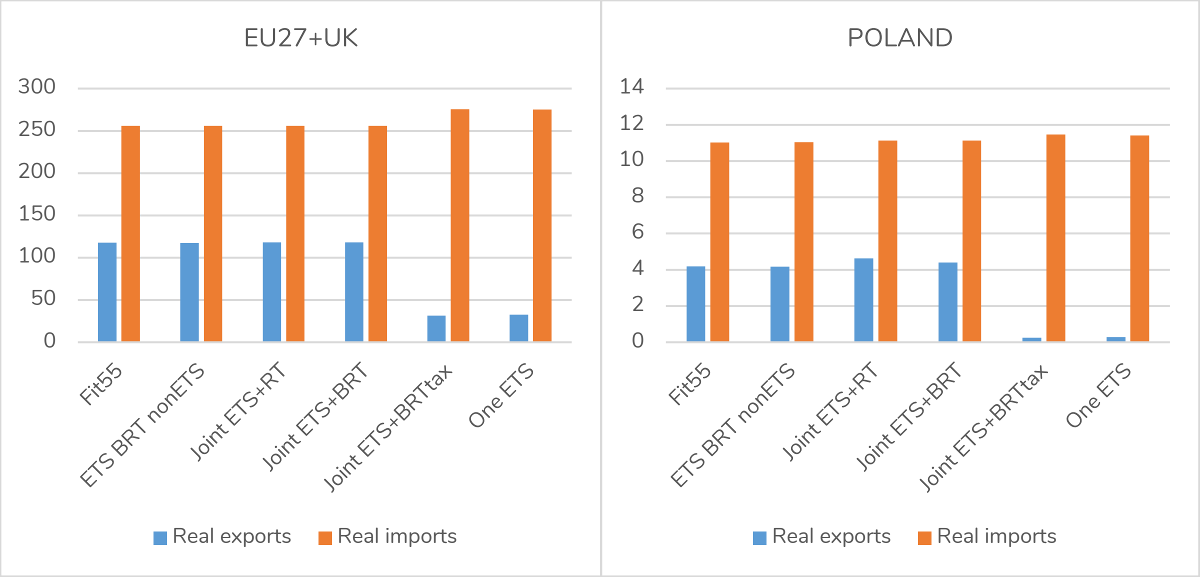
Source: CAKE/KOBiZE

228. In EU27+UK region, introducing the assumed scenarios causes a drop in agricultural production output by 25% in the Fit55 scenario and even 60% in the case of the last two scenarios (Joint ETS+BRT and One ETS) with the GHG emission taxation in agriculture. Projections for Poland in 2050 are quite similar. However, in less restrictive scenarios, agricultural production output in Poland is increasing until 2030 to compensate for the production drop in other European countries. Yet, in the following years, the production drops to a level similar to the other EU27 countries.

229. Scenarios resulting in higher reduction of production in the agricultural sector strongly influence foreign trade of agricultural products. The supply gap of agricultural products at the European market has a strong impact on foreign exchange. It needs to be mentioned that in the base year (2015) both PL and E27+UK countries were net exporters of food products. In considered scenarios the traded quantities are changing significantly. It is especially visible in Poland, where exports of agricultural products in the Joint ETS+BRT

and One ETS drop nearly to zero. The increase in the imports of agricultural products is higher at the EU level than in Poland (Figure 80).

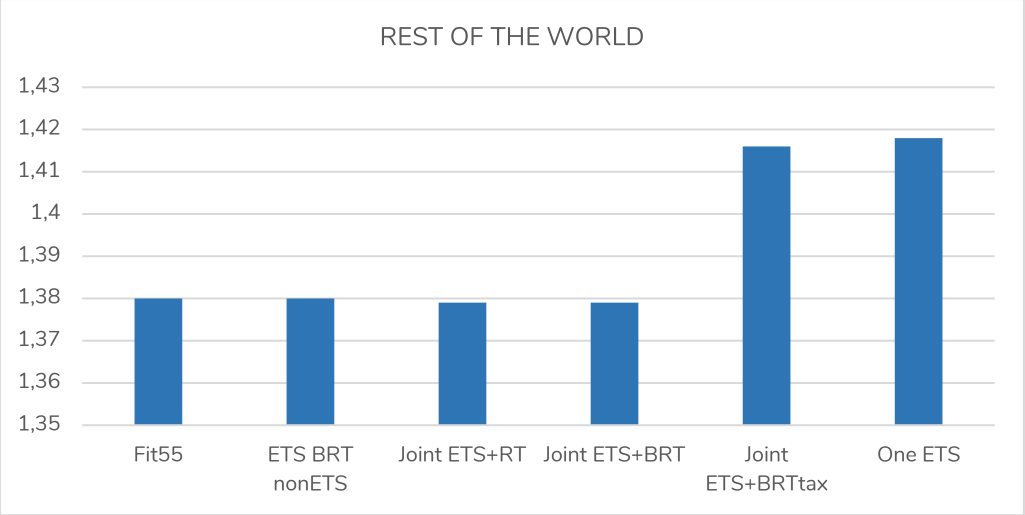
Figure 80. Foreign trade of agricultural products in EU27+UK and Poland in 2050 [billion EUR]



Source: CAKE/KOBiZE

230. Changes in the shares of agricultural products of the EU origin on the global market induce an increase in food supply in the rest of the world. Observing an increase in agricultural production in other countries of the world (Figure 81), it is clear that implementing ambitious policy regarding the limitation of GHG emissions in the EU might result in carbon leakage and lead to the overall global GHG emission increase from agriculture and deforestation.

Figure 81. Agricultural production index in the Rest of the World (RWW region) in 2050 [2015=1]



Source: CAKE/KOBiZE

231. The last statement is especially valid in case of the two last scenarios. Taxation of GHG emissions in the EU's agricultural sector could strongly decrease its competitiveness and undermine food security in European countries, which could become more dependent on foreign production not covered by strict climate policies. However, it is highly probable that in case of the realisation of assumptions of the last two scenarios, additional policy measures within the EU's Common Agricultural Policy (CAP) would be introduced to prevent the deterioration of farmers' income. Introduction of such actions would keep the situation in the agricultural sector in closer alignment with other analysed scenarios at the cost of additional public expenditures.

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Annex I – Analytical tools

A. The d-PLACE model

General overview

233. D-PLACE[41] is a recursive dynamic, global, multi-sector Computable General Equilibrium (CGE) model, based on GTAP 10 (Global Trade Analysis Project) data. In a current setting, the model distinguishes 20 industries/commodities, and 10 regions (country groups or individual countries), including 9 EU regions (additionally including the United Kingdom), and the rest of the World. The model is solved for the years 2014-2050 and the scenarios conform with external projections of GDP growth rates by country, fossil fuel price trends and the imposed emission limits. GDP growth rates and fuel prices are based on projections assigned to the EU Reference Scenario 2020[42] (for more information about assumed fuel prices see Chapter B).

Emission abatement options – assumptions used in the analysis

234. In our model simulations, greenhouse gas emissions reduction is facilitated by a wide range of abatement options. Estimated marginal and total costs of emission abatement are effectively driven by an associated range of assumptions, concerning costs and potentials of individual low-carbon technologies, rate of adoption of those technologies, the sensitivity of demands to prices of emission- or energy-intensive goods and services, etc. In essence, the model suite is a framework that allows combining assumptions in a consistent way.

235. By “consistent way” we mean that various interdependencies are taken into account. Consider green hydrogen use as an example. On the demand side, the assumptions might be formulated in terms of the price threshold above which hydrogen use becomes cost-effective, the maximum share in the energy mix, the rate of adoption depending on the price. On the supply side, the assumptions might include: the cost of electrolysers, expansion of maximum capacity over time, cost of electricity in different bands, etc. From the demand-side assumptions, one derives the demand, given the price. From the supply-side assumptions, one derives the price, given the supply. Consistency requires that we

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[41] Boratyński J., Pyrka, M., Tobiasz I., Witajewski-Baltvilks J., Jeszke, R., Gąska, J., Rabiega, W. (2022). The CGE model d-PLACE, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[42] European Commission, Directorate-General for Energy, Directorate-General for Climate Action and Directorate-General for Mobility and Transport (2020). EU Reference Scenario 2020. Energy, transport and GHG emissions. Trends to 2050. Brussels.

confront those two perspectives, thus arriving at demand/supply and price of green hydrogen, conforming both sets of assumptions.

236. It is important to recognise that simulation results (projections) are merely derivations from the assumptions. Validation of such models does not involve, as one could hope, reproducing history. This is hardly ever possible, due to various reasons, both fundamental and practical. Therefore validation consists of (1) reviewing and revising individual assumptions and (2) identifying implausibilities (anomalies) in model projections, based on current expert knowledge. Identifying an implausible result is followed by adjustments of related assumptions, an inspection of updated simulation results, and the process continues until the results are conceivable. No formal statistical (empirical) validation approach is available, though.

237. In light of the above, it is essential to display the assumptions comprehensively. We attempt that further in this section. In some cases, the assumptions can be stated explicitly. In most cases, however, it is more useful to show the results, i.e., the derivations from raw assumptions. This is because raw assumptions are often formulated in terms of parameters that are not easily interpretable. Take the example of energy efficiency improvement. In the model, it has two components – exogenous (autonomous) and endogenous energy efficiency improvements. Exogenous efficiency improvement is related to technical progress, and it is unrelated to current energy prices. In this case, assumption can be stated directly, as percentage change per year. On the other hand, endogenous improvement of an industry is modelled as the substitution of energy for capital. This substitution effect is driven by changes in energy prices relative to the capital rental rate, and the strength of this effect depends on an assumed value of the parameter called the elasticity of substitution. Yet, the elasticity parameter does not inform directly, e.g., how much energy efficiency will improve in subsequent periods.

