Centre for Climate and Energy Analyses

VIIEW 2050

EXPLORING SYNERGIES BETWEEN THE EU ETS AND OTHER EU CLIMATE POLICY MEASURES - CARBON REMOVAL, HYDROGEN, AND SECTORAL TRANSPORT POLICY

LIFEVIIEW2050

KOBiZE

Warsaw, April 2024

IOŚ-PIB

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

The authors would like to thank the members of The LIFE VIIEW 2050 Advisory Board: Antonio Soria (Joint Research Centre), Karsten Neuhoff (DIW Berlin), Artur Runge-Metzger (former European Commission), Simone Borghesi (European University Institute), Stefano F. Verde (University of Siena), Wojciech Burkiewicz (The Chancellery of Prime Minister of Poland), Jos Delbeke (European University Institute).

Upon quoting, please refer to the source, as follows:

Pyrka M., Jeszke R., Boratyński J., Witajewski-Baltvilks J., Antosiewicz M., Tatarewicz I., Rabiega W., Wąs A., Lewarski M., Skwierz S., Rosłaniec M., Lizak S., Zborowska I., Chodor M., Kobus P., Cygler M., Gorzałczyński A., Tylka A., Lewarska I., Mzyk P., Sekuła M. (2024). VIIEW on EU ETS 2050: Exploring synergies between the EU ETS and other EU climate policy measures - carbon removal, hydrogen, and sectoral transport policy, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

This document was prepared in the Centre for Climate and Energy Analyses (CAKE) established in the National Centre for Emissions Management (KOBiZE), part of the Institute of Environmental Protection - National Research Institute (IOŚ-PIB).

This document was prepared within the scope of the project: "The impact assessment of the EU Emission Trading System with the long-term vision for a climate neutral economy by 2050 (LIFE VIIEW 2050)" - LIFE19 GIC/PL/001205 – LIFE VIIEW 2050.

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

The document was completed in March 2024.

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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The project "The impact assessment of the EU Emission Trading System with the long-term vision for a climate neutral economy by 2050 (LIFE19 GIC/PL/001205 - LIFE VIIEW 2050)" is co-funded from the European Union LIFE programme and the resources of the National Fund for Environmental Protection and Water Management.

Table of contents

List of abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicle
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
DAC	Direct Air Capture
d-PLACE	Recursive dynamic, computable general equilibrium model used and developed by CAKE
EPICA	The Evaluation of Policy Impacts – Climate and Agriculture Model used and developed by CAKE
EGD	European Green Deal
ESR	Effort Sharing Regulation
ETS	Emissions Trading System
EU ETS	European ETS
ETS2	ETS for Transport and Buildings
FCEV	Fuel Cell Electric Vehicle
HDV	Heavy-duty vehicle
HEV	Hybrid Electric Vehicle
IEA	International Energy Agency
ICE	Internal combustion engine
JRC	Joint Research Centre
LEV	Low Emission Vehicle
LU	Livestock unit
MEESA	Model for European Energy System Analysis used and developed by CAKE
PHEV	Plug-in Hybrid Electric Vehicle
PyCCS	Pyrogenic Carbon Capture and Storage
RED	Renewable Energy Directive
RES	Renewable Energy Sources
REFuelEU	EU initiative to ensure sustainable aviation fuels
REPowerEU	EU plan to accelerate energy transition
SCS	Soil Carbon Storage
TEW	Terrestrial Enhanced Weathering
TR^3E	Transport European Economic Model used and developed by CAKE
ULEZ	Ultra Low Emissions Zone
ZEV	Zero Emission Vehicle

List of figures

List of graphs

List of tables

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, pfb, ocr, ctl, oap, rmk, wol, fsh, v_f
Cattle	ctl
Raw milk	rmk
Other Animal Products	oap
Wheat, Other Grains	wht, gro
Veg & Fruit: vegetables	v_f
Sugar cane, sugar beet	c_b
Farming (other agriculture fishing)	pdr,osd, pfb, ocr, wol, fsh
Other food products	pcr, sgr, ofd, b_t, vol
Meat products nec	omt
Bovine meat & mil dairy products	cmt
Forestry	frs
Chemicals	crp
Non-metallic minerals	nmm
Iron and steel	i_s

[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.

Non-ferrous metals	nfm
Paper	ppp
Construction	cns
Other manufactures	ome, omn, lum, tex, wa, lea, eeq, fmp, omf
Air transport (aviation)	atp
Water transport	wtp
Land transport	otp
Vehicles	mvh, otn
Services	trd, ofi, isr, obs, wtr, cmn, ros, osg, dwe

Source: CAKE/KOBiZE

Main conclusions

Aims of the report

- This report analyses how complementary policies interact with emission trading systems such as the EU ETS and ETS2. In particular, it examines:
  - the role of supporting (pricing) CO_2 removals (BECCS and afforestation of arable land),
  - strategies to decarbonise the transport sector (emission standards for heavy duty vehicles and accelerating the scrapping of old fossil fuel cars), and
  - the subsidisation of green hydrogen.

The emission reduction targets in the scenarios are consistent with the net-zero path as outlined in the European Green Deal and the 'Fit for 55' package. The report also considers the impact of the European Commission's recent proposals for ambitious climate targets for 2040 on key macroeconomic indicators.

European Green Deal and 'Fit for 55' background

- As a result of the implementation of the European Green Deal, the 'Fit for 55' package and the net zero target in 2050, **the emission intensity of the GDP in the EU countries will decrease by around 80% between years 2020 and 2050, while GDP will grow by 60%, resulting in a reduction of almost 70% in gross emissions** (i.e. emissions excluding removals other than the industrial CCS). However, mitigation opportunities are not evenly distributed across sectors.

- **The largest reductions in emission intensity are observed in the electricity and households sectors**. On the other hand, **reducing emissions from transport – especially shipping and aviation – and industry is proving more challenging. Two sectors show a reduction in activity – fossil fuels and agriculture.** In the case of fossil fuels, a sharp drop in activity is linked to a reduction in demand for non-renewable energy sources. In the case of agriculture, the result actually signals the exhaustion of mitigation options, with further emission reductions leading to a decline in production, raising concerns about food security and carbon leakage. **The role of carbon sinks on the path to net zero emissions is crucial. Bioenergy with CCS (BECCS) and afforestation of agricultural land develop significantly from 2040 onwards, but their scale depends on the pricing of removals.**

Macroeconomic results

- **The complementary policies to the EU ETS allow a significant reduction in carbon prices.** This reduction translates into welfare gains in some cases, although this latter result is not general and some complementary measures (such as hydrogen subsidies) lead to welfare losses.
- **The impact of pricing removals and their large-scale deployment is positive in all dimensions: it leads to a significant reduction in carbon prices, higher GDP and consumption.** Allowing for full pricing of removals leads to a drop in the EU ETS price from 880 EUR/tCO_2 to 310 EUR/tCO_2 in 2040. A similar price reduction is observed in 2050. It also reduces carbon cost in non-ETS sectors in all regions.
- **Systemic integration of removal technologies into climate policy can increase the number of carbon allowances, allowing sectors with high abatement costs to purchase additional allowances instead of investing resources in costly decarbonisation options.** This releases resources in the economy that can be used in the same or other sectors to increase production.
- At the macroeconomic level, pricing removals increases EU consumption by 0.9% in 2040 and 1.9% in 2050. The simulations also show a positive impact on GDP (by 0.6% in 2040 and 2050). In Poland, consumption in 2040 is 1.1% higher in the scenario with full pricing of removals than in the scenario without pricing. In 2050, the difference in consumption increases to 3.8%.
- **Pricing negative emissions from BECCS lowers the price in the EU ETS and pricing emissions from afforestation lowers the cost of carbon in non-ETS sectors.** Both measures contribute to consumption gains, but at the EU level the contribution of pricing BECCS is much larger than that of pricing afforestation. Pricing afforestation is more important in Poland than in other countries.
- **Subsidies for hydrogen lead to lower prices in the EU ETS.** In 2035, in the scenario with subsidies, the EU ETS price reaches a level of 270 EUR/tCO_2, which is 30 EUR lower than in the scenarios without subsidies. In 2040 the price difference remains at 30 EUR/tCO_2 and in 2050 it is 15 EUR/tCO_2.
- **However, the introduction of hydrogen subsidies leads to a decrease in GDP and consumption at the EU level.** In 2030 the loss in EU consumption is 0.3%. In 2040 and 2050 the loss is less than 0.1%. The predicted consumption loss at EU level can be explained by the distortionary effect of subsidies, which is in line with the predictions of the economic

literature. In Poland, however, the low prices of the EU ETS lead to a consumption gain of 0.8% in 2050.

- **The main effect of additional policies introduced in the transport sector is a reduction in the carbon price in ETS2.** In 2030, the price in the scenario with transport policies is 55 EUR/tCO_2, which is 10 EUR/tCO_2 lower than in the scenario without the measures. In 2040 the difference is 150 EUR/tCO_2 and in 2050 it is 300 EUR/tCO_2.
- **Based on the emission reduction target for 2030 and 2050,** in our scenarios the EU achieves a 75% reduction in 2040 compared to 1990 levels, without taking into account the level of absorption from the LULUCF sector. Including the LULUCF sector (about -396 Mt CO_2 eq. in 2040), **the achieved net reduction target in 2040 is about 83% compared to 1990 levels.**
- **The economic costs of the accelerated reduction (90% reduction by 2040) proposed by the European Commission are an order of magnitude higher than the costs of the most ambitious least-cost path considered by the IPCC.** According to the macroeconomic analysis of the total costs of the transition presented in the Sixth Assessment Report (Working Group 3), the difference in consumption growth between the most ambitious scenario (C1) and the BAU scenario is 0.04 p.p. Acceleration of decarbonisation in Poland brings reduction in the consumption growth rate in 2030s by 0.4 p.p. (1.8% annual growth in Fit55_S2+ scenario vs 2.2% in Fit55+), according to our analysis. At the EU level, consumption growth slows down by 0.2 p.p.
- **Economic loss due to acceleration varies significantly across regions.** In the accelerated scenario (Fit55_S2+), consumption in 2040 in Western Europe is expected to be around 0.8% lower than in the Fit55+ scenario. In Poland and Southern Europe, the loss is projected to exceed 4%.

Energy sector

- **BECCS is one of the technologies that can deliver negative emissions. However, it requires additional revenues for the negative emissions achieved.** BECCS technology significantly reduces the marginal cost of CO_2 abatement in sectors covered by the EU ETS. In the 100% subsidy scenario, the carbon price in the EU ETS is 30% lower than in the 50% subsidy scenario. **In the scenarios with high revenues for negative emissions, the sector achieves carbon neutrality for the EU before 2040.** For Poland this process is only slightly slower.
- **The pace of development of green hydrogen production, especially in the 2030-2035 period, is strongly dependent on subsidies** - in the reference scenario (Fit55) green hydrogen is still minimally used, whereas in the hydrogen subsidy scenario green hydrogen

technologies start to be used as early as 2030 and the initial pace of development of these technologies accelerates significantly.

- **Demand for hydrogen is mainly in the transport and industrial sectors, but additional hydrogen consumption will occur in the energy sector, where hydrogen will be used as a long-term energy storage and backup technology to replace natural gas.** This additional demand could reach about 30-35% of total hydrogen production in 2050.
- In the EU, the electricity demand for BEVs in the transport policy scenario is about 13% higher than in the reference scenario over the whole analysis period. The electricity demand for electrolyzers is more than 6% higher in 2030-2050 in the same scenario comparison. The impact of the analysed transport policy in Poland is even more obvious. The total electricity demand for charging electric cars in the transport policy scenario is about 25% higher in the period 2030-2050 than in the reference scenario. The total electricity consumption in electrolysers in 2030-2050 is about 16% higher in the scenario with additional transport policies.

Transport sector

- **Raising emission standards for heavy-duty vehicles is a key policy to reduce emissions from road freight transport** in the EU+UK area, contributing to a reduction from 69.8 to 23.7 Mt CO_2 in 2050.
- The measures adopted in the 'Fit for 55' package (in particular the ban on ICE cars and vans) are already have a significant impact on reducing passenger car emissions, but additional measures such as **accelerating the scrapping of fossil fuel vehicles could be important in eliminating the emissions remaining in 2050.** This policy reduces the share of fossil fuel cars in 2050 by about 2 p.p., both across the EU+UK area and in Poland.
- **Hydrogen subsidies have a stronger impact on freight transport than on passenger transport.** However, the impact of this policy is rather limited as it only increases the share of hydrogen trucks in the fleet by 1.5 p.p. in Poland and 1.1 p.p. in the EU+UK area.
- **In the long term, both households and companies can benefit financially from transitioning to zero-emission vehicles.** The total cost of ownership of the entire vehicle fleet in Poland could be up to 8% lower in 2045 due to the quicker transition to ZEVs, which have lower costs.

Agriculture sector

- If attempts are made to use economic mechanisms in line with the polluter pays principle to force GHG emission reductions in the agricultural sector, the negative income effect of carbon pricing in the EU agricultural sector would reach a staggering EUR 179 billion per year in 2050 (in the scenario without subsidies), exceeding the support provided by the Common Agricultural Policy (EUR 55 billion per year).
- **Setting a price for removal units, generated from afforestation of arable land, helps reduce the financial burden of climate policy on EU agriculture.** However the net income effect of the net zero policy still remains negative reaching -84 billion EUR in scenario with the highest subsidies for GHG removals.
- The introduction of climate policy assumptions leading to the carbon neutrality of the EU economy has a strong impact on the agricultural market. On average, agricultural production in the EU falls by around 25%, while prices rise to 300% of the base year level.
- From the 2050 perspective, there are no significant differences between following country-specific carbon prices and a common EU carbon price for agriculture and the rest of non-ETS sectors in terms of GHG emissions, market situation and economic impacts. However, the adjustment path in 2025-2045 differs slightly between regions and scenarios. The common EU carbon price scenarios provide a smoother and more predictable transition path.
- In Poland, climate policy has a relatively stronger negative impact on the agricultural sector than the EU average in terms of production losses and price increases. Hence, **pricing removals units, generated from afforestation of arable land, have a greater impact on the mitigation of negative net income effect in the Polish agricultural sector.**
- **Increasing payments for removals beyond 25% of the carbon price assumed in the model does not lead to an increase in the GHG removal rate by the agricultural sector**. However, payments exceeding 25% lead to a discernible environmental effect, while improving financial situation of farms.

Summary

1. EU climate policy background

1. The EU is currently aiming for a 55% reduction in domestic greenhouse gas emissions by 2030 and net zero emissions by 2050. These targets, set in December 2020 and 2019 respectively, are enshrined in the EU climate legislation. The 'Fit for 55' legislative package, part of the European Green Deal, includes measures such as the EU ETS Directive and the Effort Sharing Regulation (ESR) to achieve these targets. Other initiatives focus on specific sectors and gases. However, according to the EC's in recent years, the progress made by Member States has been substantially below what is necessary to achieve the EU's medium and long-term climate goals in the coming decades[2].

2. The European Commission's new proposal for a 2040 climate target, published in February 2024, is based on the European Climate Law. The EU agreed to set "an EU-wide climate target for 2040" on the basis of a Commission proposal to be presented by June 2024 at the latest. Looking beyond 2030, detailed guidance is needed to effectively steer the EU towards climate neutrality and to avoid decisions that could lock in high emissions and high costs. Long-term strategies are crucial given the lead time needed for investments in energy infrastructure and industry.

3. New elements in the political debate on the future of EU climate and energy policy, such as carbon dioxide removal (CDR) and green hydrogen, transport policy and the inclusion of some sectors in the EU ETS, will be the most important elements in the emission reduction pathways for 2050. The decision-making process would have a significant impact and consequence on the whole EU economy and development strategies.

2. Objectives

4. The main goal of this analysis is the identification of current and potential future instruments which could affect the functioning of the EU ETS and non-ETS sectors post 2030. We are focusing on the following key areas:

   - role and use of Carbon Dioxide Removal (CDR),
   - green hydrogen subsidies,
   - additional measures to decarbonise transport.

5. In this analysis we examine the impact of above elements on the:

[2] Climate Action Progress Report 2023, European Commission.

- CO_2 prices in the EU ETS, ETS2 and the rest of non-ETS,
- macroeconomic outcomes (GDP and consumption),
- sectoral indicators (e.g. agricultural production, energy mix, transport emissions).

3. Emission reduction pathways

6. By 2030, the emission reduction targets in the EU are adopted in accordance with the 'Fit for 55' package. To reflect the EU's net zero climate goals, it has been assumed that, the reduction target by 2050 for EU ETS sectors would be 95% and 85% for non-ETS sectors compared to 2005. The reduction target for the ETS2 system in 2050 is set at 87% compared to emissions in 2005[3]. The residual emissions are offset with negative emissions.

7. As an option for sectors not covered by the ESR regulation, a new ETS for non-ETS sectors[4] (ETSagr) has been implemented in some policy scenarios. The ETSagr has assumed emission reduction targets of 36% and 82% respectively by 2030 and 2050 relative to 2005 levels.

Table 1. Emission reduction targets for 2050 (excluding LULUCF sector)

Year/ sectors coverage	Total (vs. 1990)	non-ETS (vs. 2005)	ETS2 (vs. 2005)	EU ETS (vs. 2005)	ETSagr (vs. 2005)
2050	90%	85%	87%	95%	82%

Source: CAKE/KOBiZE

4. Policy scenarios

8. **Group I** reflects an action plan within the framework of the EU climate policy, incorporating innovative approaches to carbon dioxide removals - bioenergy with carbon capture and storage (BECCS) removals into the existing EU ETS and agricultural removals into non-ETS. Within this group of scenarios, various levels of support for removal technologies are proposed based on carbon price in the EU ETS and non-ETS[5].

[3] Emission reduction targets for EU ETS and ETS2 for 2050 is estimated on the bases of projected emission value for 1.5LIFE scenario from the European Commission's report 'In-depth analysis in support of the Commission Communication, A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy', Tabel 9, page 198, Brussels, 28 November 2018.