238. It is also worth emphasizing that we can only have a broad idea of adequate values of such parameters as the elasticities – rather their orders of magnitude than the levels. There is generally a lack of robust empirical evidence about many of the crucial parameters, making it more important to inspect the results and adjust the parameters as needed. Indeed, even though literally such outcomes as energy efficiency improvement are technically the results of modeling, they are in fact decisively controlled by the assumptions.

239. Below we present an overview of assumptions and results, related to various aspects of a low-carbon transition. The results are shown for the Fit55 scenario, being our reference scenario. In most cases we present outcomes for the EU27+UK, aggregated (as total or average) over individual model regions.

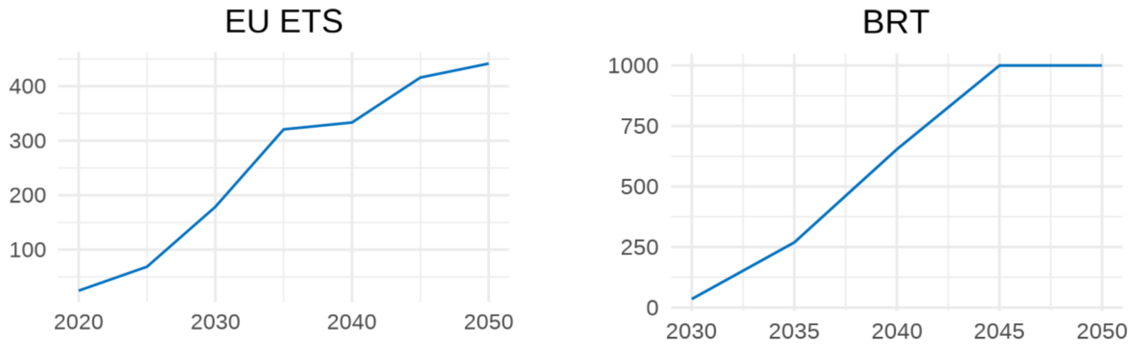
Carbon prices

240. In a certain sense, carbon prices embody all detailed assumptions on emission reduction costs and potentials (and, obviously, reduction targets). Carbon prices are equivalent to marginal costs of emission abatement. In the case of EU ETS and BRT ETS, these are also actual prices paid for emissions. In the case of non-ETS, the price is implicit – it represents a shadow price on emissions constraints imposed by various command-and-control type policies (i.e., if emission constraints could have been relaxed by 1 t CO_2 eq., the associated reduction in the cost of production is the carbon price).

241. As can be seen in (Figure 82 and 83), the prices increase fairly steeply, especially in BRT ETS and non-ETS. We impose a cap on the carbon price, at EUR 1000/t CO2eq. Reaching this cap in fact indicates exhaustion of emission reduction potentials, as represented in our models. Imposing a cap on carbon price would result in excess emissions – that is, not meeting the reduction target (by about 10 Mt CO_2 eq. in 2030, 40 Mt CO_2 eq. in 2040, and 190 Mt CO_2 eq. in 2050). However, we include a generic backstop technology, operating at the cost of EUR 1000/t CO_2 eq., preventing those excess emissions. In fact, external assessments of the potentials of various emission reduction measures rarely assume carbon prices as high as EUR 1000 /t CO_2 eq.. If this were the case, the reduction potentials could perhaps be higher, or other opportunities should arise. Backstop technologies could include DACCS, increased capacity of carbon storage, increased absorption in the AFOLU sector, and others.

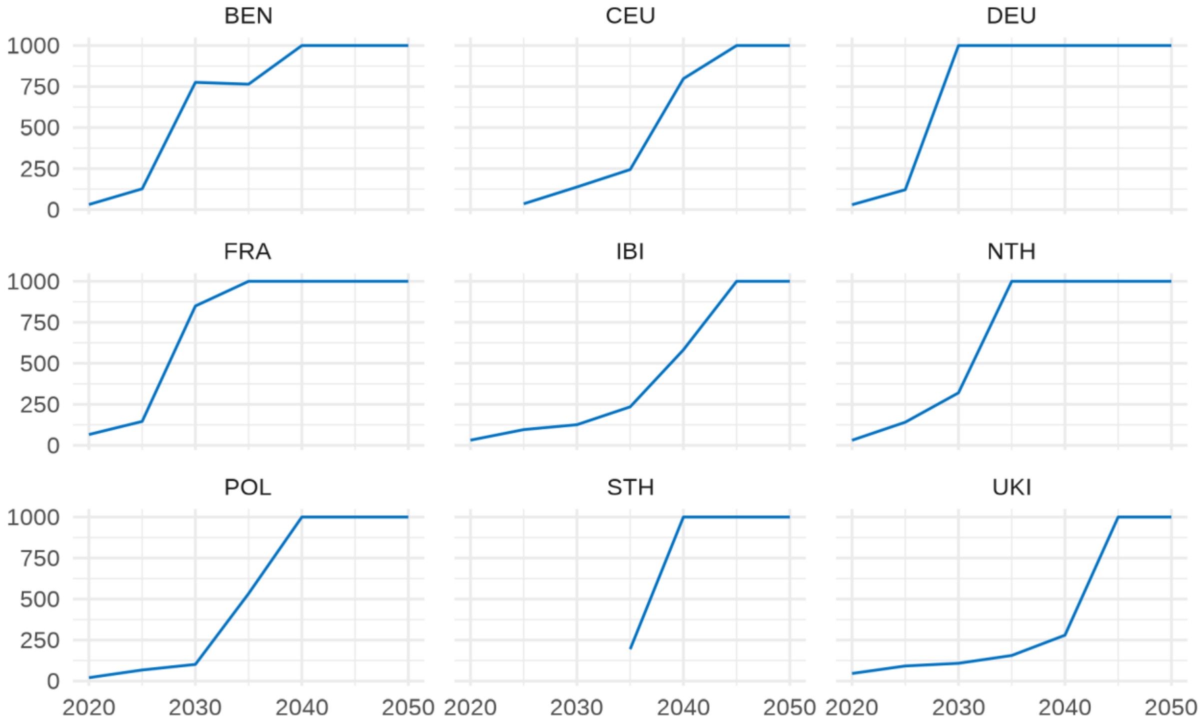
242. Worth noting, we do not map the backstop technology to sectors explicitly, so the sum of sectoral emissions reported is higher than the emission limit. This is as if excess emissions were absorbed at the total economy level.

Figure 82. Cost of emission reduction in EU ETS / BRT ETS in Fit55 scenario [EUR'2015/t CO_2 eq.]



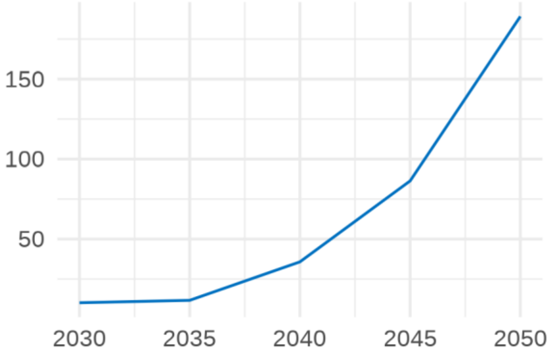
Source: CAKE/KOBiZE

Figure 83. Shadow cost of emission reduction in non-ETS in Fit55 scenario [EUR’2015/t CO_2 eq.]



Source: CAKE/KOBiZE

Figure 84. Emission reduction by generic backstop technology in Fit55 scenario [Mt CO_2 eq.]



Source: CAKE/KOBiZE

Emission absorption potential

243. It is assumed that towards the end of the simulation horizon in 2050, the net removal in the LULUCF sector in the EU will provide emissions absorption of around 500 Mt CO_2 eq. per year.

244. Another source of emission absorption is bioenergy with carbon capture and storage (BECCS). This technology is assumed to operate in the power sector, with the potential limited primarily by biomass availability, as well as limited storage capacity. Absorption from BECCS amounts to approx. 4 Mt CO_2 in 2030, 200 Mt CO_2 in 2040 and 290 Mt CO_2 in 2050.

Power sector

245. The power sector, encompassing electricity generation, district heating and "green" hydrogen supply, is the largest single contributor to emission reduction in our scenarios. In fact, from 2040 it reports negative net emissions, thanks to the BECCS technology. The models of this sector – MEESA – generate projections on the technology mix that minimize the long-run cost at the EU+ level. The model includes a large number of physical, technological and economic constraints and assumptions (which we discuss in section B of this annex. For more information, see MEESA technical documentation[43]).

Energy efficiency

246. Figure 85 shows changes of energy intensity by sector (incl. industries and the household sector), averaged over EU regions. Energy intensity is expressed as the volume of energy per unit of gross output in the case of industries and per unit of consumption in the case of households (output and consumption being expressed in constant price money terms). In most sectors, the reduction in energy intensity in the years 2020-2050 is within the range of 40-60%, i.e., between 1.7% and 3% reduction per year. In this, 1 percentage point (p.p.) is the so-called autonomous energy efficiency improvement, resulting from technical change and not associated with any cost, whereas the remaining part is modelled as substitution of energy for capital, induced by the rising energy prices. In the case of road transport, a portion of energy efficiency improvement stems from electrification.

247. An important part of energy efficiency improvement is associated with housing (buildings). Our model does not distinguish energy uses by purpose, i.e., energy used specifically for space or water heating, etc. Instead, the model distinguishes energy use by sector (industries and the households sector) and energy form. One exception is the distinction of refined oil fuels used for transport purposes and otherwise. In the model, we identify energy use by households and the service sector (except transport) with the broad category of housing/buildings energy use. Energy efficiency improvements induced by the increasing cost of emissions and energy is modelled as a substitution of energy for capital, or for a bundle of non-energy goods and services (as a proxy to spending on equipment, construction services etc. by households). It should be noted that this is a simplistic

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[43] Tatarewicz, I., Lewarski, M., Skwierz, S., (2022) The MEESA Model, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

approach, as it does not track actual stocks and characteristics of buildings, specific technologies employed, and other.

Material efficiency

248. We assume an autonomous (cost-free) material-saving technical change concerning energy- or emission-intensive materials, such as steel or cement, at the rate of 0.2% per year.

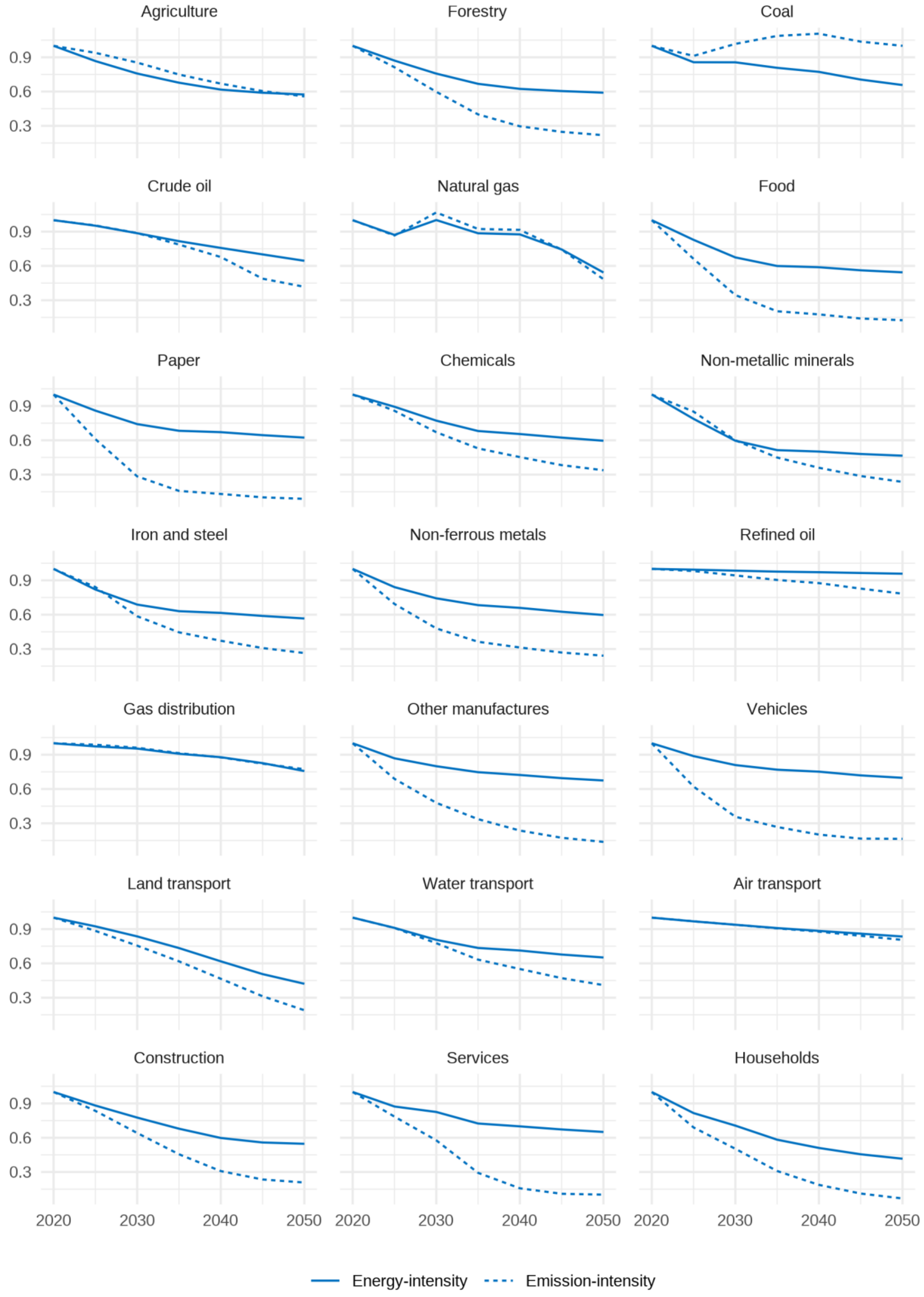
Energy mix by sector

249. Changes in the energy mix of end-users are what could be expected under a decarbonisation scenario – there is a marked decrease in the use of fossil fuels, as well as a strong upward trend in electricity share, reinforced by some increase in green hydrogen use (see Figures 86 and 87). Note that gas and gas distribution should be taken jointly – countries rely on different statistical conventions and record gas supplies in either of these two sectors. One fossil fuel that still has a substantial share even in 2050 is oil, due to demand from the transport sector. Results from the TR^{3}E model (see Chapter 7.5.2) lead us to consider transport as one of the bottlenecks in emission reduction. It is partly due to an observation that the replacement of the transport fleet is characterized by significant inertia.

Emission intensity by sector

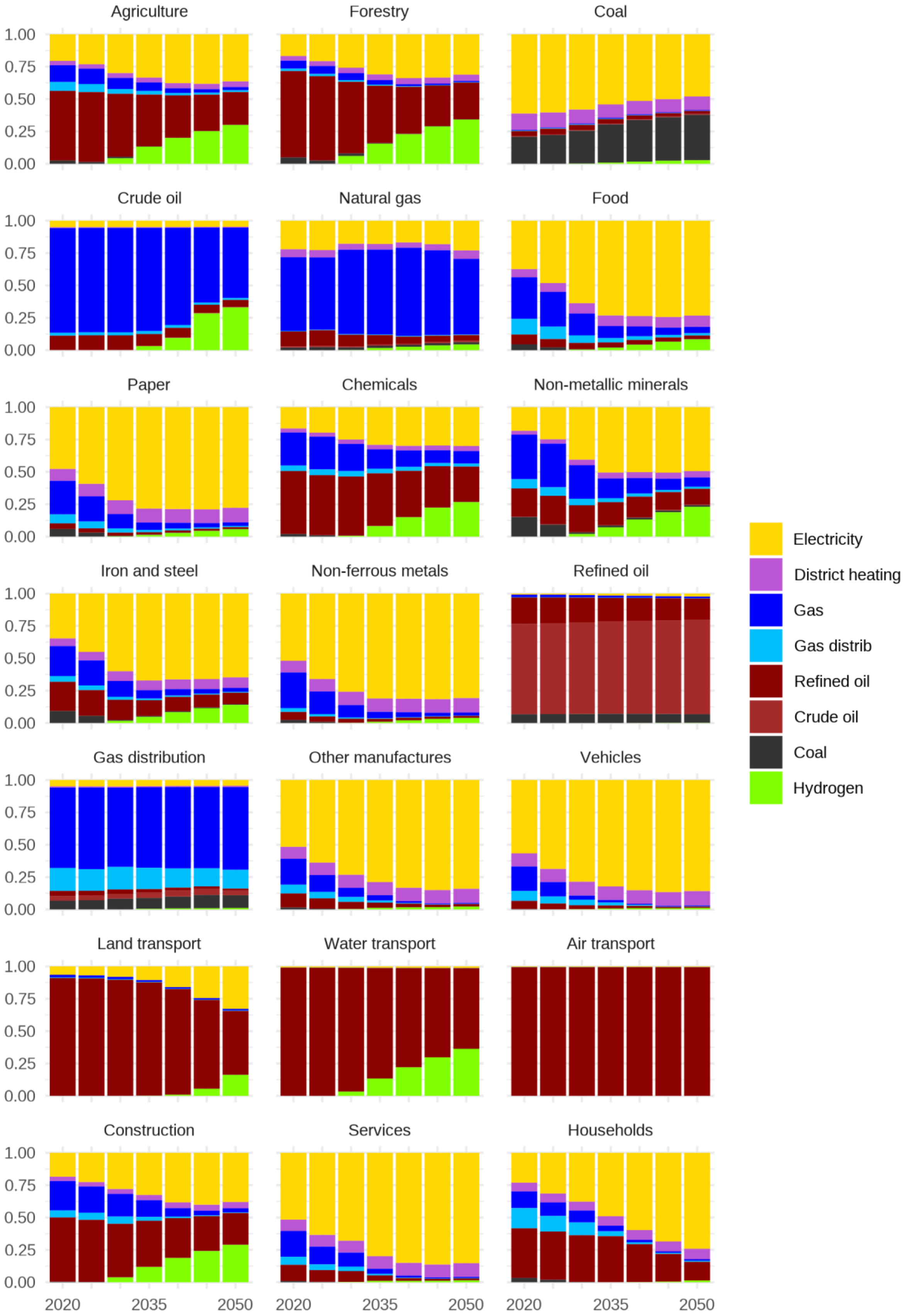
250. The decrease in emission intensity is partly associated with energy efficiency improvement, but it typically far exceeds the latter effect (see Figure 85). Electrification is an important cause here, but there are several other factors contributing to that effect in our simulations, related to sector-specific abatement technologies and actions. An overview of those options is provided below.