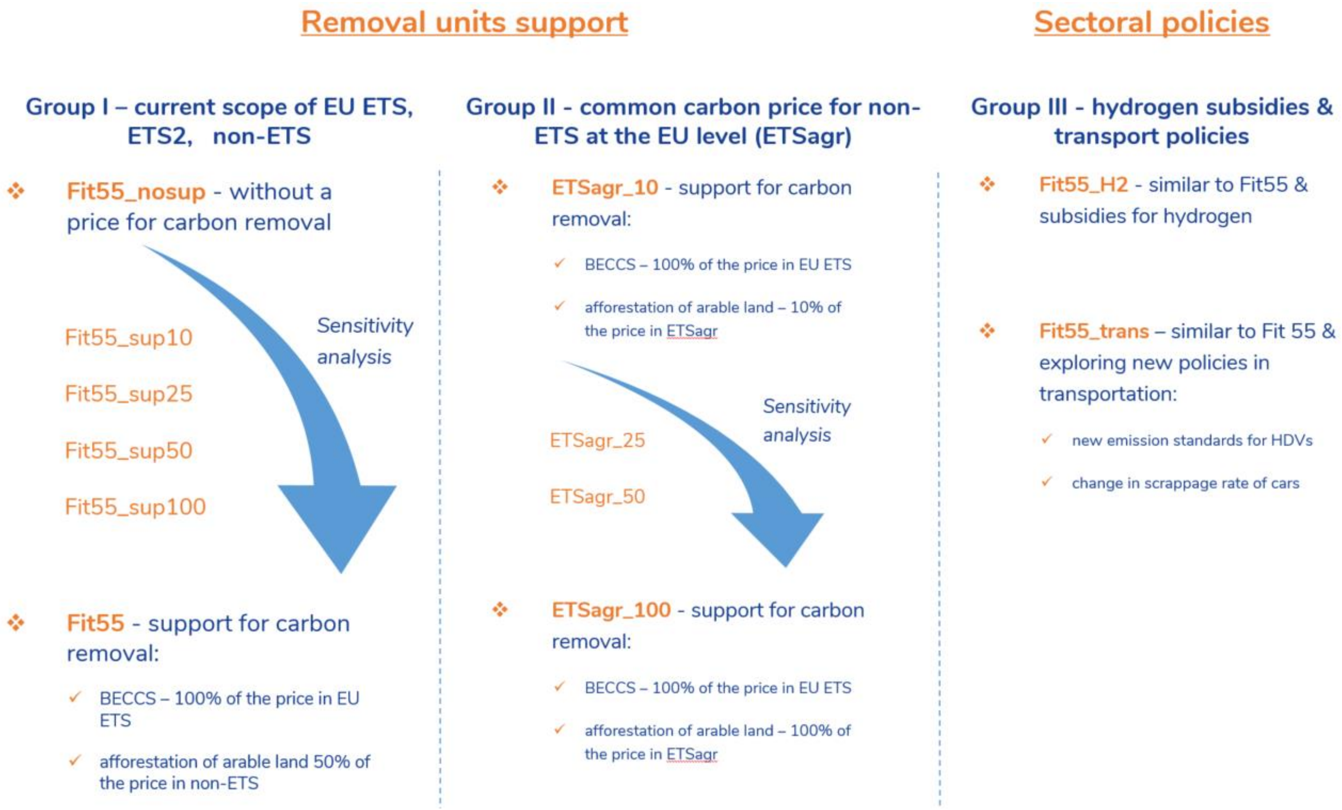
[4] 50% of the emissions came from the agriculture sector, with the remaining emissions from other sectors not included in the EU ETS and ETS2.

[5] This implies that the price paid for one unit of removal (for the absorption of 1 tCO_2 eq.) is, respectively, a certain percentage of the carbon price in the EU ETS for the BECCS technology, and for afforestation of arable land, it is a certain percentage of the carbon price in the non-ETS area, depending on the scenario from Group I.

9. **Group II** scenarios refers to a new ETSagr including sectors not currently covered by trading systems such as agriculture, trade and services sectors. The scenarios include integrating removals resulting from the afforestation of arable land into the new ETSagr system with a specified price for one unit of removal setting at a certain percentage of the carbon price in ETSagr. In addition, these scenarios fully integrate BECCS removals into the EU ETS at 100% of the carbon price in this system.

10. **Group III** of scenarios refers to changes at the policy level related to the costs of green hydrogen fuel, as well as the change in sectoral policy for transportation such as new emission standards and change in scrappage rate in transport sector. This group also includes removal units support as in Fit55 scenario from group I[6].

Graph 1. Policy scenarios



Source: CAKE/KOBiZE

[6] BECCS – 100% of the price in EU ETS, afforestation of arable land – 50% of the price in non-ETS.

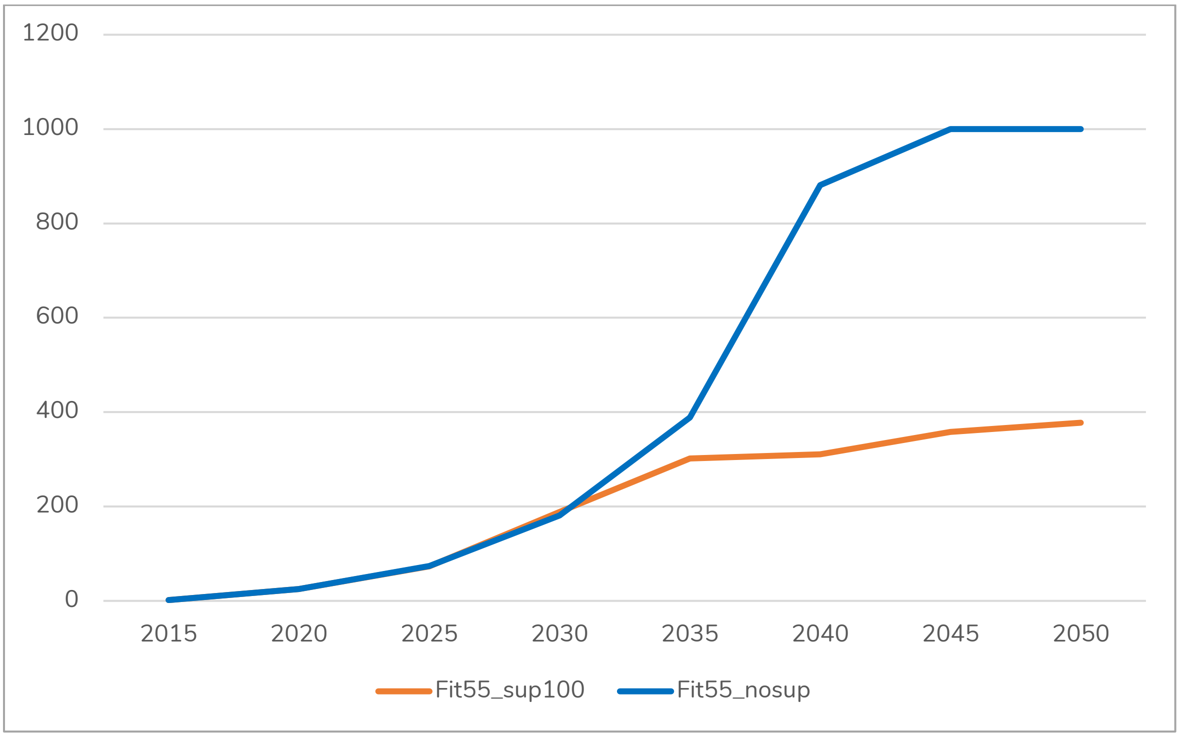
5. Carbon prices

Removal units support – scope of EU ETS, ETS2, non-ETS based on 'Fit for 55' package

11. The impact of pricing removals and their large scale deployment is favourable in all dimensions: it leads to a significant drop of carbon prices, higher GDP and consumption in 2040-2050 period.

12. **EU ETS prices.** In the Fit55_sup100 scenario from group I, the CO_2 prices in EU ETS are projected to increase to 310 EUR/tCO_2 in 2040 and 380 EUR/tCO_2 in 2050, which is significantly lower than 880 EUR/tCO_2 in 2040 and 1000 EUR/tCO_2 in 2050 in the Fit55_nosup scenario where pricing of negative emissions is not permitted.

Figure 1. Carbon prices in EU ETS [EUR/tCO_2] under alternative options of pricing removals



Source: CAKE/KOBiZE

13. **Non-EU ETS prices.** The scale of the impact on non-ETS prices varies across region. In all EU regions the CO_2 prices in Fit55_sup100 scenarios are lower than in the Fit55_nosup scenario. For Poland the CO_2 price in 2040 is at the level of 420 EUR/tCO_2 in Fit55_sup100 scenario vs. 760 EUR/tCO_2 in the Fit55_nosup scenario. In 2050 the CO_2 prices in Poland hit the level of 1000 EUR/tCO_2 in both scenarios.

14. **ETS2 prices.** There is no significant impact on price in ETS2.

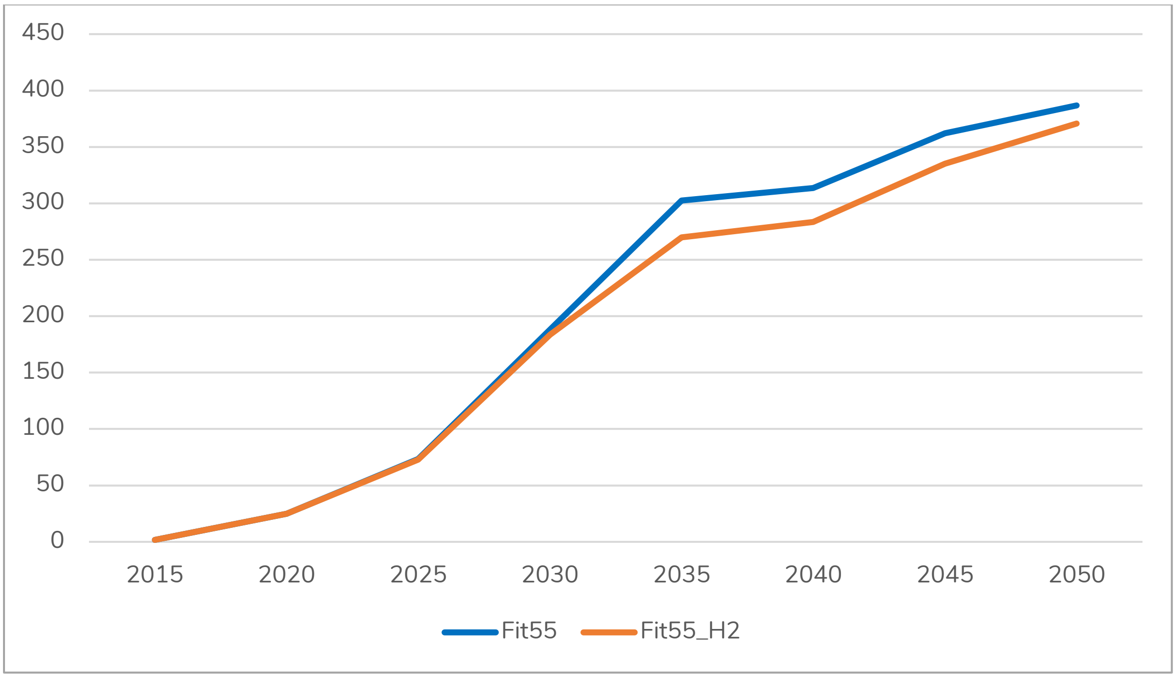
- *Removal units support – common non-ETS carbon price at EU level (new ETSagr for agriculture and other sectors)*

15. If the ETSagr (for sectors other than EU ETS and ETS2) is established, and if negative emissions from afforestation receive revenue equivalent to 100% of the ETSagr carbon price for each unit of CO_2 absorbed, the carbon price in that new system will reach 340 EUR/tCO_2 by 2040. If the negative emissions receive revenue equivalent to 50%, the carbon price goes up a bit to 350 EUR/tCO_2. If they receive 25% and 10%, the price in the ETSagr shoots up to 460 EUR/tCO_2 and 580 EUR/tCO_2, respectively. However, by 2050, the carbon price in ETSagr reaches 1000 EUR/tCO_2 in all scenarios, primarily due to the insufficient potential for emission reduction, particularly in the agricultural sector.

- *Hydrogen Subsidies*

16. **EU ETS prices.** Hydrogen Subsidies incentivises to switch from fossils fuels (natural gas and oil) to hydrogen generating downward pressure on the demand for allowances in the EU ETS. But on the other hand, the subsidy increase the demand for energy in power sector creating an upward pressure on the demand for allowances through this channel. The simulations suggest that the former effect dominates: the scenario with subsidies for hydrogen (Fit55_H2) lead to lower prices in the EU ETS compared to the Fit55 scenario. The price difference between this two scenarios is most noticeable in 2035 and 2040, with prices in Fit55_H2 being significantly lower by approx. 30 EUR/tCO_2. Over the following years, the price gap gradually narrows to approx. 15 EUR/tCO_2, reaching smaller differences in 2045 and 2050.

Figure 2. Carbon prices in EU ETS [EUR/tCO_2] under hydrogen subsidies



Source: CAKE/KOBiZE

17. **ETS2/non-ETS prices.** The impact of subsidies in use of hydrogen has negligible impact on the emission prices in the ETS2 and in the non-ETS sectors.

- *Transport Policies*

18. **ETS2 prices.** Transport sector measures lower ETS2 prices significantly. In 2030, Fit55_trans has a lower price compared to Fit55 (60 vs. 70 EUR/tCO_2), and by 2040, Fit55_trans's price is almost 30% less than Fit55 (370 vs. 520 EUR/tCO_2). In 2045 the difference grows to 55% (440 vs. 980 EUR/tCO_2). In 2050, Fit55_trans's price still remains lower than Fit55's (705 vs. 1000 EUR/tCO_2). More stringent emission standards for HDVs and higher scrappage rates for cars speed up low-carbon vehicle adoption driving lower demand and allowances prices in ETS2.

19. **Non-ETS prices.** The transport sector measures strongly influence the costs of emissions in non-ETS sectors in some regions. For instance, in 2050 in Poland the cost reaches the level of 530 EUR/tCO_2 in Fit55_trans scenario, while it hits 1000 in Fit55 scenario. In the same year in Central Europe the non-ETS cost in Fit55_trans is 780 EUR/tCO_2 and in Fit55 scenario it is 1000. This impact is due to the allocation of emission targets across sectors: as demand for ETS2 decreases, more emission units (limits) become available for non-ETS sectors, leading to reduced abatement costs in these sectors.

20. **EU ETS prices.** The impact on EU ETS prices is negligible.

6. Macroeconomic Effects

- *Removal units support scope of EU ETS, ETS2, non-ETS based on 'Fit for 55' package*

21. Lower EU ETS prices can reduce the distortionary impact of climate policy on the economy, leading to an increase in GDP and consumption. BECCS technologies can increase the number of carbon allowances, allowing sectors with high mitigation costs to purchase additional allowances instead of dedicating resources to costly decarbonization options. This releases resources in the economy that can be used in the same or other sectors to increase production. In 2040 GDP of EU27+UK in the Fit55_sup100scenario is 0.6% higher and consumption is 0.9% higher comparing to Fit55_nosup scenario. In 2050, the difference of GDP is 0.6% and the difference in consumption is 1.9%.

22. GDP of Poland in Fit55_sup100 in 2040 scenario is 0.9% higher and consumption is 1.1% higher than in Fit55_nosup. In 2050 the difference in GDP and consumption between the two scenarios are 0.9% and 3.8%, respectively.

- *Removal units support – common non-ETS carbon price at EU level (new ETSagr for agriculture and other sectors)*

23. The new ETS (ETSagr) doesn't really change the big economic picture much. In the scenario with the new system all economic indicators are nearly the same as in the Fit55 scenario.

- *Hydrogen Subsidies*

24. Introduction of subsidies to hydrogen leads to a drop in GDP and consumption at the EU level. Subsidies in 2030 reduce GDP of the EU by 0.1%, with consumption dropping by 0.3% and offsetting the impact of increased investment (0.8%). By 2040 and 2050, Fit_H2 and Fit55 scenarios align in GDP, consumption, and investment.

- *Transport Policies*

25. The introduction of more stringent emission standards for HDV and increasing the scrappage rate of old fossil fuel powered passenger cars have a minimal impact on GDP and slightly boost investment in the medium-run and consumption in the long-run.

26. This increase in consumption is attributed to several factors. Firstly, subsidies which incentivise earlier scrappage of vehicles encourage the early adoption of low-carbon vehicles reducing the negative impact of emission price hikes in 2050. Secondly, lower emissions in Fit55_trans lead to less reliance on costly negative emission technologies, which lowers import costs and boosts consumption. Lastly, increased demand for capital raises manufacturing costs, affecting trade and further influencing consumption levels.

Table 2. The impact of different research elements on prices in EU ETS, ETS2 & non-ETS sectors, and macroeconomics factors at the EU level

Impact vs. Fit55 scen.	EU ETS Prices	Non-ETS Prices	ETS2 Prices	GDP	Consumption
Removals	Significant decline in 2040 & 2050	Significant decline for 2040 in some regions (incl. PL)	Negligible	Medium positive in 2040 & 2050	Small in 2040, medium positive in 2050, large positive impact in some regions (incl. PL)
New ETSAgr	n/a	n/a	n/a	Negligible	Small in 2050
Hydrogen Subsidies	Small impact in 2040 & 2050	Negligible	Negligible	Negligible	**EU:** small negative in 2030, negligible in 2040 & 2050; **PL:** negligible in 2030 & 2040, medium positive in 2050.
Transport Policies	Negligible	Significant decline in 2050	Significant decline in 2040 & 2050	Negligible	Positive in 2050

Source: CAKE/KOBiZE

7. Effects in Energy Sector

27. The EU's ambitious climate targets for 2040 and 2050 require the large-scale deployment of CDR technologies in the energy sector. This is due to the technical limitations of GHG mitigation in many sectors (e.g. agriculture). In the near future, the energy sector will therefore need to transform from being the largest emitter into a sector that absorbs emissions. BECCS is one of the technologies that will make it possible to achieve negative emissions that compensate for emissions in other sectors. The cost optimisation results presented in this report show that BECCS technology is highly competitive in the context of high CO_2 emission allowance prices, as long as BECCS receives additional revenue for negative emissions. In the scenarios with high revenues for negative emissions, the sector achieves carbon neutrality before 2040 in the EU. In the case of Poland, this process is only slightly slower.