Figure 85. Energy and emission intensity by sector in EU27+UK (2020=1)



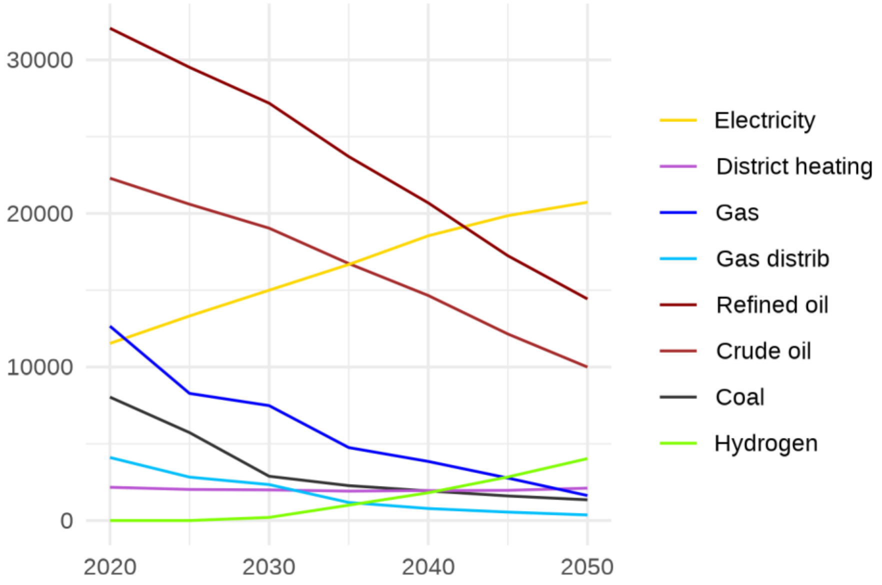
Source: CAKE/KOBiZE

Figure 86. Energy mix by sector in EU27+UK in Fit55 scenario



Source: CAKE/KOBiZE

Figure 87. Gross energy use by energy in Fit55 scenario in EU27+UK [PJ]



Source: CAKE/KOBiZE

Green Hydrogen

251. Hydrogen is considered in the model as a substitute for natural gas and oil products. The possibility of substituting gas with green hydrogen is only assumed for production activities (industries) and not for households. In the case of oil, green hydrogen is assumed as a possible replacement in transport equipment, as well as other machineries, such as ones used in construction and agriculture.

252. Green hydrogen utilisation as natural gas substitute begins around 2035 (dependent on the region), and in 2050 reaches around 40-60% shares in processes that were originally fuelled by gas. Green hydrogen as an oil substitute occurs a little earlier, in 2030-2035 and by 2050 tops at around 50% share in processes originally fuelled by oil.

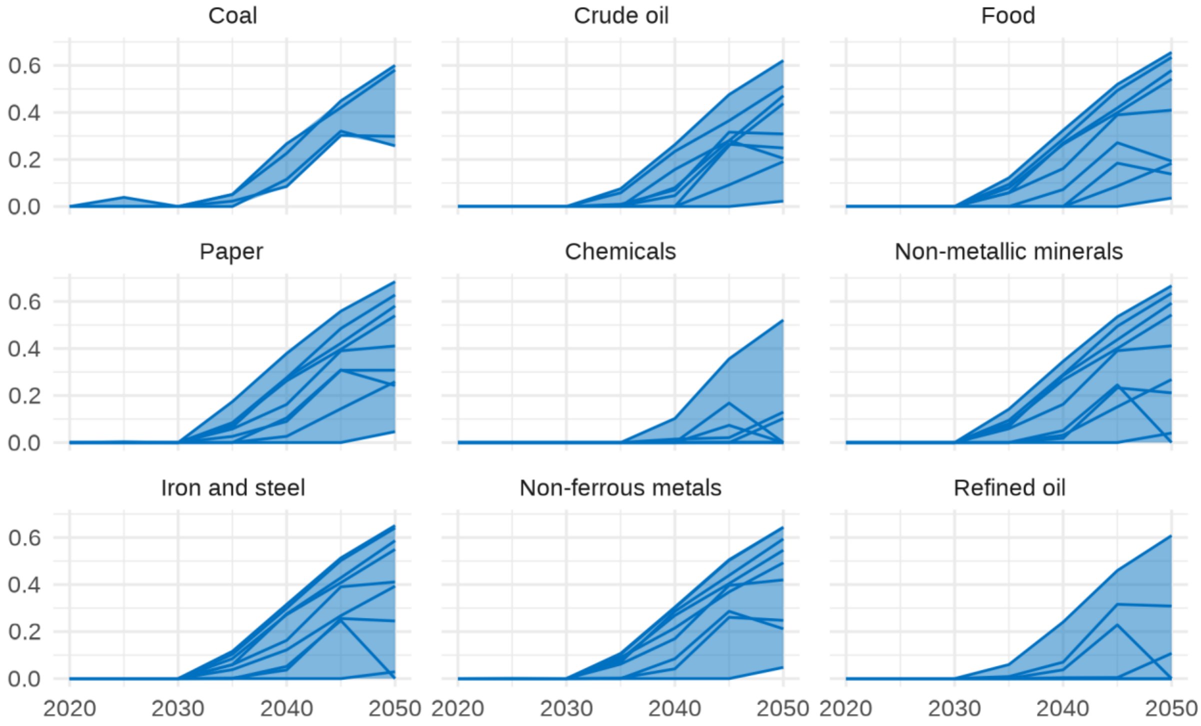
253. We did not consider hydrogen subsidies or any other support for hydrogen. Without such support, according to our results, green hydrogen is not price-competitive before 2030. The reason for it becoming competitive earlier in the case of oil, than in the case of gas, is because, according to the projections, oil energy price is higher than gas energy price. Furthermore, oil is mostly used in non-ETS sectors, where carbon prices are relatively high.

254. The result that hydrogen share as a gas substitute substantially varies by region, can be attributed to hydrogen prices also varying by region, as well as to a usually small margin between unsubsidized hydrogen prices and gas prices (emission cost inclusive), given that carbon prices in the EU ETS are still relatively low in most years (when compared to marginal abatement cost in the non-ETS).

255. In the case of water transport, we identify green hydrogen with ammonia, and so treat the cost of green hydrogen as a proxy of the cost of ammonia. In 2050 the share of ammonia as a water transport fuel is around 30-40%.

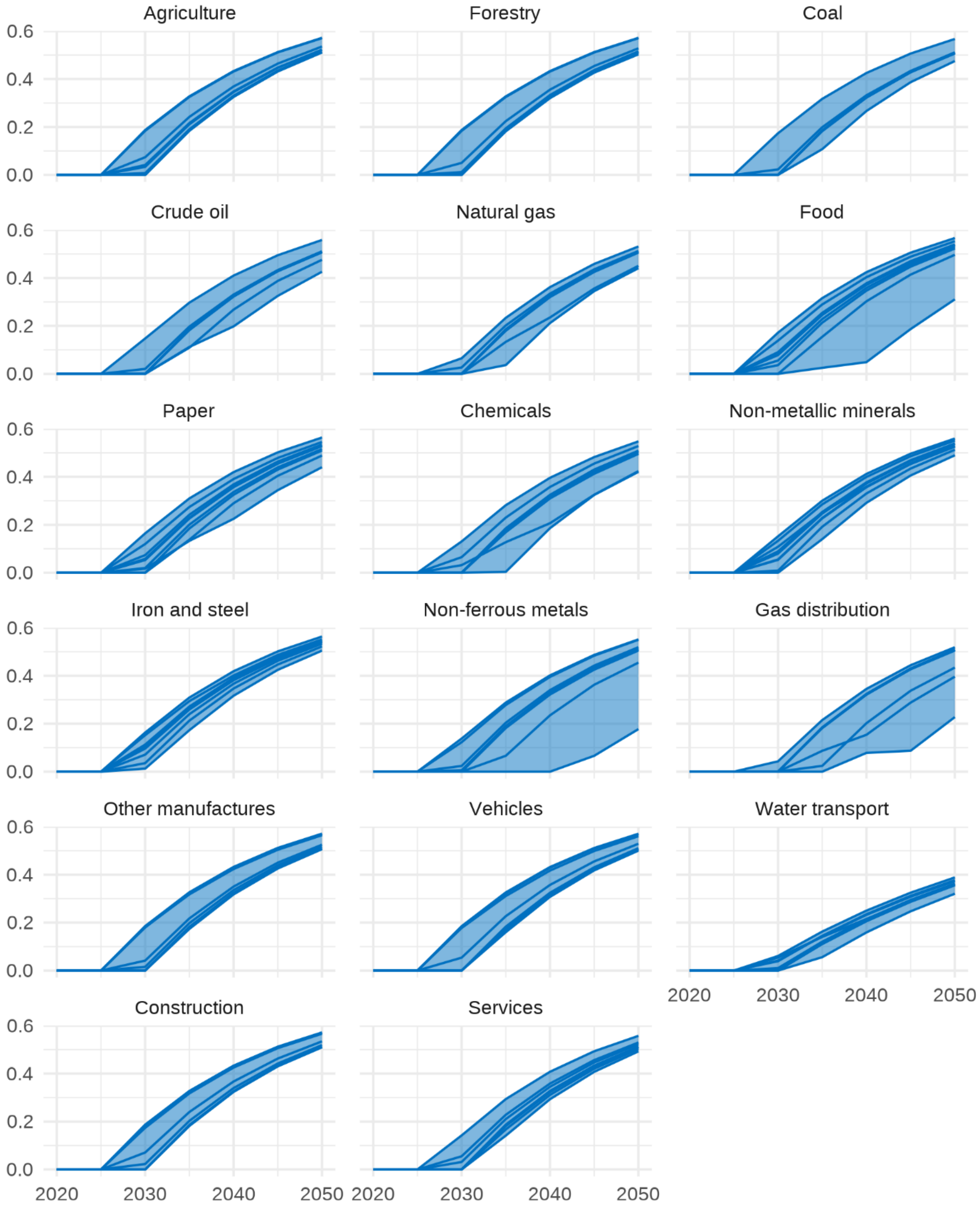
256. In Figures 88 and 89, individual lines represent green hydrogen shares in individual EU27+UK regions, whereas the shaded region shows the range of results. The same scheme applies to subsequent graphs in this section, relating to other abatement options.

Figure 88. Share of green hydrogen which replaced natural gas in EU27+UK



Source: CAKE/KOBiZE

Figure 89. Share of green hydrogen which replaced oil in EU27+UK

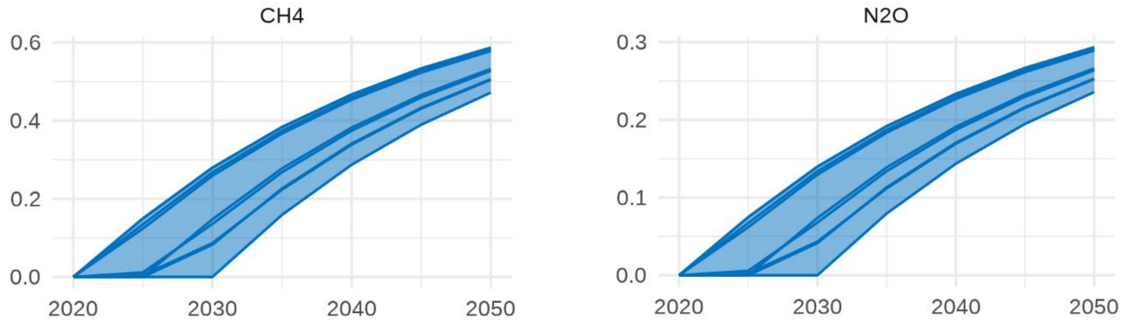


Source: CAKE/KOBiZE

Agricultural CH_4 and N_2O emissions

257. We observe 50-60% reduction of CH_4 emissions per unit of output in 2050. 25-30% reduction of N2O emissions per unit of output in 2050. Reductions are achieved mostly by a substantial change in the structure of agricultural production, in particular the reduction of cattle livestock. Abatement potentials and costs were calibrated to the results from the EPICA model.

Figure 90. Emission reduction per unit of agricultural output (CH_4 - left and N_2O - right side) due to change in production structure in EU27+UK

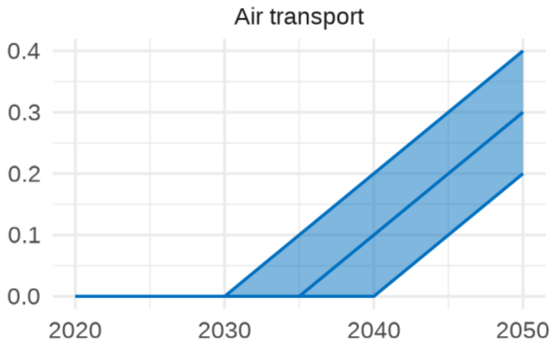


Source: CAKE/KOBiZE

Aviation

258. Utilization of biofuels in air transport begins in 2035, reaching the share of 20-40% in the year 2050. This share relates to intra-EU and part of extra-EU flights (from or between EU27+UK airports) covered by EU ETS.

Figure 91. Share of biofuels in aviation which replaced oil consumption in EU27+UK

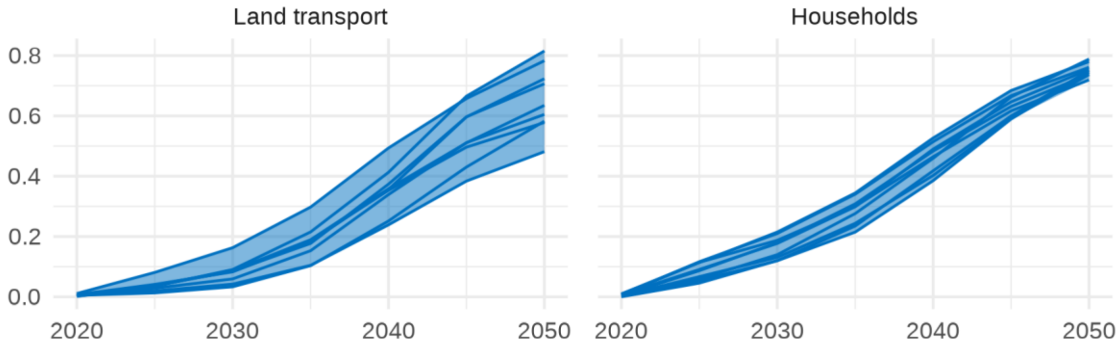


Source: CAKE/KOBiZE

Land transport.

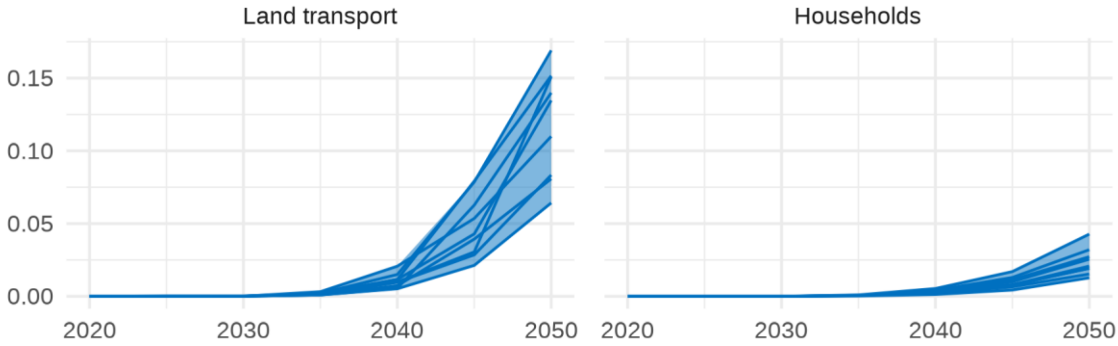
259. In the Fit55 scenario, the share of electricity in road transport by 2050 will increase to 45-80% in transport services (land transport sector), depending on the region. In the case of individual transport, which represents the household sector, this share varies between 70 and 80%. As for the use of hydrogen, its share in transport services in 2050 varies between 6 and 17%. However, for individual transport, this share is approx. 2-4%. The increase in the use of both electricity and hydrogen in road transport is due to the development and growing use of zero-emission technologies. These changes are represented in the TR^{3}E model (see for details in Chapter 7.5.2).

Figure 92. Electricity share in energy used in road transport by sector in EU27+UK



Source: CAKE/KOBiZE

Figure 93. Hydrogen share in energy used in road transport by sector in EU27+UK

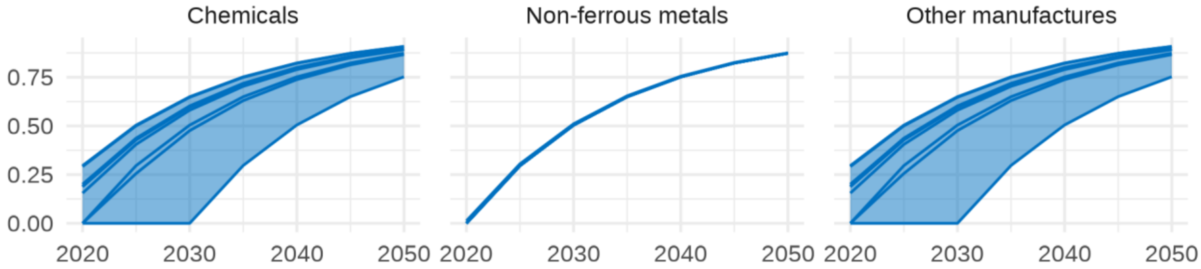


Source: CAKE/KOBiZE

Industrial F-gases

260. We assume around 90% reduction in f-gas emission intensity in chemicals, alluminium production and other manufacturing by 2050 (around 60% reduction in 2030). The reduction potential have been adopted from EC Impact Assessment Report to proposal for a Regulation on fluorinated greenhouse gases[44].

Figure 94. Reduction of industrial f-gases in chemicals, aluminium production and other manufacturing in EU27+UK



Source: CAKE/KOBiZE

Industrial CCS/CCU

261. In the case of industrial CCS/CCU we rely on maximum shares and costs of captured emissions from literature Budins et al. (2019)[45] i Leeson et al. (2017)[46]. The shares of captured CO_2 process emissions in chemicals and non-ferrous metals sectors reache around 40% in 2050, whereas in iron and steel and non-metallic minerals sectors these shares are 60% and 70%, respectively.