28. In 2050, net emissions from the power sector are negative in all scenarios except the scenario with no support for BECCS. In the Fit55_sup50 scenario, where BECCS

receives revenue equivalent to half the value of the EU ETS carbon price for each unit of CO_2 absorbed, there is a significant reduction in the deployment of BECCS technology compared to the Fit55_sup100 scenario – the amount of emissions captured by BECCS technologies is almost 20% lower. The reduced CO_2 absorption leads to an increase in the cost of carbon price in the EU ETS to around 550 EUR/tonne, compared to around 380 EUR/tonne in the Fit55_sup100 scenario. This shows the importance of an adequate level of revenue for negative emissions in the case of BECCS. In the no-subsidy scenario (Fit55_nosup), the technology does not develop at all, with a number of consequences, such as very high marginal costs of CO_2 reduction in EU ETS, difficulties in meeting climate targets and the need for more expensive solutions.

29. Significant support for removal units in the sector (Fit55_sub100 scenario) shows that the main source of CO_2 emissions appears to be gas-fired units that complement the electricity balance, particularly during winter peak hours on days with low supply of energy from wind farms. Negative emissions from BECCS allow to offset the CO_2 emissions from these technologies. In addition, scenarios without BECCS (Fit55_nosup) show that gas-fired power plants start to use hydrogen, which, despite its much higher price, becomes competitive with natural gas.

30. Another important technology for the energy transition is hydrogen. The pace of development of green hydrogen production depends strongly on subsidies in the early years. In the Fit55 scenario, the use of hydrogen in 2030 is still minimal, whereas with subsidies in the Fit55_H2 scenario, development of green hydrogen technologies accelerates significantly.

31. For the EU as a whole, the impact of the additional transport policies analysed on the energy sector is relatively small. In the Fit55_trans scenario, the electricity demand of electric cars increases by about 13% compared to the Fit55 scenario. The electricity demand of electrolysers is more than 6% higher in Fit55_trans between 2030 and 2050. In Poland the impact is more significant. Electricity demand for charging electric cars in Fit55_trans is about 25% higher in 2030-2050 than in Fit55, while the electricity demand for electrolysers in 2030-2050 is about 16% higher. Overall, electricity demand is more than 4% higher in this period compared to Fit55, leading to some changes in energy mix and increased electricity import in 2050.

8. Effects in Agriculture Sector

32. Agriculture appears to be a sector significantly impacted by economic mechanisms designed to reduce greenhouse gas (GHG) emissions. Under the scenario without supporting removals (Fit55_nosup scenario), the cost of carbon pricing for EU agriculture is projected to reach EUR 179 billion per year by 2050. This figure far exceeds the annual support from the Common Agricultural Policy, which amounts to EUR 55 billion/year. Such projections underline the financial challenges of achieving GHG emission reductions in agriculture.

33. Supporting the removals could significantly reduce the financial burden of climate policy on EU agriculture. The negative income effect of GHG reduction depends on the level of support - for example, under the scenario with 100% support (ETSagr_100 scenario), the negative income effect is estimated at EUR -84 billion. However, at the EU level, increasing the level of support for removals above 25% of the carbon price in non-ETS does not result in an increase in afforestation but only alleviates the financial consequences for farmers. However, the situation in Poland shows a more pronounced effect. There, increasing the support level at rate from 50% to 100% of the carbon price in non-ETS (or ETSagr) significantly boosts removals at the national level.

34. In 2050 that there are no significant variations between the Fit55_sup and ETSagr scenarios in terms of greenhouse gas emissions, market conditions, and economic impacts. Despite the lack of significant differences between the scenarios in 2050, the introduction of a new emission system in the EU will lead to slight variations in how regions adjust between 2025 and 2045, depending on the region and scenario. It is the result of the assumption that the Fit55_sub scenarios operate under the current framework, which allocates non-ETS targets between Member States based on their GDP per capita, while the new ETS system introduces common carbon prices for the agricultural sector. The ETSagr scenarios, in particular, are expected to offer a more consistent and predictable transition path.

35. The Fit55_H2 scenario shows no differences in agricultural sector performance compared to the baseline Fit55 scenario. The impact of the Fit55_trans scenario assumptions on the agricultural sector in the entire continent is relatively tiny. However, in Poland, the negative impact of climate policy on the agricultural sector's income effect in this scenario is noticeably lower than in Fit55, as assumed changes in the transport sector result in decreased national carbon prices in Poland.

9. Effects in Transport Sector

36. Increasing emission standards for heavy-duty vehicles has a significant impact on freight transport in Poland and the EU. Simulation results indicate that these standards

accelerate the transformation of the fleet by almost five years. The differences between scenarios are particularly noticeable in the last decade. Under the Fit55_trans scenario, in 2050, less than 10% of the fleet is expected to be diesel-powered both in Poland and the EU. However, without more stringent emission standards, over 23% of the fleet will still run on fossil fuels by 2050 in the EU. These results suggest that that price measures alone may not be sufficient to deliver the decarbonisation of road freight transport in Europe.

37. The rapid change in the structure of the heavy-duty vehicle fleet will lead to a much faster reduction in CO_2 emissions from freight transport. In the Fit55_trans scenario, HDV emissions in Poland could decrease by over 10 times between 2030 and 2050, reaching approximately 1.9 Mt CO_2, with total freight emissions at 2.6 Mt CO_2. Without the measures, emissions would only decrease by about 66%, and freight transport would emit 9.3 Mt CO_2 in 2050. Freight transport emissions in the EU follow a similar pattern, although the decreases in emissions are slightly lower.

38. Increasing the scrappage rate of old fossil fuel cars has a modest impact on the transformation of passenger transport. The decarbonization of this sector is mainly driven by existing measures from the ‘Fit for 55’ package. In both Poland and the EU, passenger cars are gradually being replaced by zero-emission vehicles between 2030 and 2050. The higher scrappage rate decreases the share of fossil fuel cars by approx 2 percentage points, leading to a decrease of 0.5 million tons of CO_2 emissions Poland and 6.9 million tons of CO_2 emissions in the EU by 2050. This additional effort supports the transition to greener transport, suggesting it can be a useful complement to the ‘Fit for 55’ package, encouraging further environmentally friendly measures.

39. Between 2025-2030, user costs are only 2-3% higher than in the Fit55 scenario. The benefits from using zero-emission technologies will appear after 2035. The highest reductions in total costs of ownership of the entire vehicle fleet are expected around 2045 and will reach up to 8%.

I. Policy and Literature Framework

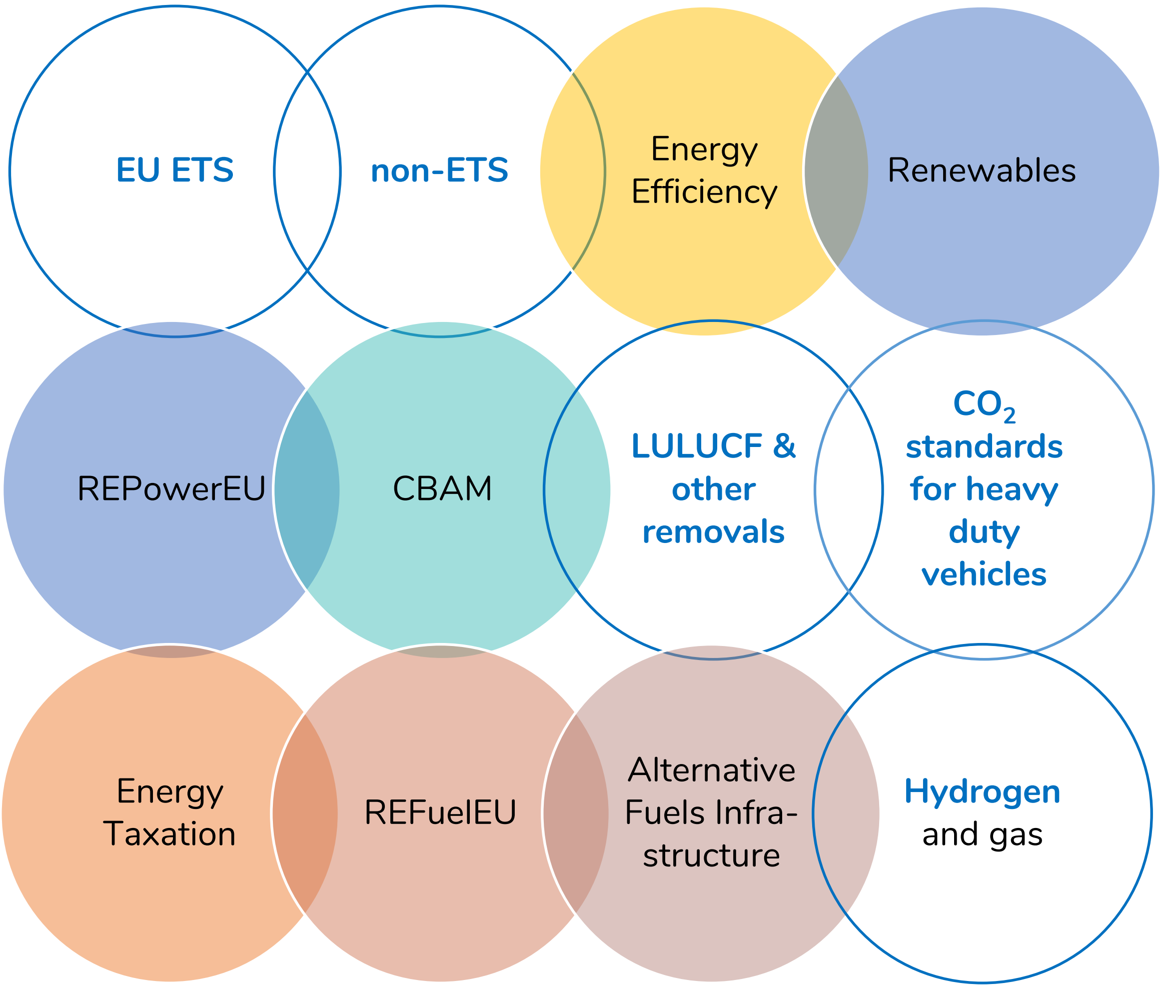
1. Climate policy background

40. The purpose of this analysis is threefold: Firstly, it serves as a key step towards the realisation of the LIFE VIIEW 2050 project, in line with the overarching objective of promoting climate resilience within the European Union. Second, our efforts include the careful preparation of an analysis, with a particular focus on the interactions between the EU Emissions Trading System (EU ETS) and other key climate and energy policies within the EU framework. As part of this assessment, we aim to provide comprehensive insights into the potential impacts of integrating the EU ETS with different policy measures. The thematic areas selected for review include phase-outs, changes to the design of the EU ETS with the creation of new ETS frameworks for agriculture and other non-ETS sectors, advancements in hydrogen deployment, and changes in sectoral policies, especially within the transport sector. Moreover, our analysis is strategically positioned to facilitate an informed discussion on the implications of the 2040 target, drawing on the empirical evidence derived from our extensive research. Through this multi-dimensional analysis, we seek to make a substantive contribution to the ongoing discourse on the development of EU climate policy and potential pathways towards ambitious goal of the European Green Deal to provide insights that are crucial for informed decision-making amid the imperative of climate action.

1.1 European Green Deal and 'Fit for 55'

41. The European Green Deal is a broad and ambitious policy framework implemented in the European Union to achieve climate neutrality by 2050 and promote sustainable growth across various sectors of the economy. The 'Fit for 55' represents the first stage of the legislative package, targeting the year 2030 and implementing the European Climate Law commitments. It consists of various new policies and amendments to existing ones, aimed at aligning the EU's climate and energy legislation with the target of reducing net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The proposed measures are broad in scope, covering key emission reduction mechanisms such as the EU Emissions Trading System (EU ETS), renewable energy (RES) and energy efficiency (EE). Additionally, the package extends its scope to entirely new areas, including removals and hydrogen development.
42. Graph 1 provides a more detailed overview of the different areas covered by the 'Fit for 55' package, illustrating its far-reaching impact on the EU's energy and climate landscape. The report has selected several topics (in blue) for analysis, namely: removals, ETS, non-ETS, hydrogen, transport sector policies such as CO_2 standards for heavy duty vehicles.

Graph 2. Key elements of EU climate and energy policy



Source: CAKE/KOBiZE

1.2 Emission reduction target for 2040

43. On February 6th 2024, the Commission presented the Communication and Impact Assessment on the new proposed emission reduction target for 2040, analysing the three possible scenarios for achieving EU climate neutrality by 2050. In its proposal, the Commission recommends a net greenhouse gas emission reduction of 90% by 2040 compared to 1990 levels in order to meet the objectives of the Paris Agreement and the objectives of the European Climate Law. This act sets out the EU's commitment to become the first climate neutral continent by 2050 at the latest, providing a clear roadmap for the desired direction of our societies. It also sets out a commitment to reduce net greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. It also calls on the Commission to come forward with a proposal no later than six months after the first Global Stocktake to set an EU-wide climate target for 2040.

44. This proposal is based on assessments of progress and measures at EU and national level, taking into account the reports of the IPCC and the European Scientific Advisory Board on Climate Change, as well as the results of the first Global Stocktake (2023) and other international climate policy developments, including common timeframes for NDCs. The Commission presented the EU's projected indicative greenhouse gas (GHG) budget for 2030-2050. This budget is defined as the indicative total amount of net greenhouse gas emissions expected to be emitted during this period without jeopardising the EU's commitments under the Paris Agreement. In order to address this challenge effectively, the Commission should take into account a number of factors, including the latest and most reliable scientific evidence, as well as considerations of social, economic and environmental impacts, investment needs, a just and socially equitable transition, cost-effectiveness, economic efficiency, competitiveness, energy affordability and security of supply.

45. This new element in the political debate on the future of EU climate and energy policy will be the most important element in the emission reduction pathways for 2050, and the decision-making process would have significant implications and consequences for the entire EU economy and development strategies. It will be crucial for the next National Determined Contribution (NDC) to be submitted by the EU to the UNFCCC by 2025, as well as for the process of preparing updated national energy and climate plans for 2021-2030 (NECPCs). All these important issues would be carefully addressed by the new European Commission, which would take office after the elections in June 2024 and during the Polish Presidency of the EU in 2025.

1.3 European Emission Trading System

46. The cornerstone of the EU's energy and climate policy is the EU Emissions Trading System (EU ETS), which operates as a carbon market with a cap-and-trade system for emission allowances in energy-intensive industries and the power generation sector. Emissions under this scheme account for about 36% of total EU greenhouse gas emissions. This system has been the EU's main instrument for reducing emissions and has contributed to a remarkable 37.3%[7] reduction in EU emissions since its introduction in 2005.

47. The ‘Fit for 55’ package aimed to increase the ambition of the EU ETS through a series of high-impact reforms, including:

[7] With the EC’s recent data for 2023 EU ETS emissions are around 47% below 2005 levels, https://climate.ec.europa.eu/news-your-voice/news/record-reduction-2023-ets-emissions-due-largely-boost-renewable-energy-2024-04-03_en?prefLang=pl

- Strengthening the level of emission reductions.
- Establishing a new stand-alone emissions trading system for buildings and road transport (ETS2).
- Revising the Market Stability Reserve (MSR).
- Extending the EU ETS to maritime transport.
- Implementing the global carbon offsetting scheme for international aviation.
- Increasing the budget of the Modernisation and Innovation Fund.

48. Another potential new element in the EU climate policy is the creation of an emission trading scheme for agriculture. In this context, the European Commission is exploring possible ways to price greenhouse gas emissions from agricultural activities along the agri-food value chain through the Emissions Trading Scheme (separate from the EU ETS) that could incentivise climate change mitigation actions in the agri-food sector (ETSagr). There are also other proposals, such us the concept of the European Central Carbon Bank (ECCB) which could serve the dual purpose of monitoring carbon removal efforts and regulating the EU ETS. Careful consideration needs to be given to the types and quantities of carbon removals that will be available to participants in the EU ETS. The integration of carbon removals is essential to offset residual emissions and maintain the credibility and stability of the EU ETS. The primary market is expected to run out of allowances around 2040. This, coupled with the subsequent reliance on the secondary market for purchases, raises concerns about market stability and liquidity. Similar to the role of central banks in monetary policy, the ECCB (European Central Carbon Bank) could influence the dynamics of the carbon market. As a regulator, it would monitor supply and demand for EUA allowances or CO_2 removal units and intervene to stabilise prices if necessary. Such a mechanism could reduce instances of market speculation and abrupt price spikes, thus ensuring a reliable and credible market environment.

1.4 Removals

49. To meet the EU's ambitious climate change targets, efforts to reduce emissions must be complemented by measures to remove carbon dioxide from the atmosphere.

50. The 'Fit for 55' package introduced a binding commitment for the EU to reduce emissions and increase removals in the land-use and forestry sector. The revised LULUCF Regulation sets a separate net land-based carbon removal target of 310 million tonnes of CO_2 eq. by 2030. The EU-wide target is to be implemented through binding national net removal targets for the LULUCF sector. The Commission's

proposal for 2040 envisages the removal of up to 400 million tonnes of carbon dioxide per year. This would be achieved through natural removals combined with large-scale deployment of industrial technologies. In the last decade before 2050, according to the EC removals will need to reach around 450 million tonnes per year, including from DAC technologies. It is worth noting that in 2018, the EC indicated the possibility of increasing removals in the LULUCF sector to almost 500 million tonnes per year in 2050 in the most ambitious scenarios (1.5LIFE 1.5LIFE-LB scenario from the European Green Deal Impact Assessment[8]).

51. Carbon dioxide removal (CDR) technologies and strategies will play a crucial role in further decarbonisation, providing a complementary approach to mitigating the impacts of greenhouse gas emissions. As a first step towards better integration of CDR into the EU climate policy, the European Commission has proposed a Regulation establishing a voluntary EU-wide Carbon Removal Certification Framework (CRCF)[9]. The Regulation will be the first step towards establishing a comprehensive framework for carbon removal and soil emission reduction in EU legislation and will contribute to the EU's ambitious goal of achieving climate neutrality by 2050. The framework covers the different types of carbon removals: permanent carbon storage through industrial technologies, carbon storage in long-lasting products, and carbon farming. The aim is to stimulate the development of carbon removal technologies and sustainable carbon farming solutions, while creating new business opportunities for industries using carbon removal technologies and developing carbon storage products, and for farmers using innovative carbon farming practices. The proposal sets the rules at EU level for quantifying, monitoring and verifying carbon removals. The Industrial Carbon Management Strategy, published in February 2024, foresees that up to 280 million tonnes of the planned 400 million annual removals after 2030 will be sequestered through technological solutions, a significant increase from at least 50 million tonnes per year before 2030.