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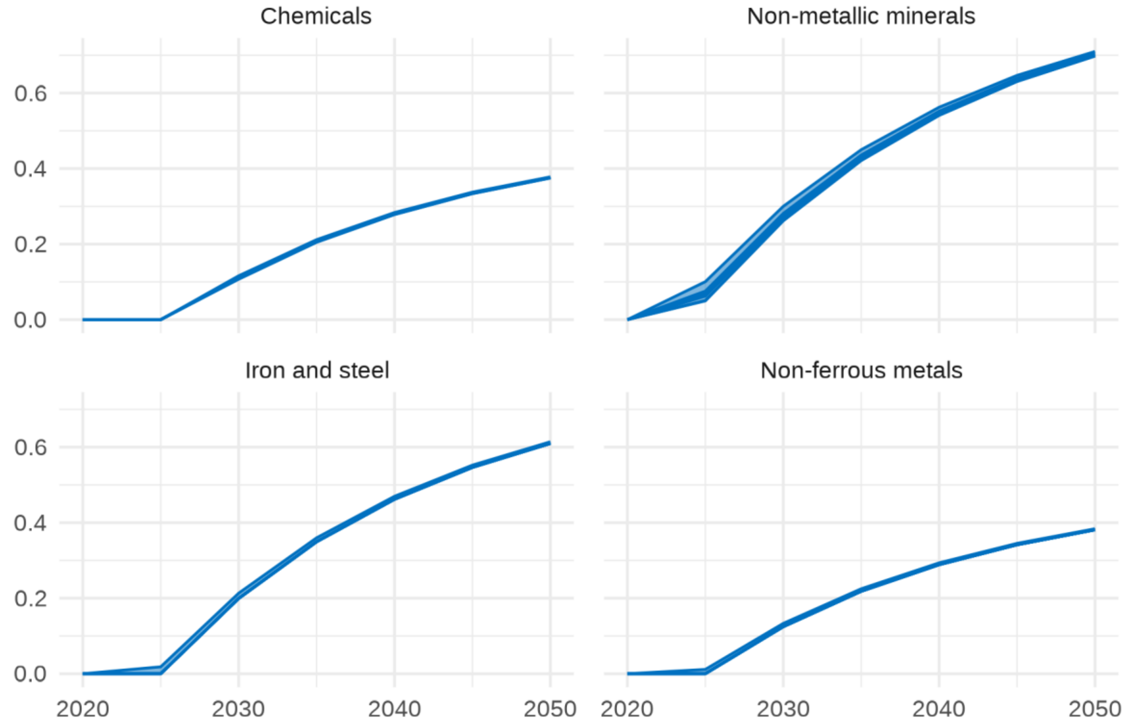
[44] European Commission, Commission staff working document Impact Assessment Report Accompanying the document proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (eu) 2019/1937 and repealing Regulation (eu) no 517/2014, Strasbourg, 2022

[45] Budinis S., Krevor S., Mac Dowell N., Brandon N., Hawkes A., An assessment of CCS costs, barriers and potential, Energy Strategy Reviews 22 (2018) 61–81.

[46] Leesona D., Mac Dowell N., Shah N., Petita C., Fennella P.S., A Techno-economic analysis and systematic review of carbon captureand storage (CCS) applied to the iron and steel, cement, oil refiningand pulp and paper industries, as well as other high purity sources, International Journal of Greenhouse Gas Control 61 (2017) 71–84.

Figure 95. Share of CO_2 emission in industry captured by CCS/CCU in EU27+UK

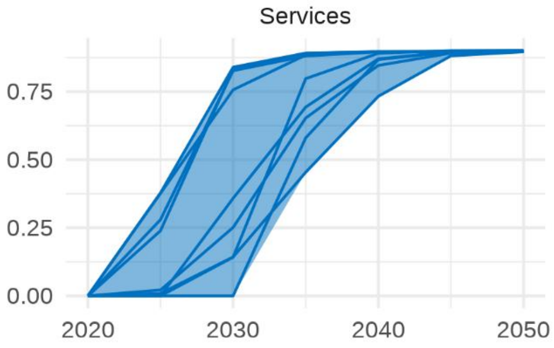


Source: CAKE/KOBiZE

CH_4 emissions from waste and N_2O emissions in chemicals and services

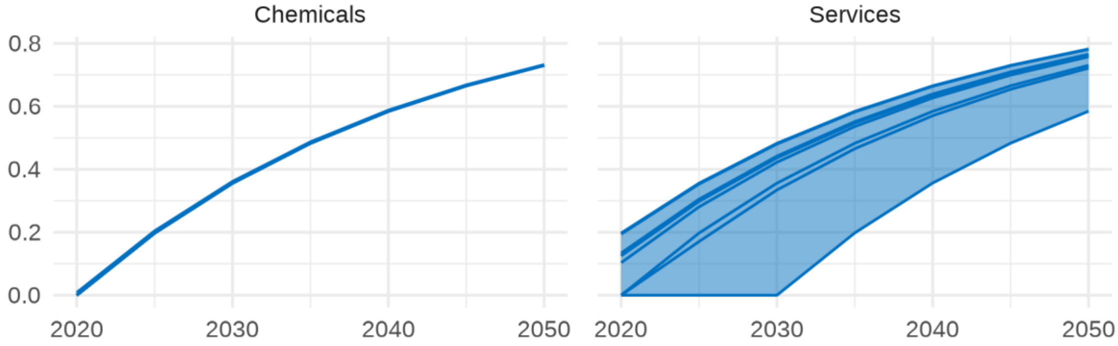
262. Figures 96 and 97 below illustrate the emission intensity reductions for CH_4 emissions from waste and N_2O emissions in chemicals and services sectors. In the case of CH_4 from waste, the reduction in emission intensity reaches around 90% in 2050, whereas N_2O emission intensity decreases by roughly 60-80%.

Figure 96. Reduction of CH_4 in waste in EU27+UK



Source: CAKE/KOBiZE

Figure 97. Reduction of N_2O emissions in chemicals and services in EU27+UK



Source: CAKE/KOBiZE

B. Energy system model – MEESA

263. The Model for European Energy System Analysis – MEESA[47] is a model of the energy system for 27 EU Member States, additionally including the United Kingdom, Switzerland and Norway, designed for a long-term integrated assessment and energy planning in this region. MEESA model is designed, among other, to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations, market regulations, cross-border energy flow, required levels of emission reduction and required share of renewable energy sources (RES) in a given period. The model covers key dynamics and relations that reflect the functioning of the power, district heat and green hydrogen sectors.

264. MEESA allows to prepare a long term optimisation of the future energy mix for connected EU countries based on specific technical, economic and political conditions. The underlying principle of a model, built on basis of the OSeMOSYS[48], is an optimisation of an objective function under a set of constraints that define the scope of all possible solutions to the problem. Given a vector of demands for electricity, district heat and green hydrogen, the model assures sufficient supply to demand, utilizing the technologies and resources considered. Energy demand data, exogenous to the model, is given at the final level of the energy chain. The value of the objective function helps to choose the solution considered best according to the criteria specified. MEESA allows modelling of all steps in the energy

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[47] Tatarewicz, I., Lewarski, M., Skwierz, S., (2022) The MEESA Model, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

[48] Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazilian, M., Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. Energy Policy, 39 (10), pp. 5850-5870.

flows from supply to demand, which is generally referred to as the energy chain and steps called levels.

265. In all scenarios, the contribution of the power and district heating sectors to the reduction effort was assumed to an extent ensuring the achievement of general objectives adopted at the national and the EU levels, with the following elements taken into account:

- The time horizon was defined for the years 2020-2050, i.e. covering the key period for assessing the impact of the energy and climate policy and achieving the Community goals in the field of GHG reduction.
- Demand for electricity, district heating and green hydrogen was determined in an iterative process between MEESA models and the macroeconomic model (d-PLACE) and sectoral models of transport (TR^3E) and agriculture (EPICA). At the MEESA model level, additional demand for heat pumps and energy storage is generated.
- National targets for each EU country in terms of phase-out of coal, approaches to nuclear power (including units planned and under construction) and other significant investments that are of interest to a given country[49,50].
- Cross-border exchange capacity under the ENTSO-E – both in relation to historical data[51] and their planned development[52]. The MEESA model takes into account the cross-border exchange, to a large extent as an important function of the wholesale electricity market, but also securing the supply by maintaining the generation reserve at a level specified for each country, with import capacities not being included in the power reserve balance.
- Maximum potentials of RES generation capacity common for the analytical scenarios (onshore wind farms, solar power plants, biomass, biogas, geothermal power plants)[53,54,55]. On the other hand, concerning offshore wind farms, the power potentials forecast by Wind Europe[56] and the World Bank[57,58] were used (due to

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[49] National energy and climate plans (https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en#final-necps access: 31.12.2021)

[50] World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles.aspx access: 31.12.2021)

[51] Transparency Platform (https://transparency.entsoe.eu access: 30.11.2020)

[52] Ten Year Network Development Plan 2020, ENTSO-E, Brussels 2020.

[53] Ten Year Network Development Plan 2018, ENTSO-E, Brussels 2018.

[54] Ten Year Network Development Plan 2020, op.cit.

[55] P. Ruiz, A. Sgobbi, W. Nijs, C. Thiel, F.D. Longa, T. Kober, B. Elbersen, G. Hengeveld, The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries, Luxembourg 2015.

[56] Our energy, our future. How offshore wind will help Europe go carbon-neutral, Wind Europe, 2019.

[57] Offshore Wind Technical Potential in Romania, The World Bank, 2020.

[58] Offshore Wind Technical Potential in Romania, The World Bank, 2020.

the lack of the Black Sea basin in the Wind Europe study, for Romania and Bulgaria the potential included in the World Bank studies was assumed limited to wind farms attached to the seabed marine).

- CCS (Carbon Capture and Storage), CCU (Carbon Capture and Utilisation), BECCS (Bioenergy with Carbon Capture and Storage) (total CO_2 capture potential in the EU based on EC estimates[59]), hydrogen production with the possibility of use also in the energy sector. The model assumes that the electricity used to produce hydrogen will come from renewable energy sources (the so-called green hydrogen). The analysis also assumes, following the declarations of gas turbine manufacturers, that newly built units of this type will be able to co-combust hydrogen.
- Energy storage facilities – short-term: battery operated in a 24-hour/several-day cycle and – long-term: pumped-storage power plants and hydrogen storage, which can store energy in longer cycles, including seasonal ones (the model assumes the production of hydrogen in the electrolysis process).
- Electric cars are treated in the MEESA model as quasi-energy storage, contributing to the equalisation of daily loads. Electrification of transport will increase electricity consumption and change the demand curve, which may be an important element of future changes in the electricity market.
- Fuel prices are based on projections assigned to the EU Reference Scenario 2020[60]. However, in order to reflect the current situation on the fuel market, the following adjustments were made to the forecast used: in 2025 gas prices are three times higher than in the EU Reference Scenario 2020 forecast, coal prices 2 times higher and oil prices 1.5 times higher. From 2030, prices return to the path of the EU Reference Scenario 2020 forecast.
- Prices of CO_2 emission allowances are the result of iteration with the d-PLACE model and sectoral models. Solving the models iteratively results in obtaining a price path that leads to the set reduction goals. From the MEESA model perspective, changes in allowance prices cause changes in the energy mix and affect the achieved emission reduction. From the perspective of the d-PLACE model, changes in emission reductions achieved in the energy sector affect the prices of emission allowances in the EU ETS system.

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[59] A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy, COM(2018) 773, European Commission, Brussels 2018.

[60] European Commission, Directorate-General for Energy, Directorate-General for Climate Action and Directorate-General for Mobility and Transport (2020). EU Reference Scenario 2020. Energy, transport and GHG emissions. Trends to 2050. Brussels.

- Energy demand is the output variable of the d-PLACE model. The three most important mechanisms included in the model that determine the energy demand are: (i) autonomous improvement of energy efficiency; (ii) substitution of energy with other production factors, mainly capital, resulting from changes in relative energy prices; (iii) substitution between various energy carriers, in particular, replacing fossil fuel consumption with electricity (electrification) in industry and in the transport sector, resulting from changes in the costs of using individual carriers.
- The technical and economic assumptions in the MEESA model were based mainly on the final assumptions adopted at the end of 2020, which are the basis for the development of the new EU Reference Scenario 2020[61]. Potential data gaps were additionally supplemented with information from studies prepared by recognised research centres dealing with energy modellings and investment processes, such as International Energy Agency, Joint Research Centre, Tractebel, Ecofys or Frontier Economics.

C. Transport model – TR^{3}E

266. TR^{3}E model is a simulation model for the transport sector[62]. TR^{3}E is a deterministic model, where its characteristics are assumed by the form of equations. The model simulates the changes in transport activity, vehicle choice, as well as modal choice and respective CO_2 emissions in relation to a given baseline scenario. Such exercises are performed both for passenger and freight transport. Therefore, TR^{3}E can be used for the analysis of different transport policy development scenarios. The model consists of two modules: a demand module (where flows of transport activity are calculated) and a supply module (where more detailed characteristics of vehicle categories and technologies are developed). In the TR^{3}E model, every EU27 Member State and the United Kingdom are represented.

267. TR^{3}E model takes into account the demand of households and private firms for passenger transport activity. Both work and non-work transport purposes are distinguished. Moreover, geographic division of areas where the transport activity takes place is utilised. Agent can maximise the utility on the urban and non-urban roads, depending on the type of activity.

268. In the freight module of the TR^{3}E model, the rail, aviation and water transport activity is modelled. The vehicle fleet module for road transport distinguish two road freight vehicle types: LDV: light-duty vehicles (<3.5 tonnes); and HDV: heavy-duty vehicles (>3.5 tonnes). In

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[61] EU Reference Scenario 2020. Energy, transport and GHG emissions. Trends to 2050, op.cit.

[62] A detailed full description of the model TR^{3}E can be found in the documentation Rabiega et al. 2022, https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_TR3E_v.2_transport-model-documentation.pdf

the other areas of transportation, we assume one vehicle per category, respectively: train, plane and ship.

269. The aforementioned vehicle types have their internal division. Light duty vehicles are divided into six types: petrol, diesel, LPG, CNG, electric and hydrogen. For heavy-duty vehicles, three technologies are distinguished: diesel, electric and hydrogen (separately for domestic and international transport). Currently (2015-2020) only diesel HDV are in operation and there is no other type of vehicle in use, but due to the EU's emission reduction goals, the use and development of zero-emission technologies is assumed. In contrast, the types of air and water transport are not presented in detail due to the absence of data and technologies. Therefore, new technologies in these transport sectors are modelled implicitly as the fall in emission intensity of air and water transport per tonne-kilometre. Rail transport is divided into two technologies: diesel and electric, but as they constitute only a small share of the EU's emissions, therefore it is not being modelled in detail.

270. In the TR^{3}E model, the choice between the transport modes is derived on the basis of demand functions that take into account specific prices for users and differences between those prices. In the transport demand module, the concept of cost per mile was used. There are three components of the cost per mile:

- cost of fuel (constant),
- cost of maintenance per vehicle,
- cost of a new vehicle.

271. Data on CO_2 emissions are taken from the JRC-IDEES database. It contains the CO_2 emissions data for all vehicle categories, including different fuel types (i.e. petrol, diesel, CNG, LPG, hybrids, plug-in hybrids). The emission coefficients in kt CO_2/ktoe can be found in this database. Apart from the emission factors, the JRC-IDEES shows data on the emission intensity in grams of CO_2/km for every vehicle category, both in passenger and freight transport. In the TR^{3}E model, emission intensity is calculated endogenously according to changes in the fleet (depending on the deployment of electric and hydrogen vehicles) within the set years and vehicle category. The CO_2 emissions are then calculated as the activity level of a given transport mode multiplied by its emission coefficient. In each year the average emissions intensity is recursively calculated based on emission factors of previous years and the new emission factors.

272. Modelling scenarios differ in terms of the growth in passenger and freight activity. These trajectories are calculated based on the GDP growth and are exogenous from the point of view of the partial equilibrium TR^{3}E model. Different assumptions on the development of the economy and specific indicators are set, such as the CO_2 emissions intensity, the prices of different types of vehicles, and the costs of fuels. Varying activity growth projections for various scenarios are being defined. Activity growth assumed in

the model is correlated with the growth assumptions of the EU Reference Scenario 2020 (based on the PRIMES model). The average activity growth in the period 2020-2050 is ca. 1.2% annually for passenger transport (Table 9). For freight transport, up to 2040, the average growth level is ca. 1.8% per year. After 2040, the growth in transport activity is assumed to decrease. Until 2045, activity is increasing by 0.9%, and until 2050 – by 0.4% (Table 10).

Table 9. Passenger activity growth (annual change in %) in EU27+UK within 2020-2050 according to scenarios

Scenario	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Fit55	1.4	1.3	1.0	1.1	1.3	1.3
ETS BRT nonETS	1.4	1.3	1.0	1.1	1.3	1.3
Joint ETS+RT	1.4	1.3	1.0	1.2	1.3	1.3
Joint ETS+BRT	1.4	1.3	1.0	1.2	1.3	1.3
One ETS	1.4	1.3	1.0	1.1	1.3	1.3

Source: CAKE/KOBiZE

Table 10. Freight activity growth (annual change in %) in EU27+UK in 2020-2050 according to scenarios

Scenario	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Fit55	2.5	1.8	1.4	1.6	0.9	0.4
ETS BRT nonETS	2.5	1.9	1.4	1.6	0.9	0.4
Joint ETS+RT	2.5	2.0	1.5	1.0	0.7	0.9
Joint ETS+BRT	2.5	1.9	1.4	1.2	0.8	0.9
One ETS	2.5	1.9	1.3	1.3	0.9	0.8

Source: CAKE/KOBiZE

D. Agricultural model – EPICA

273. The EPICA model is a partial equilibrium model of the agricultural sector in Poland. Typically, the partial equilibrium models provide a rather deep and technical representation of the specific sector of interest, while largely neglecting its ties to the rest of the economy. Partial equilibrium models describe both supply and demand sides of the sector. In case of EPICA, the supply side of the model has been implemented as a linear programming model calibrated using PMP (positive mathematical programming) consisting of different representative farms, optimising their profits based on resource and technological constraints.