52. The global food system contributes significantly to greenhouse gas emissions. It is also worth emphasizing the unique potential of agriculture and land use sectors (crops, animal husbandry, forestry, fisheries and aquaculture) - referred to as AFOLU (Agriculture, Forestry and Other Land Use) or LULUCF (Land Use, Land Use Change and Forestry) - they can take action to reduce greenhouse gas emissions and absorption. Apart from Bioenergy with Carbon Capture and Storage (BECCS), the land-management options for GHG removal include afforestation or reforestation (AR),

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[8] https://climate.ec.europa.eu/document/download/dc751b7f-6bff-47eb-9535-32181f35607a_en?filename=com_2018_733_analysis_in_support_en.pdf

[9] On 10 April, the European Parliament approved an agreement with national governments on a new carbon removal certification scheme.

wetland restoration (WR), soil carbon storage (SCS), pyrogenic carbon capture and storage (PyCCS), terrestrial enhanced weathering (TEW)[10].

53. Bioenergy with Carbon Capture and Storage (BECCS) - This technology is classified as a Negative Emission Technology (NET). NETs are geo-engineering methods to remove greenhouse gases from the atmosphere and reduce the impact of the energy system on global warming. The development of NET technologies is necessary because it is not possible to decarbonise all processes in the economy in an economically justifiable way.

54. One of the main advantages of BECCS is the ability to generate negative greenhouse gas emissions by removing CO_2 and injecting it into geological formations or using it in industrial processes. The fuel in this process is biomass, which absorbs CO_2 from the atmosphere during photosynthesis as it grows. When the biomass is burned in the energy boiler, the CO_2 released is captured. Negative emissions from this technology can offset emissions in areas where total reduction is impossible, such as agriculture and industry. The cost optimisation results obtained in this report indicate that BECCS technology is highly competitive in the context of high CO_2 emission allowance prices. This study analyses the necessary long-term directions of action in the process of building a climate-neutral economy in Poland and the EU as a whole, and identifies the economically optimal support path for BECCS.

55. Afforestation and reforestation (AR) - Given the large land occupation, significant contribution to the removal of natural carbon sinks, and relatively low food output to land use ratio for animal agriculture[11,12] there is potential of returning land currently used for animal agriculture to forest cover, the climax vegetation[13]. The planting of additional trees will sequester CO_2. In particular, GHG removal can be achieved through the planting of trees on land that has not been forested recently (afforestation) or the restocking of recently depleted land with (restoration) or without (reforestation) an

[10] Land-Management Options for Greenhouse Gas Removal and Their Impacts on Ecosystem Services and the Sustainable Development Goals Pete Smith, Justin Adams, David J. Beerling, Tim Beringer, Katherine V. Calvin, Sabine Fuss, Bronson Griscom, Nikolas Hagemann, Claudia Kammann, Florian Kraxner, Jan C. Minx, Alexander Popp, Phil Renforth, Jose Luis Vicente Vicente, Saskia Keesstra Annual Review of Environment and Resources 2019 44:1, 255-286

[11] Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science 2018;360:987-92

[12] Eshel G, Shepon A, Makov T, Milo R. Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States. Proceedings of the National Academy of Sciences 2014;111:11996-2001

[13] Lamb A, Green R, Bateman I, et al. The potential for land sparing to offset greenhouse gas emissions from agriculture. Nature Clim Change 2016.

emphasis on restoring ecological processes[14]. UN statistics[15] state that during 1990 to 2015 the total global forest area decreased from 4.28 to 3.99 billion hectares, and the area of planted forests increased from 167.5 to 277.9 million hectares. Most of the secondary forests provide temporary and permanent habitats, including those for nesting, feeding, and mating opportunities for a large variety of fauna and flora species. Through forest landscape restoration, apart from GHG removal improves human livelihoods as well as ecological integrity and ecosystem services across a landscape[16].

56. Water rewetting (WR) - Peatlands are the most extensive land storage of organic carbon. In their natural state (mires), they absorb carbon dioxide from the atmosphere, accumulating carbon in peat. If they are dried, they become substantial sources of greenhouse gases, contributing to the greenhouse effect. Globally, drained peatlands emit approximately 2 Gt of CO_2 per year, which corresponds to approximately 5% of anthropogenic emissions; thus, rewetting peatlands used for agricultural purposes can simultaneously reduce GHG emissions from agriculture and, in the long term, increase carbon sequestration. The balance of greenhouse gas flow between peat bogs and the atmosphere depends primarily on their moisture content. Mires are net carbon sinks, and therefore, in the long term (over several dozen years), they cause negative radiative forcing[17,18]. In the shorter term, however, the absorption of carbon dioxide is compensated by methane emissions. However, let us also consider the atmosphere's relatively short duration of methane. It becomes clear that the impact of swamps on the climate is more "cooling" the longer the time window we take into account. From the perspective of tens to thousands of years, mires have a cooling effect.[19]

57. Soil carbon storage (SCS) – is a critical ecosystem service that is a result of complex interactions among various ecological processes. Human activities have a significant impact on these processes, leading to either an increase or decrease in carbon storage. The carbon sequestration capacity of soil at the scale of crop field can be influenced by

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[14] Fuss S, Lamb WF, Callaghan MW, Hilaire J, Creutzig F, et al. 2018. Negative emissions—Part 2: Costs, potentials and side effects. Environ. Res. Lett. 13:063002

[15] Food and Agriculture Organization of the United Nations (FAO). 2015. Global Forest Resources Assessment (FRA) 2015. How are the World's Forests Changing? Rome: FAO. https://www.fao.org/3/i4793e/i4793e.pdf

[16] International Union for Conservation of Nature (IUCN). 2017. Bonn Challenge Barometer of Progress: Spotlight Report 2017. Gland, Switz.: IUCN. https://www.iucn.org/sites/dev/files/content/

[17] Frolking S., Talbot J., Jones M.C., Treat C.C., Kauffman J.B., Tuittila E.S., Roulet N. (2011). Peatlands in the Earth's 21st century climate system. Env Rev 19:371–396. https://doi.org/10.1139/a11-014.

[18] Joosten H., Couwenberg J., Von Unger M. (2016a). International carbon policies as a new driver for peatland restoration. W: Bonn A., Allott T., Evans M., Joosten H., Stoneman R. (red.). Peatland restoration and ecosystem services: science, policy and practice. Cambridge University Press/British Ecological Society, Cambridge: 291-313.

[19] Joosten H., Sirin A., Couwenberg J., Laine J., Smith, P. (2016b). The role of peatlands in climate regulation. W: Bonn A., Allott T., Evans M., Joosten H., Stoneman R. (red.). Peatland restoration and ecosystem services: science, policy and practice. Cambridge University Press/British Ecological Society, Cambridge: 63-76.

a wide range of local controls on ecosystem processes, such as rainfall infiltration, soil erosion, and deposition of sediment, and soil temperature. These local controls can vary due to landscape heterogeneity, resulting in differences in soil organic carbon (SOC) contents along topographic gradients[20]. For example, slope position can affect soil moisture and nutrient levels, which subsequently affects the root growth of plants[21]. This, in turn, can have significant consequences for soil carbon. The combined effects of changes in carbon inputs and losses from land use, land management, and landscape-level effects on carbon input and loss rates cause variation in the carbon sequestration capacity across landscapes. Land management, especially in agricultural settings, has a significant impact on SOC levels, and current research is focused on understanding these impacts. These changes in soil carbon, however, typically take many decades to occur, making actual measurements of changes in SOC stocks difficult. In the future, various factors, such as warming and CO_2 levels, land management, and landscape heterogeneity, will affect SOC capacity in complex ways[22].

58. Pyrogenic Carbon Capture and Storage (PyCCS) – is a GHG removal technology based on pyrolysis, the thermal treatment of biomass at temperatures of 350-900°C in an oxygen-deficient to anoxic atmosphere. Three main carbonaceous products are generated in this conversion, which can subsequently be stored in different ways to produce NE: solid biochar, pyrolytic liquid (bio-oil), and permanent pyrogases. Biochar, being less susceptible to degradation into CO_2 and CH_4 than non-pyrogenic biomass, breaks down into micro- and nano-particles, which can be transported to deeper soil horizons, groundwater, or other compartments, thereby enhancing protection against degradation. Multiple studies have demonstrated the stability of pyrogenic carbon over centennial timescales. Biochar is context-dependent, but it is rather beneficial to soil fertility. Present estimates suggest that Biochar soil application could sequester 2.5 gigatons (Gt) of CO_2 annually[23]. Another viable approach is to utilize Biochar as an additive in construction materials, asphalt, plastics, paper, and textiles. However, the sustainable biochar manufacturing process lacks knowledge, effective low-emission synthesis technology, and standardization, which hampers its market growth due to high costs, finance shortage, and immature carbon market[24].

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[20] Thompson, J. A., & Kolka, R. K. Soil carbon storage estimation in a central hardwood forest watershed using quantitative soil-landscape modeling. Soil Science Society of America Journal 69, 1086-1093 (2005).
[21] Ehrenfeld, J. G., Kaldor, E. & Parmelee, R. W. Vertical distribution of roots along a soil toposequence in the New Jersey pinelands. Canadian Journal of Forest Research 22, 1929-1936 (1992).
[22] Ontl, T. A. & Schulte, L. A. (2012) Soil Carbon Storage. Nature Education Knowledge 3(10):35
[23] Kurniawan, Tonni Agustiono; Othman, Mohd Hafiz Dzarfan; Liang, Xue; Goh, Hui Hwang; Gikas, Petros; Chong, Kok-Keong; Chew, Kit Wayne (April 2023). "Challenges and opportunities for biochar to promote circular economy and carbon neutrality". Journal of Environmental Management.
[24] Biochar Market Size, Share & COVID-19 Impact Analysis, By Technology (Pyrolysis and Gasification), By Application (Farming, Livestock, Power Generation, and Others) and Regional Forecasts, 2023-2030 https://www.fortunebusinessinsights.com/industry-reports/biochar-market-100750

59. The weathering of carbonate and silicate rocks on land (TEW) – is a key process in the global carbon cycle and, through its coupling with calcium carbonate deposition in the ocean, is the primary sink of carbon on geologic timescales. Terrestrial enhanced weathering takes advantage of natural weathering processes by crushing and spreading rocks, more specifically alkaline minerals, on agricultural land or forest floors where these minerals react with carbon dioxide and water[25]. During these reactions, carbon dioxide is converted into dissolved bicarbonate: a stable form of carbon that will not be re-released into the atmosphere. Reactions between weathered minerals and carbon dioxide occur naturally; terrestrial enhanced weathering approaches speed up and scale up this process[26]. Uncertainty remains around the speed at which this happens, with some suggesting lack of rainfall may limit it. The effectivenes of enhanced weathering varies due to the uncertainty surrounding mineral dissolution rates. On average in 2020 TEW cost were twice higher than reforestation[27] and required relatively high energy input for mining, crushing and transport of the rock material[28].

60. Considering the industrial character of PyCCS and TEW, especially high energy requirements and high equipment investments, it can not be considered as a farm activity competing for the land, capital, and labour with crops or farm animals. In case of this measures the agriculture sector might be considered only as a manager of the land where biochar or crushed rocks are applied. However, any side effects for agricultural production of both measures mentioned above are still unknown. It is also questionable if, having in mind energy inputs in those activities the potential removals of GHG should be accounted to agricultural sector. Due to these uncertainties, PyCCS and TEW were not implemented in our model for the agricultural sector (EPICA). Even SCS is connected with typical farm processes its possible effects are very uncertain, especially regarding efficiency of storing carbon in the soil and its duration. Having in mind that EPICA is solved at the country scale proper assumptions of parameters for modeling SCS is still questionable, thus SCS was not implemented in the model.

[25] Schuiling, R. D.; Krijgsman, P. (2006). "Enhanced Weathering: An Effective and Cheap Tool to Sequester CO_2". Climatic Change. 74 (1–3): 349–54. Bibcode:2006ClCh...74..349S. doi:10.1007/s10584-005-3485-y. S2CID 131280491.

[26] Rudy Kahsar, Cara Maesano, Daniel Pike, Isabel Wood From Trees to Tech and Beyond: Carbon Dioxide Removal (CDR) in All Its Variations https://rmi.org/from-trees-to-tech-and-beyond-carbon-dioxide-removal-cdr-in-all-its-variations/

[27] Beerling, David (2020-07-08). "Potential for large-scale CO_2 removal via enhanced rock weathering with croplands". Nature. 583 (7815): 242–248. Bibcode:2020Natur.583..242B. doi:10.1038/s41586-020-2448-9. hdl:10871/122894. PMID 32641817. S2CID 220417075. Archived from the original on 2020-07-16. Retrieved 2021-02-09.

[28] P. Renforth, The potential of enhanced weathering in the UK, International Journal of Greenhouse Gas Control, Volume 10, 2012, Pages 229-243, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2012.06.011. https://www.sciencedirect.com/science/article/pii/S1750583612001466

1.5 Hydrogen

61. In the strategies of the European Union and the national documents of the EU Member States, hydrogen fuel is seen as a very important technological option to reduce CO_2 emissions. In the future, hydrogen is expected to be an energy carrier that will largely replace coal, natural gas and oil. It can act as the missing link in the decarbonisation process, as it solves a number of problems, including: enabling decarbonisation in the transport and industrial sectors, as well as providing long-term energy storage to stabilise the operation of the electricity system under a large share of renewable sources characterised by high load volatility. Hydrogen can also be an alternative to natural gas, which is particularly important in the context of the ongoing crisis in the European gas market.

62. In July 2020, the European Commission proposed the Hydrogen Strategy for a Climate Neutral Europe, which aims to accelerate the development of green hydrogen and secure its role as the foundation of a climate neutral energy system by 2050. The EU Hydrogen Strategy identifies green hydrogen and its value chain as one of the key areas for unlocking investment to support sustainable growth and employment, which will be crucial in the context of the post-COVID-19 recovery. It sets the following strategic objectives, which define the size of the EU hydrogen market over the next decade:

    - by 2024 - installation of at least 6 GW of electrolyzer capacity and annual production of at least 1 million tonnes of hydrogen from Renewable Energy Sources (RES),
    - by 2030 - installation of at least 40 GW of electrolyzer capacity and annual production of at least 10 million tonnes of hydrogen from RES.

63. In July 2021, the European Commision in Fit for 55 package increases its projections of the required to achieve the neutrality goal in electrolysers to 44 GW.
64. Another legal document at EU level that envisages the large-scale use of hydrogen in the energy transition is the REPowerEU plan. The REPowerEU plan increases the targets for the development of installed electrolyser capacity compared to the EU Hydrogen Strategy and Fit for 55 package. It has been pointed out that the project is based on the full implementation of the proposals of the 'Fit for 55' package, i.e. reducing greenhouse gas emissions by at least 55% by 2030 and achieving climate neutrality by 2050, as stated in the European Green Deal. According to this plan, the installed capacity of electrolysers in the EU is expected to reach 65 GW in 2030. The European Commission estimates in SWD(2022) 230 final[29] that achieving the REPowerEU targets will require additional investment of €210 billion by 2027 (and

[29] Commission Staff Working Document, Implementing the REPowerEU Action Plan: Investment needs, Hydrogen Accelerator and Achieving the Bio-methane targets - SWD(2022) 230 final

€300 billion by 2030) compared to the 'Fit for 55' package, but would save almost €100 billion per year in reduced fossil fuel imports. Strong growth in demand for renewable hydrogen will lead to an increase in installed wind and solar capacity. Compared to the 'Fit for 55' package, 41 GW of additional wind capacity and 62 GW of additional solar capacity will be added. According to REPowerEU, the share of renewable energy in gross final energy demand should be at least 45%. The basic concept of hydrogen use in the energy sector is that excess solar and/or wind power is used to produce hydrogen by electrolysis of water during periods when electricity production from renewable sources is higher than electricity consumption. The hydrogen is then stored, for example as a compressed gas or in metal hydrides. When electricity production from wind and/or solar is lower than electricity consumption, the stored hydrogen can be used to produce electricity in fuel cells or burned in dedicated turbines.

65. Chapter 8.3 analyses the quantities of hydrogen required to meet the growing demand for fuel and energy in the EU to ensure full decarbonisation by 2050, and assesses the capacity of the electricity sector to produce green hydrogen. It also examines the potential for using green hydrogen to store renewable energy and its ability to improve the stability of onshore and offshore wind turbines.

66. Hydrogen is seen as one of the ways to reduce transport emissions. It has the potential to replace fossil fuels, especially in urban transport (buses), road transport (e.g. heavy and long-distance transport) or non-electrified rail transport. Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are already reducing transport emissions. However, in order to fully decarbonise this sector, it will be necessary to implement fuel cell vehicles (FCEV - Fuel Cell electric vehicle). FCEVs will be particularly important in the field of public transport and heavy and long-haul road transport. This is a segment where there are limited opportunities to use BEV. Hydrogen will become an alternative for transport sectors where electrification is unprofitable or impossible. In the case of heavy and long-distance road transport, efforts should also be made to replace internal combustion engines powering refrigerated semi-trailers with electric motors.

67. The use of hydrogen buses in public transport, in addition to electric buses, will contribute to achieving the goals in the field of low-emission transport set out in the *Strategy for sustainable and smart mobility*[30] of the European Commission. From 2025, cities with a population of over 100,000 inhabitants will be obliged to purchase only zero-emission vehicles in order to achieve full zero-emissions of the public transport fleet by 2030. The Polish hydrogen strategy assumes that 100 to 250 new hydrogen

[30]Communication from the Commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions – Sustainable and Smart Mobility Strategy – putting European transport on track for the future COM/2020/789 final

buses will be in operation by the end of 2025. However, 800 to 1,000 new hydrogen city buses are expected to be in operation by 2030[31]. Potential opportunities for the use of hydrogen should be explored not only in road transport, but also in railway applications. A hydrogen-powered railway could become attractive for freight transport and, above all, passenger transport at the regional and supra-regional level. It will become more competitive in long-distance transport. Hydrogen-powered trains will replace combustion vehicles used on non-electrified railway lines.

68. A condition for a widespread use of hydrogen as an energy carrier in the EU is the availability of energy infrastructure for connecting supply and demand. Hydrogen may be transported via pipelines, but also via non-network based transport options, e.g. trucks or ships docking at adapted LNG terminals, insofar as technically feasible. The infrastructure needs for hydrogen will ultimately depend on the pattern of hydrogen production and demand and transportation costs and will be linked to the different stages of the development of hydrogen production, increasing significantly after 2024. Furthermore, infrastructure to support carbon capture use and storage may be needed for the production of low-carbon hydrogen and synthetic fuels. With increasing demand, the optimisation of the production, use and transport of hydrogen will have to be secured and is likely to require longer-range transportation to ensure that the entire system is efficient through the revision of the Trans-European Networks for Energy (TEN-E) and the review of the internal gas market legislation for competitive decarbonised gas markets. To ensure interoperability of markets for pure hydrogen, common quality standards (e.g. for purity and thresholds for contaminants) or cross-border operational rules may be necessary. This process should be combined with a strategy to meet the transport demand through a network of refuelling stations, linked to the review of the Alternative Fuels Infrastructure Directive and the revision of the Trans-European Transport Network (TEN-T)[32].

1.6 CO_2 emission standards for heavy-duty vehicles

69. On February 14, 2023, the European Commission published a draft revision of the EU regulation on setting CO_2 emission standards for new heavy-duty vehicles[33]. The Commission has proposed ambitious new CO_2 emissions targets for this category of vehicles from 2030. These targets aim to reduce CO_2 emissions in the transport sector. Currently, trucks, city buses and long-distance buses are responsible for more

[31] Polish Ministry of Climate and Environment; *Polish hydrogen strategy until 2030 with an outlook until 2040*; https://www.gov.pl/web/klimat/polska-strategia-wodorowa-do-roku-2030

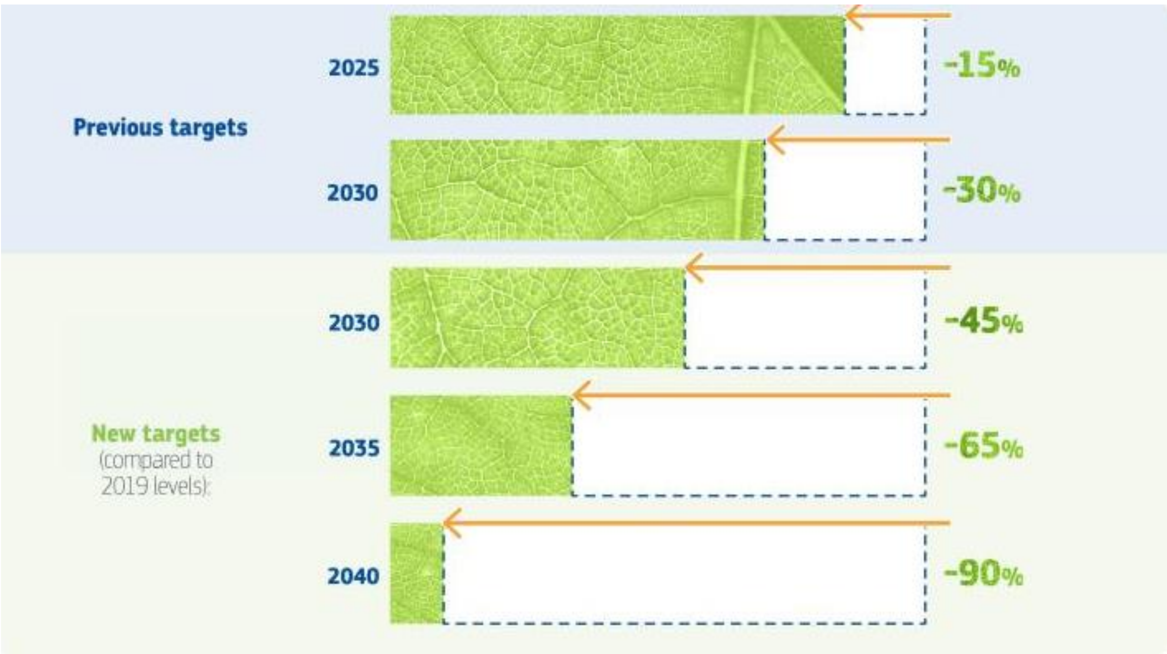
[32] Communication from the Commission to the European parliament, the council, the European economic and social committee and the committee of the regions – Hydrogen strategy for a climate-neutral Europe; COM/2020/301 final

[33] On 18 January 2024, the Council and European Parliament reach provisional agreement on the CO_2 emission standards for heavy-duty vehicles.

than 6% of total EU greenhouse gas emissions and more than 25% of road transport greenhouse gas emissions. According to the proposal, by tightening emission standards, this segment of the road transport sector would contribute to the eventual transition to zero-emission mobility and to the achievement of the EU's climate goals and the zero level of greenhouse gas emissions and pollutants from transport. The EC proposal covers three groups of heavy vehicles, including trucks (over 5 tons), city and long-distance buses - coaches (over 7.5 tons) and trailers and semi-trailers (over 8 tons). The Commission proposes to gradually introduce stricter CO_2 emission standards compared to 2019 levels for new CO_2 certified heavy-duty vehicles. Compared to the average CO_2 emissions in the 2019 reporting year, the average CO_2 emissions of the EU fleet of new heavy vehicles are to be reduced by:

- 45% in the reporting periods 2030-2034,
- 65% in the reporting periods 2035-2039,
- 90% in reporting periods from 2040.

Graph 3. Previous and new targets for heavy – duty vehicles



Source: European Commission, link: https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/reducing-co2-emissions-heavy-duty-vehicles_en, *accessed on March 27, 2024*

70. The Regulation includes an incentive mechanism for:

- Zero-emission vehicles (ZEV), lorries without an internal combustion engine, or with an internal combustion engine that emits less than $1gCO_2$ per kWh or per km.

- Low-emission vehicles (LEV), lorries with a technically permissible maximum laden mass of more than 16t, with CO_2 emissions of less than half of the average CO_2 emissions of all vehicles in its group registered in the 2019 reporting period.

71. If a manufacturer's fleet of new heavy-duty vehicles includes at least 2% zero and low-emission vehicles (ZLEV), with at least 0.75% being subject to CO_2 targets, the average specific CO_2 emissions of the manufacturer will be reduced. The manufacturer's average specific CO_2 emissions will decrease by one percent for each percentage point that the benchmark is exceeded.

2. Literature review on interaction of policies

72. Perhaps the most influential view on the interaction between climate policy instruments has been formulated in the article by William Nordhaus, the Nobel Prize laureate. Nordhaus (2011)[34] states that "*necessary and sufficient condition for an appropriate innovational environment is a universal, credible, and durable price on carbon emissions*". In other words, if one instrument (e.g. the ETS) creates a price on emissions, no other instruments are necessary to steer the decarbonization. For instance, when carbon price is in place, it creates sufficient incentives for firms to invest in low-carbon technologies and any further push by other instruments is not necessary. If policy makers believe that low-carbon technologies require substantial innovative effort and if they fear that the market alone underinvest in innovations, they should supplement climate policy with an R&D policy that support innovations, but the latter must be technology-neutral. That is, it should support all technologies regardless of their role in the low-carbon transition. The combination of both policies: carbon pricing and a technology-neutral support for innovation effort will create conditions in which market will choose a mix of technologies which is optimal for the welfare of the society.

73. Nordhaus article, also known as "price fundamentalism", provides a strong argument with solid theoretical grounds against the mix of climate policies, but it does not provide a definitive answer to the problem. In reality the conditions considered by the Nordhaus (for instance, that a hypothetical emission price must be universal, i.e. cover all emissions in all countries) are unlikely to be met. Nordhaus argument does not imply that in the specific situation of the EU, supplementing EU ETS with other policies is always unjustified. Nevertheless, in the light of his results, in each case it requires a

[34] Nordhaus, William, 2011. "Designing a friendly space for technological change to slow global warming," Energy Economics, Elsevier, vol. 33(4), pages 665-673, July.

careful examination whether the additional policy does not distort the price set in the EU ETS system.

74. The logic outlined in the Nordhaus's article was supported by results from a simple theoretical model by Fankhauser et al. 2010[35]. They show that in the presence of cap-and-trade system, such as ETS, the subsidies to low-carbon abatement options, such as subsidies to Renewable Energy Sources (RES), will have no environmental impact (because total emissions are fixed by the ETS) and lead simply to a reduction in the emission price. In the illustrative case, if all abatement options are covered with the same subsidy and the level of a subsidy per unit of abated emission is set by policymakers, an increase in the subsidy by one euro will decrease the price of emission allowances by one euro. The authors note that cap-and-trade systems could be supplemented with carbon tax, for instance to introduce a price ceiling or price floors for the emission allowances. The parameters of such hybrid systems must be determined by the shape of the marginal benefit to abatement curve. The shape of the curve should be identified with the consideration of the damages.

75. Fischer et al. 2016[36] provide further insight on when supplementing carbon pricing with additional instruments is beneficial and when it can be harmful. They consider the situation when market imperfection leads to several market failures: without state interventions the market leads (i) to excessive emissions (emission externality), (ii) underdeployment of new energy efficient (EE) solutions, for instance, because consumers are not aware of all benefits brought by the EE technologies (EE undervaluation), (iii) underdeployment of early-stage technologies (learning-by-doing externality) and (iv) underinvestment in R&D (knowledge externality). Ideally, each failure requires its own correcting instrument: a carbon price, a subsidy to investment increasing energy efficiency, a subsidy to deployment of early stage technologies, and a technology-neutral R&D subsidy. If all failures occur, the application of all four policies reduces the cost of decarbonization by 25% compared to the scenario when only carbon pricing is applied.

76. The size of gains from overlapping policies is assessed using a GDynEP (CGE) model in the study by Corradini et al. 2018[37]. The authors analyse GDP impacts when some part of ETS revenues is recycled in the form of investment in the development of low-carbon technologies, e.g. renewables. For instance, in the ambitious policy scenario

[35] Fankhauser,S., Hepburn,C., Park,J., 2010. "Combining multiple climate policy instruments: how not to do it." Climate Change Economics 1(3), 209–225.

[36] Fischer, Carolyn, Preonas, Louis and Newell, Richard G., 2017. "Environmental and Technology Policy Options in the Electricity Sector: Are We Deploying Too Many?," Journal of the Association of Environmental and Resource Economists, University of Chicago Press, vol. 4(4), pages 959-984.

[37] Corradini, Massimiliano, Costantini, Valeria, Markandya, Anil, Paglialunga, Elena and Sforna, Giorgia, 2018. "A dynamic assessment of instrument interaction and timing alternatives in the EU low-carbon policy mix design," Energy Policy, Elsevier, vol. 120(C), pages 73-84.

devoting 50% of revenues from ETS to support renewables results in the GDP loss of 2.84% (with respect to the BAU scenario, for the periods 2015-2050). If no ETS is used to support renewables and all of it is directed to households in the form of lump-sum transfers, the GDP loss increases to 3.91%. However all these results rest on the condition that investment in renewables brings substantial technological progress. The authors estimate the relation between investment and progress using historical data, but this estimation rests on the assumption that investment is exogenous (i.e. does not depend on the technological progress and does not depend on other variables influencing the progress), which in most real life situations may be difficult to justify. Indeed, it is likely that both, investment and progress are simply driven by a time trend and the empirically observed correlation between them is spurious. In this instance, contrary to model assumptions, additional investment would result in little additional progress.

77. Gawel et al. 2014[38] proposes two additional arguments why ETS should be complemented with policy instruments that support the deployment of RES. First, they argue that the level of the cap in ETS system cannot be set at the optimal level if that level would involve high price of allowances, because it would be blocked by interest groups, such as emitting industries. The policies that support the deployment of renewables will shift down the demand for allowances and therefore reduce the price. Lower price will than enable policymakers to set a more ambitious ETS caps that are closer to the optimum. This logic, however, rests on two important assumptions: first that the ETS targets are partly determined by the emission industries and that their influence is not offset by pro-climate interests groups. The second assumption is that if emission industries can influence ETS targets, they are ready to accept a tighter target if price of allowance is sufficiently low.

78. The second argument in favour of complementing ETS with other instruments proposed by Gawel et al. is that, in addition to climate, policy makers might have other concerns, for instance the risk associated with the use of nuclear power. ETS alone may support nuclear energy which, according to some policymakers, might be not aligned with sustainable development. The introduction of instruments supporting RES might correct the trajectory of transition and ensure that the decarbonization is achieved with the technologies that policymakers consider appropriate.

79. Herweg (2020)[39] examined another aspect of policy convergence with the EU ETS, focusing on the impact of national-level restrictions such as Germany's closure of coal-

[38] Gawel, Erik, Strunz, Sebastian, Lehmann, Paul, 2014. "A public choice view on the climate and energy policy mix in the EU — How do the emissions trading scheme and support for renewable energies interact?," Energy Policy, Elsevier, vol. 64(C), pages 175-182.

[39] Herweg, Fabian, 2020. "Overlapping efforts in the EU Emissions Trading System," Economics Letters, Elsevier, vol. 193(C).

fired power plants. The study delved into how these measures influence the operation of the EU ETS system, particularly MSR, consequently affecting the overall trajectory of emission reductions. The analysis showed that when overlapping mechanisms are in place, assuming marginal abatement costs are not highly convex, there is an increase in allowance banking. This, in turn, leads to an overall reduction in emissions. Put it simply, a higher level of banking corresponds to lower overall emissions in the long term.

80. To sum up, the theoretical models and empirical studies provide insights into the potential impacts of supplementing carbon pricing with additional policy instruments, however there is no common opinion on the nature of these policies – complementary or distortion. The effectiveness of overlapping policies depends on various factors, including market imperfections, the presence of multiple market failures, and the specific context of each policy implementation. Arguments for supplementing carbon pricing with additional instruments extend beyond purely economic considerations, encompassing factors such as political feasibility, technological appropriateness, and broader sustainability goals. Ongoing research, including this report, continues to explore the implications of policy convergence with existing mechanisms like the EU ETS, shedding light on how other measures influence the overall trajectory of emission reductions. As mentioned above, much of the empirical research concerns the overlap between ETS and policies such as renewable energy and energy efficiency, so in our report we have chosen other mechanisms that are currently the main topics of policy and research discussion, including removals and hydrogen.

II. Analytical Part: Insights from Modeling EU's Climate Policy

3. The models used for scenario analysis

81. The study presents the results of energy and climate policy modeling, carried out using tools developed by the Centre for Climate and Energy Analysis (CAKE). These tools include the macroeconomic model d-PLACE[40], the energy system sectoral model MEESA[41], and other sectoral models such as TR^3E[42] for transport and EPICA[43] for agriculture. The models have a time horizon up to 2050. Details of the regional coverage presented in the study are given at the beginning of the report in section on regional aggregation and respective codes.

Graph 4. Regional aggregation

Source: CAKE/KOBiZE

[40] Boratyński, J., Pyrka, M., Tobiasz, I., Witajewski-Baltvilks, J., Jeszke, R., Gąska, J., Rabiega, W. (2022). The CGE model d-PLACE, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_d-PLACE_v.2_d-place-model_documentation.pdf.

[41] Tatarewicz, I., Lewarski, M., Skwierz, S. (2022).The MEESA Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_MEESA_v.2_energy-model_documentation.pdf

[42] Rabiega, W., Sikora, P., Gąska, J., Gorzałczyński A. (2022). The TR^3E Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_TR3E_v.2_transport-model-documentation.pdf

[43] Wąs, A., Witajewski-Baltvilks, J., Krupin, V., Kobus, P. (2022). The EPICA Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_EPICA_v.2_agriculture-model_documentation.pdf

82. The models operate in an iterative process[44]. This process involves exchanging critical parameters, for example carbon price, fuel usage, GHG emissions, prices, and output value, between the models in the simulation. This integration ensures a comprehensive actions aimed at reducing GHG emissions. Estimated emission changes in various sectors of the economy (and resulting marginal costs of reduction, in the EU ETS, ETS2, and non-ETS areas), lead to achieving the intended reduction target in the EU. Sectoral models, alongside the CGE model, allow for a more detailed capture of sector-specificities and reduction technologies in key areas of the economy. For more detailed description of the models and assumptions see Annex I.

83. **D-PLACE** is a global, multi-sector model that uses the GTAP 10 dataset. It is a recursive dynamic Computable General Equilibrium (CGE) model that distinguishes 29 sectors, including energy-intensive and trade-exposed industries. The model basically follows standard formulations, with nested Leontief-CES production functions, marginal cost pricing, and bilateral trade based on the Armington assumption. The baseline scenario is in line with external projections for GDP growth rates by country, fossil fuel price levels, and GHG emission limits.

84. **MEESA** is a linear optimization model for the energy sector. It identifies solutions by selecting the optimal production units based on the criterion of minimum discounted energy system costs, given boundary conditions. The model takes into account among others current production structure of individual EU countries, the potential of renewable and conventional sources, national energy policies.

85. **EPICA** is an optimization model for the agricultural sector. The model assumes the optimization of agricultural income at the level of individual farm types. This reflects a situation in which farmers aim to maximize their income by adjusting the production structure to the current or expected market and policy situation. The model reflects farmers' choices regarding production structure (referred to as farm activities) and production intensity with appropriate processes and practices.

86. **TR^{3}E** is a partial equilibrium model for transport sector. It covers four main transport modes (road, rail, aviation, and maritime) for both passenger and freight transport, encompassing up to 37 means of transport, as well as the characteristics of engine types and technology options for each means. The model outputs activity levels, energy consumption (oil, electricity, and hydrogen), and emissions levels. The model includes an expanded fleet module for passenger cars, light-duty vehicles, and heavy-duty vehicles.