274. To quantify the responses of agricultural production, the supply model is constructed as a set of independent models for different farms. Different market and policy scenarios for each of distinguished farm types have been constructed. The main assumption of the

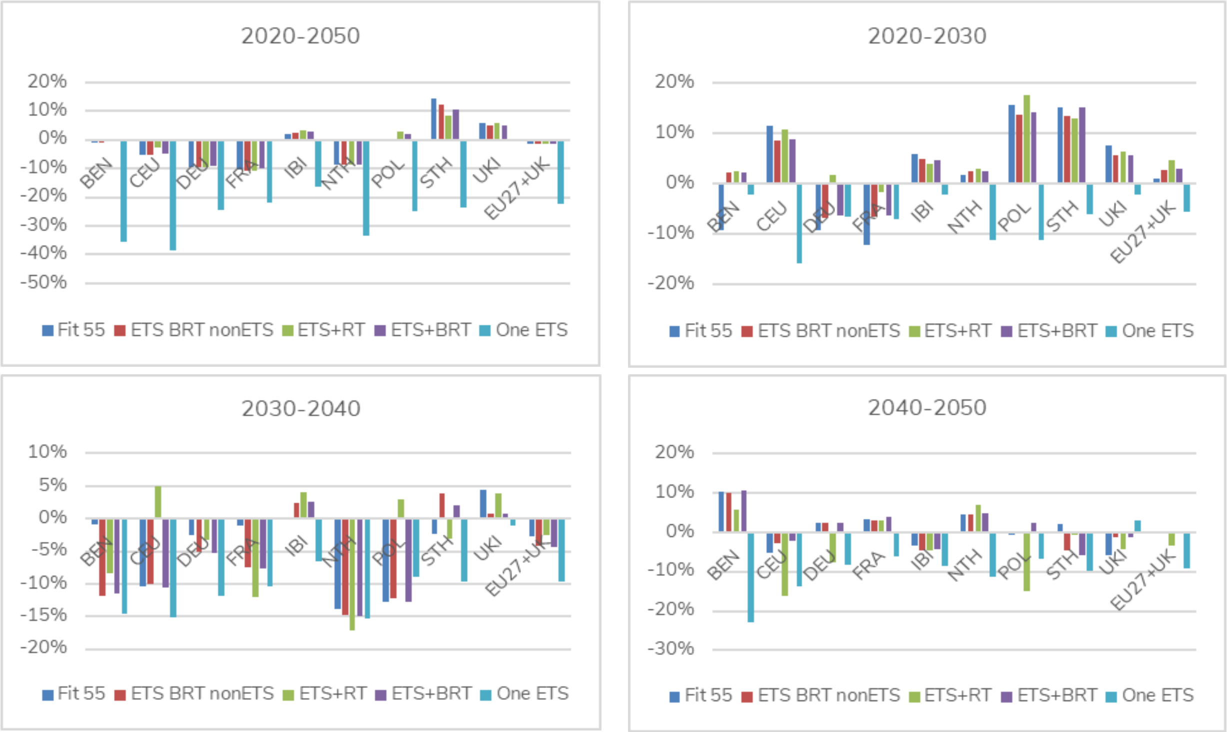
model is that farmers aim to maximise their income by adjusting the production structure to the present market and political situation. The main result of the supply model for each farm type is a structure of farm activities (crops and livestock). Based on that, other farm outputs (e.g., the total use of inputs, total production, total emission and economic accounts) are calculated.

275. The EPICA's market module being a partial equilibrium, combines supply from the farm module and demand for products of agricultural origin from the core CGE model (d-PLACE).

276. The base data set implemented in the EPICA model covers the year 2015. Polish agriculture is one of the key contributors of GHG emissions among such sectors of EU27+UK countries (based on data from 2017), being the sixth largest emitter with a share of 7.2% of total GHG emissions (Eurostat 2018). There is a possibility of interaction with the CGE model (d-PLACE) in terms of changes in price levels in the economy and with the energy model (MEESA) in terms of the use of agricultural biomass as an energy source. Due to the high level of detail of agricultural activities, the EPICA model and its data set are currently built to represent only the agricultural sector of Poland.

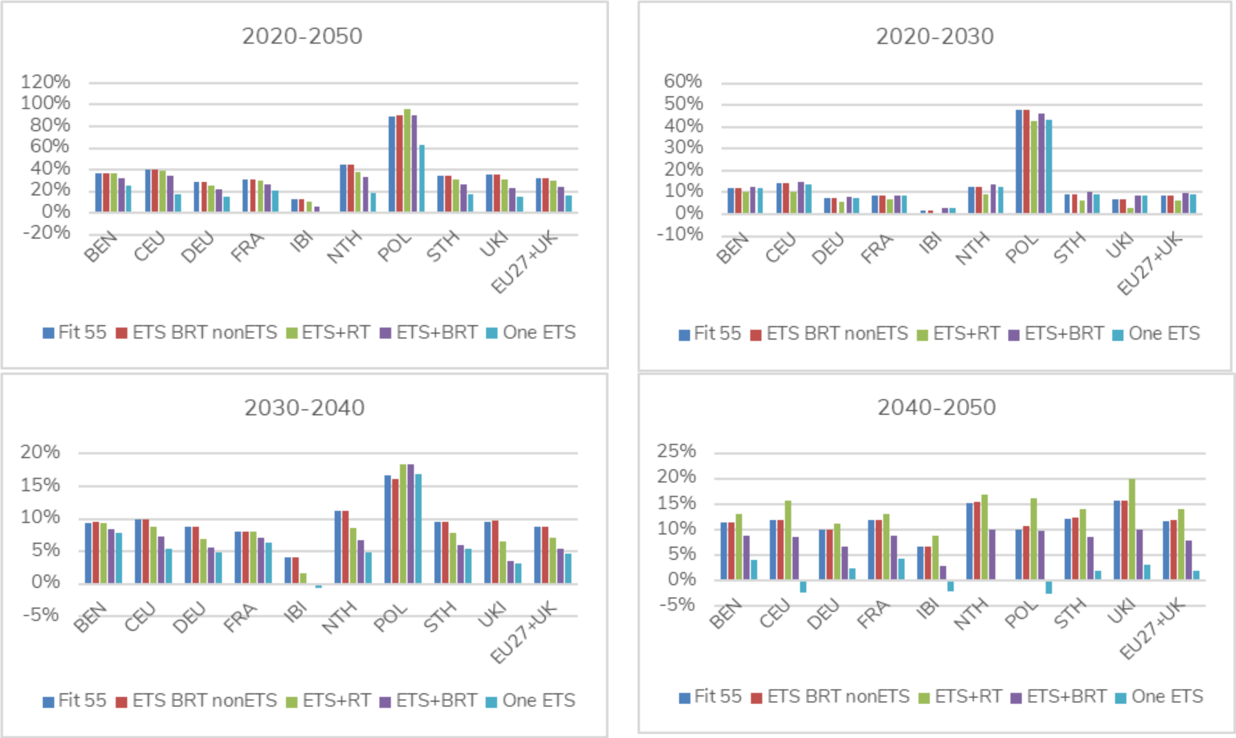
Annex II - Additional macroeconomic results

Figure 98. Changes in output of Agriculture sector in different time periods [%]



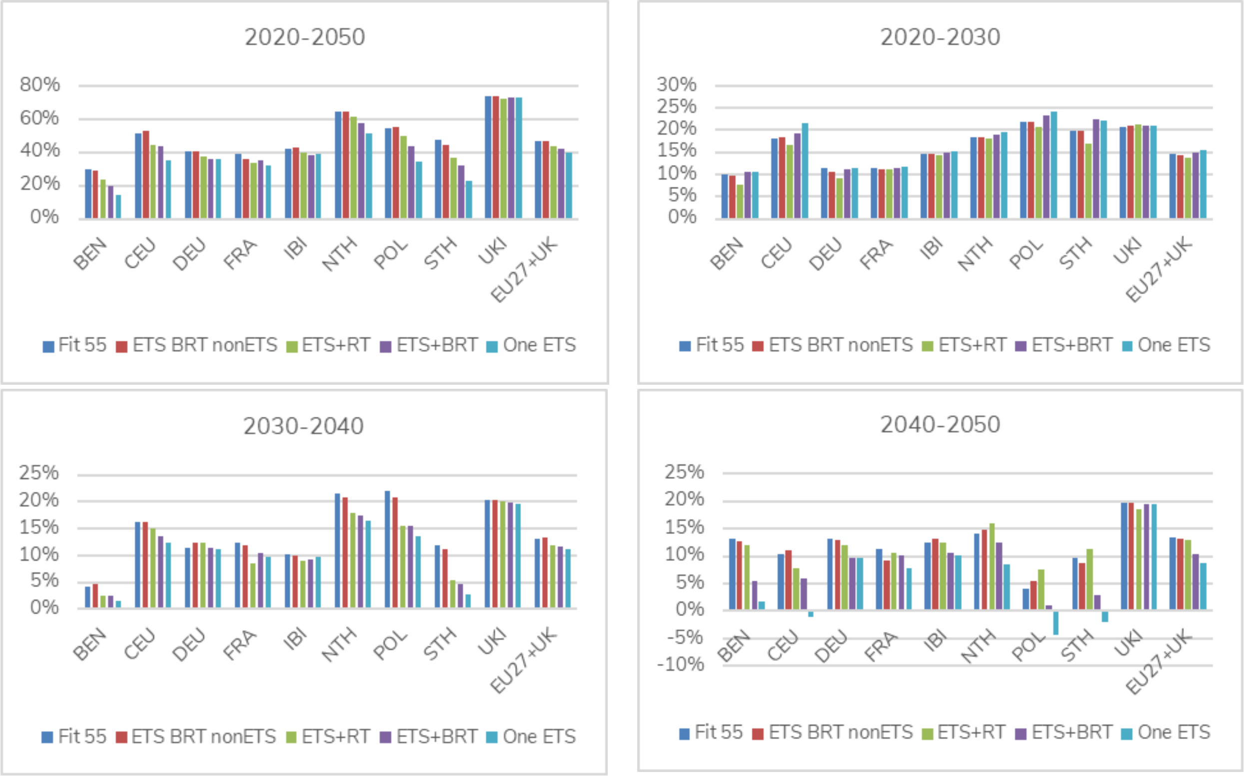
Source: CAKE/KOBiZE

Figure 99. Changes in output of Aviation sector in different time periods [%]



Source: CAKE/KOBiZE

Figure 100. Changes in output of Chemicals, Iron and Steel and Non-metallic minerals sectors in different time periods [%]



Source: *CAKE/KOBiZE*

LIFE VIIEW 2050

Vision on Impact & Improvement of the EU ETS Working by 2050

Centre for Climate and Energy Analyses

National Centre for Emissions Management
Institute of Environmental Protection
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