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[44] Boratyński, J., Witajewski-Baltvilks, J., Tatarewicz, I., Pyrka, M., 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 2021. https://climatecake.ios.edu.pl/wp-content/uploads/2021/12/CAKE_Models_Linking_21.12.2021_final.pdf

4. Objective and scope of the analysis

87. In this report, we undertake a comprehensive exploration of a crucial segment of the EU's climate policy, namely the emissions trading system, to fulfil the objectives outlined by the LIFE VIIEW 2050 project. Our primary focus is to conduct a detailed analysis examining the complex interrelationships among the EU ETS and other pivotal climate and energy policies within the European Union. The detailed purpose and research chosen areas are presented below:

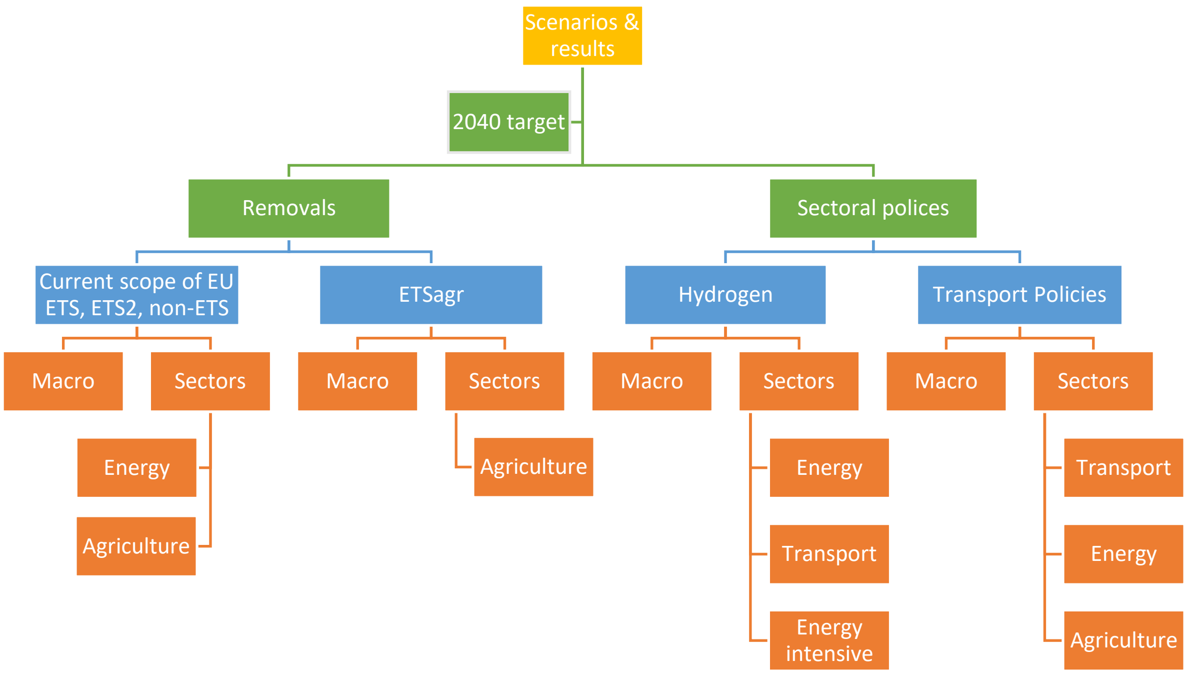
The purpose:

- Preparation of an analysis to assess the impact of interactions between the EU ETS and other EU climate and energy policies,
- Facilitation of a discussion on the implications of the 2040 target, supported by findings from our results.

The areas chosen:

- Carbon removals,
- Changes in EU ETS design, including creation 'ETSagr' – new ETS for agriculture and the rest of the non-ETS,
- Hydrogen development,
- Changes in sectoral policies focusing on transport.

Graph 5. Structure of the report



Source: CAKE/KOBiZE

5. Emission reduction pathways

5.1 Toward a low-carbon economy in the EU

88. The report's scenarios assume the achievement of an emission reduction target in line with the EU's climate policy. The 'Fit for 55' package and the European Green Deal provide the basis for determining the emission reduction trajectory. The EU has established an economy-wide net emissions reduction target of 55% below 1990 levels for 2030. Based on our calculations, if we exclude the Land Use, Land Use Change, and Forestry sector (LULUCF)[45], there would be a 53% reduction in greenhouse gas (GHG) emissions by 2030 compared to 1990 levels.

89. It is expected that the EU will achieve climate neutrality in line with the European Green Deal by 2050. However, there is a lack of detailed policies outlining the trajectory for implementing the reduction path post-2030. Due to a lack of detailed policies, it is assumed that the EU-wide emission reduction target, excluding the LULUCF sector, will be 90% compared to the 1990 emissions level. Therefore, according to these assumptions, the remaining 10% of emissions (i.e. residual emissions) must be compensated by absorption from the LULUCF[46].

90. The EC recently proposed the 2040 ambition[47] to complete future policy architecture. The level of a net reduction target is set at 90% compared to 1990. This reduction target will undergo negotiations among the Member States, the European Parliament and the European Commission, therefore the final adopted level remains uncertain. In our scenarios, the EU achieves a 75% reduction in 2040 compared to 1990 levels. This is based on the previously set targets for 2030 and 2050. The LULUCF sector was not included in the calculation of this reduction target. However, if the LULUCF sector is taken into account (-396 Mt CO_2 eq. in 2040), the net reduction target achieved is around 83% compared to the 1990 levels[48].

[45] According to Regulation (EU) 2023/839 of the European Parliament and of the Council, it is anticipated that in 2030, the absorption level from the LULUCF sector will reach -310 million CO_2 eq.
[46] The absorption value is based on the European Commission Impact Assessment accompanying the document 'Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people', SWD(2020) 176 final, Part 2/2, Figure 91, page 148. This absorption value also corresponds to 1.5LIFE scenario from the European Commission's report 'In-depth analysis in support of the Commission Communication, A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy ', Tabel 9, page 198, Brussels, 28 November 2018.
[47] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, Brussels, 7 February 2024, COM(2024) 63 final.
[48] On the February 6th 2024 the Commission proposed the most ambitious of the three options considered in the Impact Assessment for the Communication on Europe's 2040 climate target. The net reduction levels by

5.2 Approach to 2030

91. The EU has divided its economy-wide emissions reduction target between the EU ETS and non-ETS sectors based on its climate policies. The EU ETS directive[49] sets a target of 62% emissions reduction in sectors covered by the EU ETS by 2030 compared to 2005 emissions. The non-ETS sectors, according to the Effort Sharing Regulation (ESR)[50], must reduce their emissions by 40% in 2030 compared to 2005. This reduction effort has been redistributed among Member States based on their GDP per capita. Member States have adopted national reduction targets in non-ETS ranging from -10% to -50% (-17.7% for Poland). The countries with the lowest GDP per capita have the least ambitious reduction targets, while those with the highest GDP per capita have the most ambitious ones. The scenarios assumed non-ETS targets for each Member State in accordance with Annex I of the ESR regulation.

92. The 'Fit for 55' package has resulted in the implementation of a new EU-wide trading system for buildings and road transport, called ETS2, within the non-ETS sectors. This trading system covers CO_2 emissions from fuel combustion in the EU, which must be reduced by 43% in 2030 compared to the 2005 level. The ETS2 system was introduced as a result of an amendment to the EU ETS Directive. However, this does not mean that CO_2 emissions from buildings and road transport are excluded from the non-ETS scope. Therefore, even with the new trading system in place, countries will still need to include emissions covered by ETS2 in their non-ETS reduction commitments.

Table 3. Emission targets for 2030 (excluding LULUCF sector)

Year/sectors coverage	**Total** (vs. 1990)	**non-ETS** (vs. 2005)	**ETS2** (vs. 2005)	**EU ETS** (vs. 2005)
2030	53%	40%	43%	62%

Source: CAKE/KOBiZE

2040 presented in the Impact Assessment had the following values depending on the scenario: 78.5% - option 1, 88% - option 2, and 92% - option 3. Considering the absorption level from the Commission's Impact Assessment, i.e., -218 and -316 or -317 million CO_2 Mt, for option 1 and options 2 or 3, respectively, the value of the net 2040 target (including the LULUCF sector) in our scenario would be: 79% and 81%. Thus, our assumed net reduction target is close to option 1 from the Impact Assessment.

[49] Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system

[50] Regulation (EU) 2023/857 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement, and Regulation (EU) 2018/1999

93. To analyse the mechanism proposed in the 'Fit for 55' package, the total supply of carbon emission allowances in the ETS2 has been determined based on the reduction target. The carbon price is calculated endogenously and is the result of market clearing, which adjusts the overall demand and supply of allowances in the ETS2.

94. Once a specific carbon price and the value of emission reduction in the sectors covered by ETS2 have been determined, the emissions covered by the ETS2 are subtracted from the emission limit for the non-ETS sectors in a given state/region, which is primarily determined on the basis of Annex I of the ESR Regulation. This calculation results in a new national limit for the remaining non-ETS sectors.

95. Consequently, based on the assumptions made, the abatement costs are calculated separately for the sectors covered by ETS2 and the non-ETS sectors. The abatement costs for the remaining non-ETS sectors vary between individual states/regions, whereas for the EU ETS and ETS2, they are uniform across all regions.

5.3 Approach to 2050

96. To reflect the EU's climate goals, it is assumed that the reduction target in 2050 for sectors covered by the EU ETS is 95% compared to 2005. Consequently, in order to achieve the primary assumed Community-wide reduction target of 90% for all sectors of the economy in 2050, the remaining non-ETS sectors will have to reduce their emissions by 85% compared to 2005 levels. The reduction target for the ETS2 system in 2050 is set at 87% compared to 2005 emissions[51].

97. The methodology used in the ESR Regulation for 2030 has been adapted to determine national reduction targets for the year 2050 in the non-ETS. The emission reduction targets for 2050 were redistributed among the EU Member States based on the projected values of GDP per capita[52]. National targets for EU Member States were assumed to be in a range from 75% to 90% (for Poland, 79.6%) compared to the 2005 level. The national emission limits for 2050 were adjusted for each EU region in the next step, taking into account the ETS2, using the same method as for the 2030 approach. The established national emission limits for non-ETS sectors in 2050 are reduced by the projected emissions in ETS2, resulting in new limits for the remaining non-ETS sectors.

[51] Emission reduction targets for EU ETS and ETS2 for 2050 is estimated on the bases of projected emission value for 1.5LIFE scenario from the European Commission's report 'In-depth analysis in support of the Commission Communication, A Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy ', Table 9, page 198, Brussels, 28 November 2018.
[52] adopted from the EU Reference Scenario 2020

Table 4. Emission targets for 2050 (excluding LULUCF sector)

Year/sectors coverage	**Total** (vs. 1990)	**non-ETS** (vs. 2005)	**ETS2** (vs. 2005)	**EU ETS** (vs. 2005)
2050	90%	85%	87%	95%

Source: CAKE/KOBiZE

5.4 New emission trading system

98. As an alternative to the national reduction limits for non-ETS sectors covered by the ESR Regulation, the analysis considered the introduction of a new emissions trading system for non-ETS sectors (referred to as ETSagr). In order to meet the EU's Community-wide reduction target, the sectors covered by the ETSagr (after exclusion of emissions from buildings and road transport - ETS2) would have to reduce their emissions by 36% in 2030 and by 82% in 2050 compared to 2005 levels. In this new trading system, around 50% of the emissions would initially come from the agricultural sector, with the remaining emissions coming from other sectors not covered by the EU ETS and ETS2. The implementation of this new system would result in a significant change in the calculation of the carbon price. This is due to the fact that by aggregating the national emission limits in the non-ETS sectors into a common ETSagr, the same price will apply across the EU for the sectors covered by the new trading system.

Table 5. Emission targets for ETSagr

Year/sectors coverage	**ETSagr (vs. 2005 level)**
2030	36%
2050	82%

Source: CAKE/KOBiZE

6. Policy scenarios

99. This chapter provides a comprehensive explanation of the simulated scenarios, including:

(i) removal units support – within the current climate policy architecture, i.e. EU ETS, ETS2, non-ETS,

(ii) removal units support – after the implementation of a new emissions trading system (ETSagr) covering agriculture and other sectors not currently covered by the EU ETS and ETS2,

(iii) as well as complementary sectoral policies such as hydrogen subsidies and changes in transport sectoral policies.

These simulated scenarios encompass the main challenges and expected progress of EU climate policy as outlined in the introductory section of the report, in particular in Chapter 1.

6.1 Group I of scenarios – removal units support, scope of EU ETS, ETS2, non-ETS based on 'Fit for 55' package

100. The Fit55_nosup scenario, which is the base approach, considers the existing EU climate policy, including the European Green Deal and implementation of the 'Fit for 55', without any changes to the current architecture. This scenario does not support CO_2 removal technologies, assumes no subsidies for hydrogen fuel at the EU level, and maintains the current approach to sectoral policies, such as transport.

101. As the performance of the EU ETS depends not only on the mechanism itself but also on other climate policy instruments, several scenarios have been selected for further analysis to define new directions in the development of EU climate policy and to assess their impact on the EU ETS system.

102. The scenarios presented in Group I reflect the EU climate policy action plan that includes innovative approaches to carbon removal. In this group of scenarios, we consider the creation of carbon removal units within the EU, both through the use of BECCS technology (in the energy sector) and through afforestation of arable land (in the agriculture sector). The scenarios envisage the integration of BECCS removals into the existing EU ETS system, with a price for removals linked to the EU ETS carbon price. Similarly, removals from afforestation of arable land are integrated into non-ETS sectors, with a removal price that depends on the carbon price in those sectors. Within this group of scenarios, different levels of support for removal technologies are proposed based on the carbon price in the EU ETS and non-ETS. This means that the

price paid for a unit of removal (for the absorption of 1 tCO_2 eq.) is a certain percentage (10%, 25%, 50%, 100%) of the EU ETS carbon price for BECCS technology and percentage of the non-ETS carbon price for afforestation of arable land.

103. An important aspect of this analysis is the availability of biomass. The potential of biomass of non-agricultural origin for each region is based on a comparable source[53]. However, it is assumed that only half of this potential is available for the energy sector. To ensure sustainability, only biomass of domestic origin has been considered, excluding imports from third countries. In addition, we assume the possibility of obtaining biomass of agricultural origin. The availability and cost of this biomass is estimated by the agricultural model, while the energy model determines the demand for biomass.

104. In order to assess the macroeconomic impact of the introduction of pricing for removals, additional Fit55_besup and Fit55_agsup scenarios were developed in scenario group I using the following assumptions:

- Fit55_besup - pricing of removal units from BECCS technology at the level of the 100% carbon price in the EU ETS and lack of support for removals from afforestation of arable land in the agricultural sector,
- Fit55_agsup - the opposite scenario, assuming pricing of removal units from afforestation of arable land in the agricultural sector at 50% of the carbon price in the non-ETS and no support for BECCS.

6.2 Group II of scenarios – removal units support, common non-ETS carbon price at EU level (ETSagr)

105. The second group scenarios consider the establishment of a pan-European emissions trading system (ETS) for non-ETS sectors (referred to as ETSagr). This system would apply to all sectors of the economy not currently covered by the EU ETS and ETS2. In this set of scenarios, a single carbon price is set at the EU level for direct emissions from agriculture, services, and manufacturing activities that are not included in the EU ETS. The scenario focuses primarily on creating a price-coherent support system for afforestation of arable land at the EU level. The scenarios include the integration of removal units from afforestation of arable land into the new ETSagr system. A unit of removal (absorption of 1 tCO_2-eq) is assigned a price, which is set at a certain percentage (10%, 25%, 50%, 100%) of the carbon price in ETSagr. The proposed

[53] 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.

scenarios involve marginalising the non-ETS area in the EU, where according to our approach, the carbon price differs between regions. Therefore, in the scenarios from Group I, a different level of support was de facto applicable for afforestation of arable land in each region. Whereas, in Group II scenarios, support for afforestation of agricultural land depends on the optimally adjusted[54] carbon price at the EU level.

6.3 Group III of scenarios – sectoral policies (hydrogen subsidies and transport)

106. The third group of scenarios relates to policy changes in the cost of green hydrogen through the use of fuel subsidies and changes in sectoral transport policies.

107. The Fit55_H2 scenario aims to increase the use of green hydrogen. However, this carrier is currently very expensive compared to its emission-contributing equivalents (e.g. grey hydrogen from methane reforming). The high cost of green hydrogen is largely due to the early stage of development of this zero-emission carrier. In order to increase the competitiveness of this fuel and to assess its potential impact on the market, subsidies have been introduced to reduce the price of the fuel for end users (in all industries and households). The Fit55_H2 scenario includes the introduction of subsidies with a fixed timetable: 50% in 2025, 50% in 2030, 40% in 2035, 30% in 2040, 20% in 2045 and 10% in 2050. The subsidy percentages refer to the final cost of green hydrogen to end users in the Fit55_H2 scenario.

108. The Fit55_trans scenario assumes an increased scrappage rate for fossil fuel-powered passenger cars and the implementation of more stringent emission standards for the new fleet of heavy-duty freight transport vehicles and trailers in the transport sector. In this scenario we assume that the average lifespan for fossil fuel passenger cars decreases from an EU-wide average of 10.3 years to 7.8 years. We model this change by shifting the parameters governing the Gompertz distribution which is used to describe the yearly survival rate of vehicles. The change we impose implies that fossil fuel powered cars are hardly used after the age of 20, whereas before the change about 40% of passenger cars were used up to and beyond this age.

109. The change in the use of passenger vehicles can result from a variety of exogenous policies. One such policy has already been introduced in the city of London. The city imposed an ultra-low emission zone (ULEZ) in the entire borough of Greater London and furthermore, it introduced a financial scheme which will aid individuals and small

[54] The optimal carbon price refers to the minimum price that allow to achieve the common emission limit set for ETSagr.

businesses scrap vehicles that do not meet stringent standards of the ULEZ. For example, car owners can receive up to 2000 GBP, while wheelchair accessible cars and vans are eligible for a payment of up to 10000 GBP[55].

110. For large and heavy-duty vehicles, we anticipate a gradual increase in emission standards based on regulations proposed by the European Commission on February 14, 2023. According to this regulation, compared to the reference period of 2019, new vehicles must achieve a reduction of 45% in emissions during the reporting periods of 2030-2034, 65% during 2035-2039, and 90% from 2040 onwards. This regulation effectively establishes the proportion of new zero-emission vehicles required to be introduced into service, given only a marginal reduction in emissions for fossil fuel-powered vehicles.

Table 6. Description of scenarios related to the climate policy architecture

Scenarios		Supplementary measures
Group I – removal units support, scope of EU ETS, ETS2, non-ETS based on 'Fit for 55' package	Fit55_nosup	Without a price for carbon removal from BECCS (Bioenergy with Carbon Capture and Storage) and afforestation of arable land.
	Fit55_sup**10** Fit55_sup**25** Fit55_sup**50** Fit55_sup**100**	Pricing for removals: - BECCS – **10%, 25%, 50%, 100%** of the price in EU ETS, - afforestation of arable land – **10%, 25%, 50%, 100%** of the price in non-ETS.
	Fit55	Pricing for removals: - BECCS – 100% of the price in EU ETS, - afforestation of arable land – 50% of the price in non-ETS.
	Additional scenarios developed to assess the macroeconomic effects	
	Fit55_besup	Pricing for removals: - BECCS – 100% of the price in EU ETS, - without a price for carbon removal for afforestation of arable land.
	Fit55_agsup	Pricing for removals: - afforestation of arable land – 100% of the price in non-ETS, - without a price for carbon removal for BECCS.

[55] https://t2fl.gov.uk/modes/driving/ultra-low-emission-zone/scrappage-schemes

Group II – removal units support, common non-ETS carbon price at EU level (ETSagr)	ETSagr_**10** ETSagr_**25** ETSagr_**50** ETSagr_**100**	Pricing for removals: - BECCS –100% of the price in EU ETS, - afforestation of arable land – 10%, 25%, 50%, 100% of the price in ETSagr.
Group III – sectoral policies (hydrogen subsidies and transport)	Fit55_H2	Subsidies for hydrogen, gradually reduced over time: from 50% in 2025/ 2030 to 10% in 2050. Pricing for removals: - BECCS – 100% of the price in EU ETS, - afforestation of arable land – 50% of the price in non-ETS.
	Fit55_trans	New emission standards + change in scrappage rate in transport sector. Pricing for removals: - BECCS – 100% of the price in EU ETS, - afforestation of arable land – 50% of the price in non-ETS.

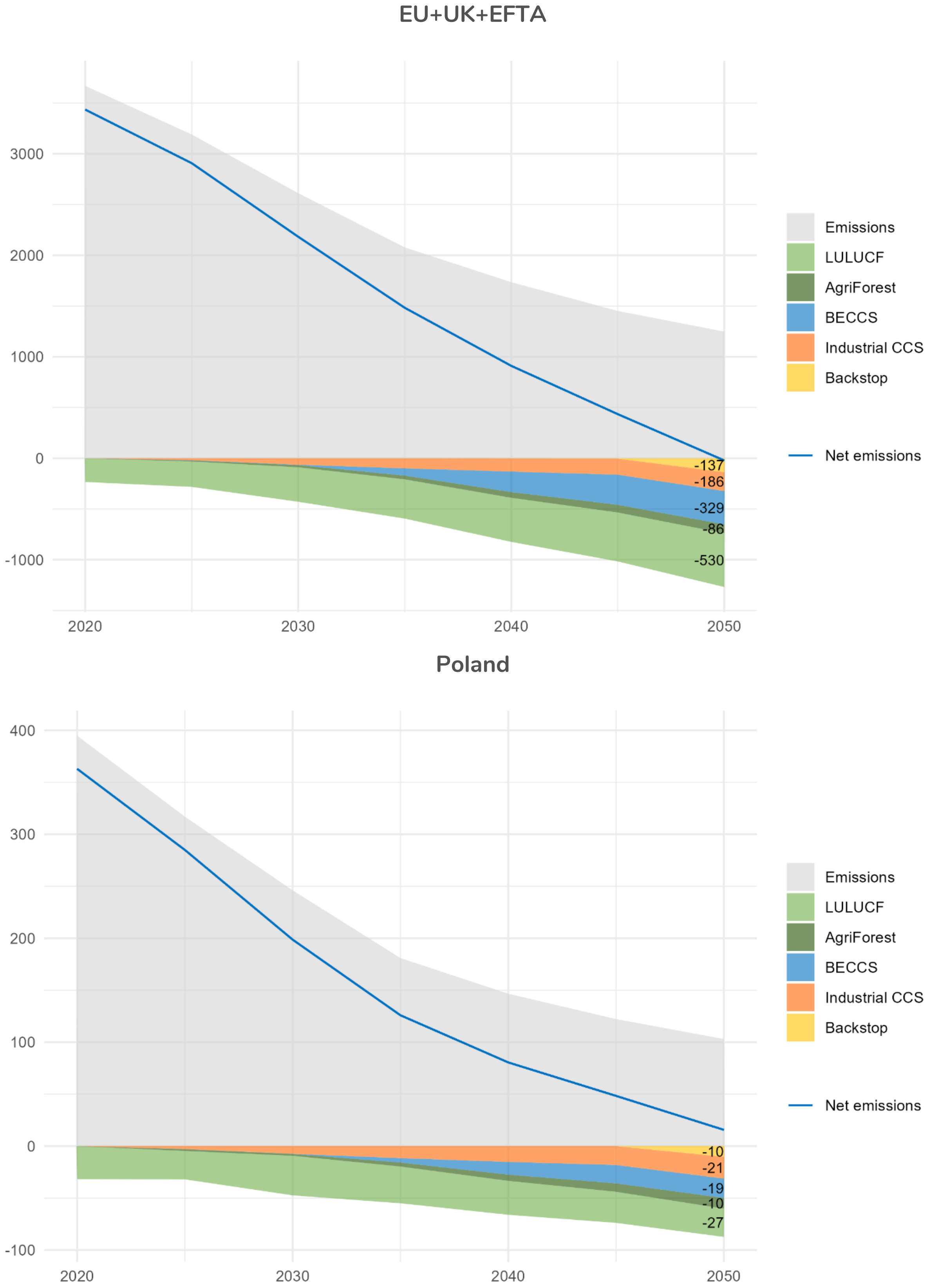
Source: CAKE/KOBiZE

7. Modeling framework and general insights from the Fit55 Scenario

111. This section briefly characterises the path to net-zero as presented in our modeling framework under the Fit55 scenario. While other scenarios differ in detail, sometimes significantly, they share most of the general features and assumptions.

112. From the macroeconomic perspective, the main external drivers of the scenarios are productivity growth (translated into country specific GDP growth), GHG emission reduction targets implied by climate policies, and changes in fossil fuel prices on world markets. They are accompanied by a large number of detailed technological assumptions related to the capacities and costs of different abatement options. Modeling results include energy mix and costs, carbon prices, sectoral output, sectoral emissions, exports and imports, and others. Policy costs are ultimately captured as changes in real household consumption between different policy scenarios.

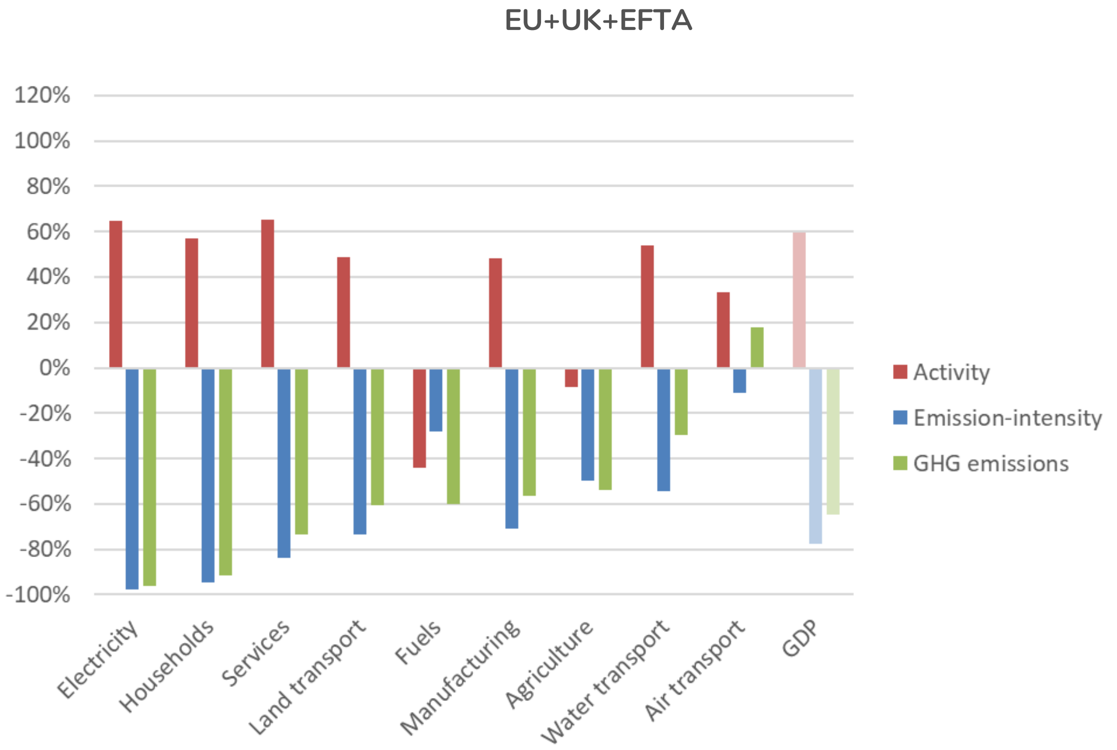
Figure 3. Greenhouse gas emissions and sinks, EU+UK+EFTA [Mt CO_2 eq.]

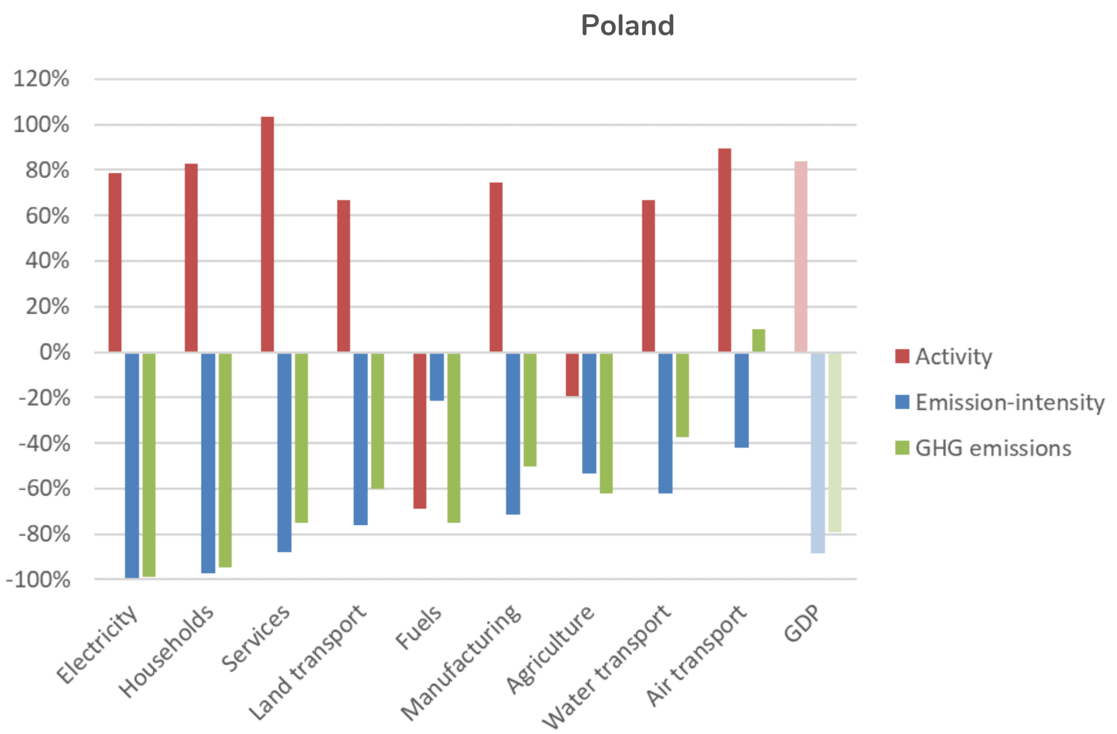


Source: CAKE/KOBiZE

113. Figure 3 illustrates the significant role of carbon sinks on the path to net zero emissions. The biggest single contribution comes from LULUCF, with about 0.5Gt of removals in 2050 (in the EU and the UK, and in EFTA countries participating in the EU ETS – Figure 3a). The LULUCF removal potential is an external assumption (see section 1.4) and is the same in all scenarios. The other results are simulation results. Bioenergy with CCS (BECCS) and afforestation of agricultural land (AgriForest) develop significantly from 2040 onwards, reaching a total of about 0.4 Gt of CO_2 removed in 2050 (BECCS being the largest part). Later in the report we argue that the scale of BECCS and afforestation of agricultural land depends on the pricing of removals - without pricing, these options are not used. Industrial CCS is responsible for about 0.2Gt of CO_2 sequestration in 2050, with backstop technologies closing the gap to the net zero target. The backstop category represents an unspecified set of technologies - such as direct atmospheric CO_2 capture and storage, measures to increase removal potential or other options - that allow emissions to be removed/reduced at the assumed cost of 1000 EUR'15 per tonne of CO_2 eq. Figure 3 excludes emissions from international aviation and maritime, which are not subject to carbon pricing in our scenarios. Similar patterns of emission reductions facilitated by removals are observed in the case of Poland (Figure 3b). From the perspective of a single region, net emissions in 2050 are not necessarily zero, as positive net emissions can be offset by increased reductions or removals in other regions. Natural uptake (LULUCF and afforestation of agricultural land) and CCS (BECCS and industrial CCS) each provide around 40 Mt of removals in 2050, while emissions fall to around 100 Mt per year.

Figure 4. Activity, emission intensity and emissions by aggregated sectors in 2050 (% change versus 2020)*





* excluding removals, except industrial CCS

Source: CAKE/KOBiZE

114. Figure 4a shows that the emission intensity of GDP in the EU countries decreases by 78% between 2020 and 2050, while GDP grows by 60%, resulting in a 65% reduction in gross emissions (i.e. emissions excluding removals other than industrial CCS). However, abatement efforts and sources are not evenly distributed across sectors. The largest reductions in emission intensity are observed in the electricity and households sectors. On the other hand, maritime and air transport are the bottlenecks - in particular air transport shows a reduction in emission intensity of less than 20%, which, together with the increase in activity, leads to a slight increase in emissions. Two major sectors show a reduction in activity - fuels and agriculture. In the case of fuels (including fossil fuel extraction and oil refining), a sharp drop in activity is linked to a reduction in demand for non-renewable energy sources. In the case of agriculture, the result actually signals the exhaustion of abatement options, with further emission reductions only possible through output reductions, raising concerns about food security and carbon leakage. The picture for Poland (Figure 4b) is similar to that for the EU. However, Poland has higher cumulative GDP growth - more than 80% compared to 60% in the EU - making comparable emission reductions more difficult. In addition, output declines in the fuel industry (including coal mining) and agriculture are more pronounced in Poland than in the EU.

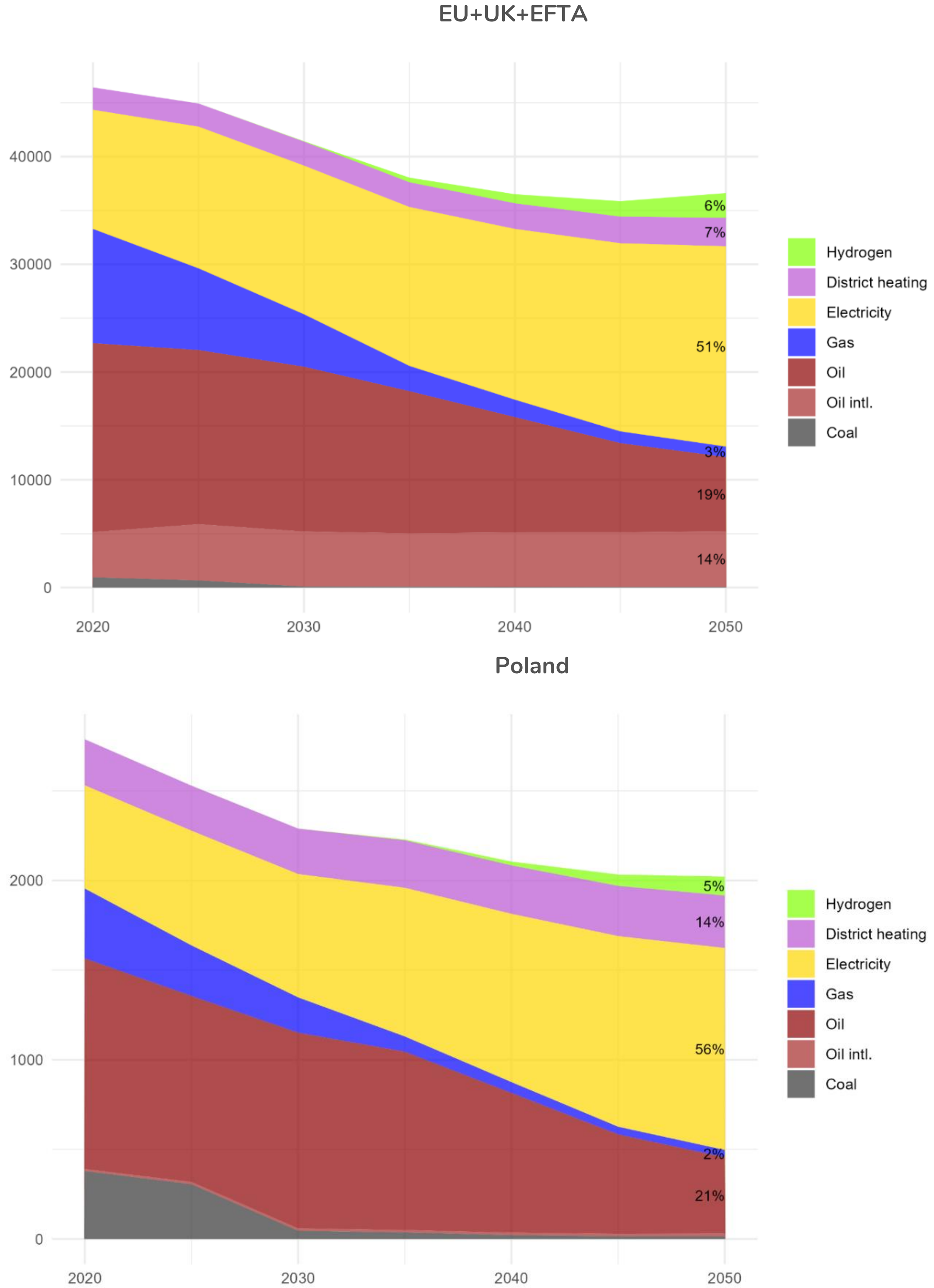
115. Multiple effects add up to a reduction in emissions intensity. The most meticulous description of these effects is available for the electricity, transport and agriculture sectors, for which separate, technologically detailed models are used. Some more detailed aspects of the low-carbon transformation of the respective sectors are discussed later in the report. Staying with the macroeconomic perspective, an important contributor is the reduction of final energy consumption (i.e. energy use by industry and households) and the shift towards electricity and hydrogen (see Figure 5).

116. In order to reconcile the energy savings with the assumed GDP growth on the net zero path, we estimate that the final energy intensity (measured as final energy per unit of GDP) needs to be reduced by 2.9% per year in the years 2020-2030, 2.7% in the years 2030-2040 and 1.4% in the years 2040-2050. In the case of Poland these rates are 4.6%, 2.9% and 1.6% respectively.

117. The share of electricity in the final energy mix in the EU reaches over 51% in 2050 (56% in Poland), while green hydrogen reaches 6% (5% in Poland). Note that the latter figure does not include hydrogen used within the electricity sector as a storage mechanism. Our models also do not take into account the use of hydrogen in the possible production of synthetic fuels. The relatively high share of oil still in 2050 is due to inertia in the replacement of the transport fleet and to the fact that extra-EU aviation and maritime are not subject to carbon pricing in our scenarios (hence the non-decreasing share of oil used in this sub-sector, labelled *Oil intl*; its share in Poland is

negligible). We assume a phase-out of coal in the final energy mix between 2020 and 2030, which is reflected in a significant decrease, especially in Poland[56].

Figure 5. Final energy use [PJ]



Source: CAKE/KOBiZE

56 Coal is phased out only approximately in the model implementation, thus the negligible remaining share (below 1%) shown in the graph for Poland.

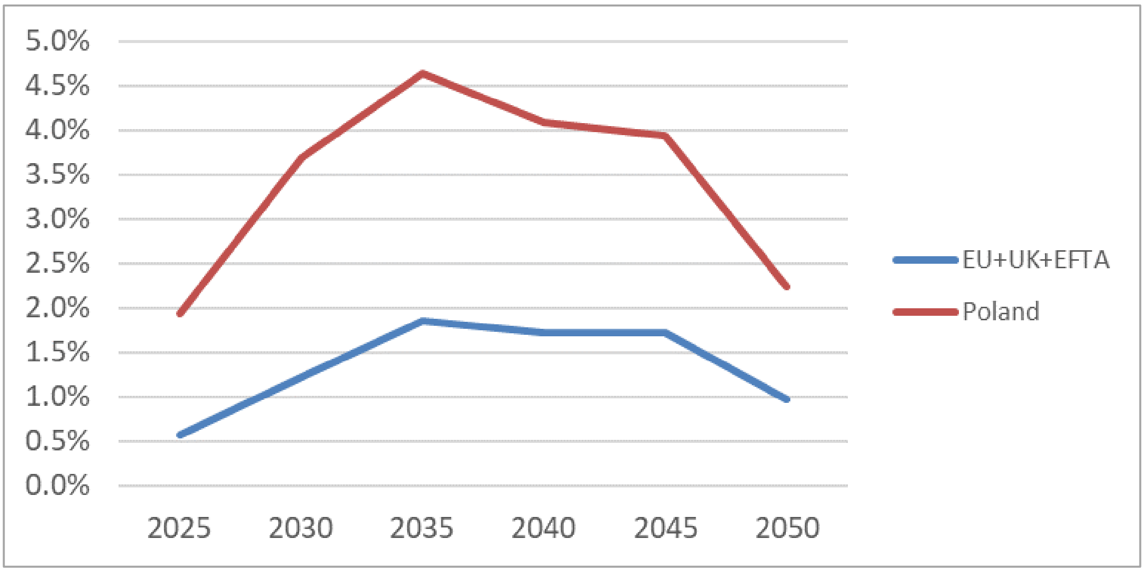
118. In addition to improving energy efficiency and changing the energy mix, final users (emitters) are also taking sector-specific measures, such as reducing fugitive or landfill methane emissions, CCS in emission-intensive industries, the use of ammonia in maritime, etc.

119. Carbon prices are the main channel through which emission limits are signalled to producers and consumers. Carbon prices therefore drive technology adoption (such as the technology mix in electricity generation, the structure of the transport fleet or CCS) and energy efficiency. They also have an impact on the demand side - costs are passed on in product prices and therefore affect exports and imports through the competitiveness channel, as well as household demand. In our modeling framework, the levels of carbon prices (in different pricing sub-systems) are harmonised across sectors to achieve the desired emissions reductions. In this report, we also analyse how carbon prices are influenced by other policies.

120. It should be emphasised that carbon prices, as reported later in this study, are modelled estimates of marginal emission abatement costs (in EUR per tonne of CO_2 eq.) in respective groups of sectors (covered by the EU ETS, ETS2, etc.). They are interpreted as explicit charges on emissions in all our scenarios, although in reality (e.g. in non-ETS) they may be implicit in the costs of other policies (e.g. subsidies or standards). Furthermore, there is not a one-to-one relationship between marginal abatement costs and market prices of allowances, as the latter are subject to volatility related to the behaviour of market participants, which is not present in our modeling framework.

121. Carbon prices in our simulations reach the level of hundreds of EUR (see following sections) per tonne of CO_2 eq. (the level of 1000 EUR'15 per tonne of CO_2 eq. is an arbitrary upper bound for carbon prices in our modeling). However, as emissions fall, the impact of high carbon prices on the economy becomes less significant. Figure 6 shows that government revenues from EU ETS and ETS2 carbon prices as a share of GDP for the EU countries as a whole. They are slightly below 2% of GDP in 2035-2045, but fall to 1% in 2050. The respective shares are much higher in Poland, reaching 4.5% in 2035 and falling to just over 2% in 2050. These shares illustrate the magnitude of the funds raised to support mitigation actions, but they should not be confused with the macroeconomic costs of climate policy.

Figure 6. The share of EU ETS and ETS2 carbon price revenues in GDP, EU+UK+EFTA and Poland [%]



Source: CAKE/KOBiZE

8. Results of policies overlapping

8.1 Role of Removals

122. The first scenarios examined are Group I scenarios that emphasise the importance of pricing emissions from removals. The impact of pricing on emission prices and macroeconomic variables will be considered first, followed by the impact on the energy sector and agriculture. The results for other sectors, including transport, are not presented as the impacts are minor.

8.1.1 Macro Effects and Pricing in the EU ETS System

123. The analysis begins by examining scenarios that explore the role of removals and demonstrate how their deployment could affect carbon prices and macroeconomic outcomes. It then proceeds to a quantitative analysis that shows outcomes under various levels of support for removals. The impact in 2030 is negligible, so the analysis focuses on 2040 and 2050.

The effects induced by removal pricing

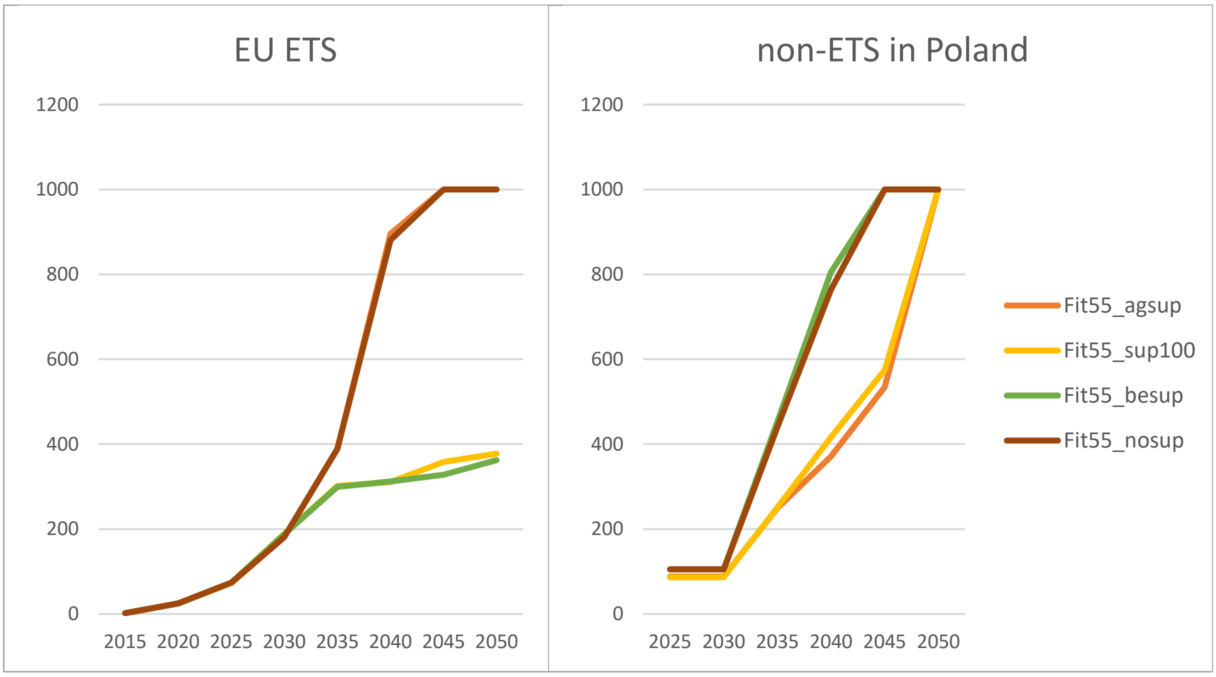
124. The removal of pricing and its large-scale deployment has a favourable impact in all dimensions. It leads to a significant drop in carbon prices, higher GDP, and consumption.

125. In the Fit55_sup100 scenario, which allows for pricing of removals associated with BECCS and afforestation, the price is equated to the level of price in the EU-ETS (in the case of BECCS) and to the price of carbon in non-ETS (in the case of afforestation). The EU ETS price in 2040 and 2050 is 310 EUR/tCO_2 and 380 EUR/tCO_2, respectively. The values are significantly lower compared to those of 880 EUR/tCO_2 and 1000 EUR/tCO_2 in the Fit55_nosup scenario where pricing of negative emissions is not permitted.

126. The impact on non-ETS prices varies across regions, although in all EU regions, the price in the Fit55_sup100 scenario is lower than in the Fit55_nosup scenario. For instance, in Poland in 2040, the price is 420 EUR/tCO_2 in the Fit55_sup100 scenario compared to 760 EUR/tCO_2 in the Fit55_nosup scenario. In both scenarios, prices reach the upper bound of 1000 EUR/tCO_2 by 2050, which is the maximum price of emissions in our simulations due to the assumption of a backstop technology like DACCS. This technology provides unlimited supply of carbon dioxide removal at the price of 1000EUR/tCO_2 eq.

127. The impact on the price in ETS2, although not reported in the figure, is negligible.

Figure 7. Left panel: Price of carbon [EUR/tCO_2] in EU ETS under alternative options of pricing removals. Right panel: Price of carbon in non-ETS in Poland under alternative options of pricing removals



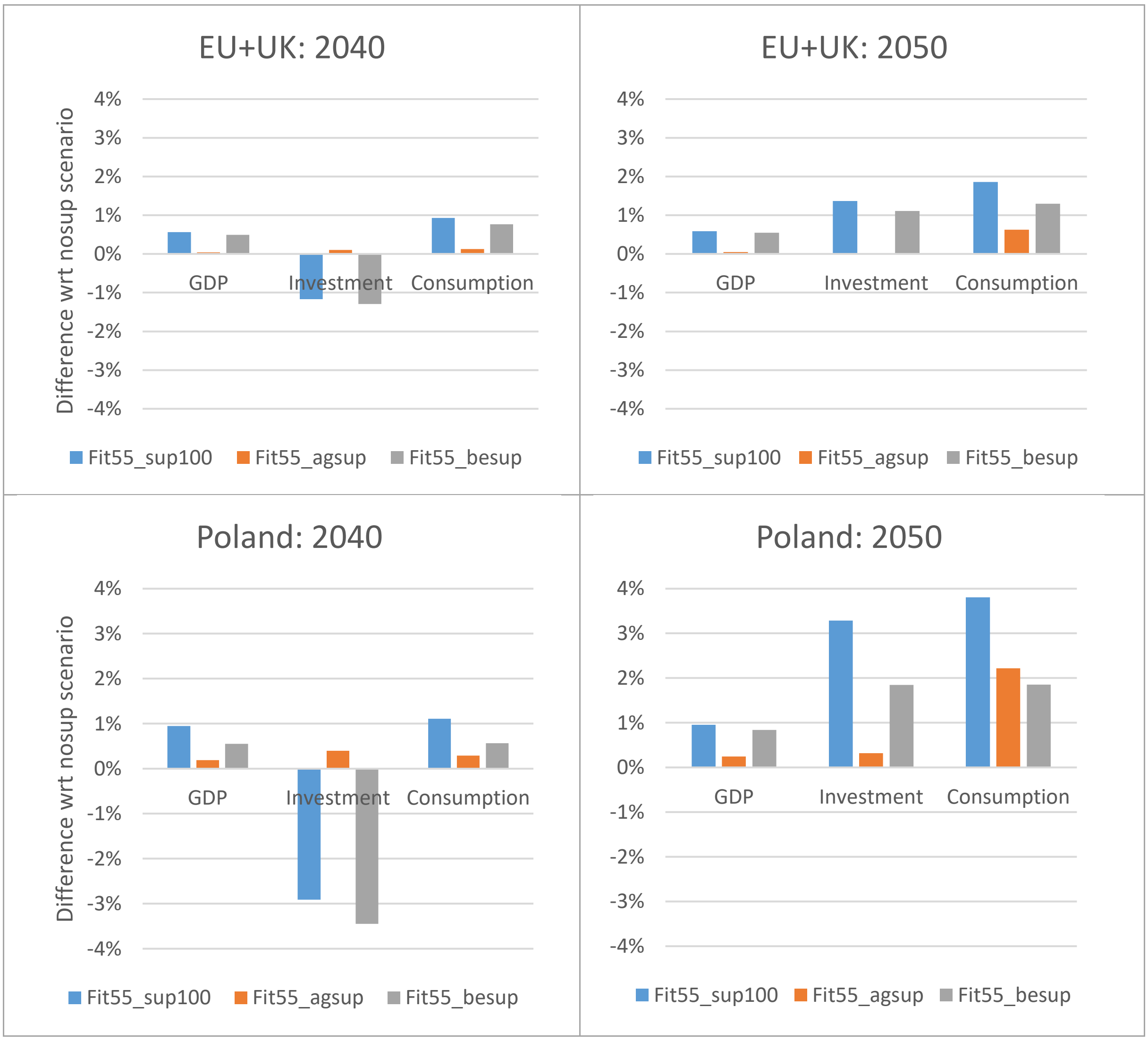
Source: CAKE/KOBiZE

128. In terms of macroeconomic impacts, the pricing of removals leads to an increase in both GDP and consumption. In the Fit55_sup100 scenario, the GDP of EU+UK is 0.6% higher and consumption is 0.9% higher compared to the Fit55_nosup scenario in 2040.

In 2050, the difference in GDP remains unchanged (0.6%), but the difference in consumption grows to 1.9%. Similarly, a positive impact on consumption and GDP is reported for Poland, although the size of the impact on consumption is considerably larger: in 2050 consumption in Poland is 3.8% larger, comparing to the Fit55_nosup scenario. The large impact of Poland is mostly driven by the positive effect of pricing removals from afforestation (see detailed description below).

129. To examine the significance of pricing removals from BECCS and afforestation, and to better understand the mechanisms behind the macroeconomic outcomes, two additional scenarios are considered: one where pricing is applied to BECCS but not to afforestation (Fit55_besup), and another where pricing is applied to afforestation but not to BECCS (Fit55_agsup).

Figure 8. Impact on GDP, investment and consumption with respect to Fit55_nosup scenario under alternative scenarios of pricing removals in 2040 (left panel) and 2050 (right panel) for the EU (top) and Poland (bottom)



Source: CAKE/KOBiZE

130. The comparison between macroeconomic outcomes in the scenario of no removal pricing (Fit55_nosup) and the scenario where the BECCS technology is paid for removals at the price equal to the price of EU ETS (Fit55_besup) is presented in Figure 8. The pricing policy results in a significant decrease in the price of EU ETS, with the price being 310 EUR/tCO_2 in the Fit55_besup scenario in 2040, compared to 880 EUR/tCO_2 in the Fit55_nosup scenario. In 2050, there is a significant price divergence between the Fit55_besup and Fit55_nosup scenarios, with prices of 360 EUR/tCO_2 and 1000 EUR/tCO_2, respectively.

131. The difference in prices is due to the shift in the supply of allowances at the EU ETS market. As previously explained, the Fit55_besup scenario assumes that negative emissions provided by BECCS will allow regulators to issue additional allowances (removals) and introduce them to the EU ETS market. This setup results in the bending of the supply curve of EUA. The fixed (vertical) supply curve, where supply is independent of EUA prices, is replaced by an upward sloping supply curve where high prices incentivise investment in BECCS and lead to an increase in the number of available EUA. This setup is neutral from the climate perspective, but from the EUA market perspective, the additional supply reduces the prices.

132. The support for BECCS has a minimal impact on emission prices in ETS2 and non-ETS sectors in almost all regions[57].

133. Lower EU ETS prices can reduce the distortionary impact of climate policy on the economy, leading to an increase in GDP and consumption. BECCS technologies can increase the number of carbon allowances, allowing sectors with high mitigation costs to purchase additional allowances instead of dedicating resources to costly decarbonization options. This releases resources in the economy that can be used in the same or other sectors to increase production.

134. In 2040, the GDP of the EU+UK is 0.5% higher in the Fit55_besup scenario compared to the Fit55_nosup scenario. This increase in GDP allows for higher household consumption, with a difference of 0.8% between the two scenarios in 2040. The impact on investment is determined by two opposing forces. Firstly, less investment is required in sectors with high mitigation costs. Secondly, demand for BECCS, as well as higher disposable income by households, pushes investment up. Ultimately, the former effect dominates, and investment in the Fit55_besup scenario is 1.3% lower than in the Fit55_nosup scenario. In 2050 the impact is comparable to the one in 2040, but now the forces pushing investment up dominates.

135. Next, we consider the impact of removing pricing from afforestation. Specifically, we compare the Fit55_nosup scenario with the Fit55_agsup scenario, which assumes

[57] The exceptions are in Benelux and Central Europe, where it leads to a slightly higher non-ETS prices.

pricing negative emissions from afforestation at the same level as the emission price in the non-ETS sectors. The removed carbon dioxide is then used to ease the emission limit imposed on non-ETS.

136. Similar to the Fit55_besup scenario, the impact on climate goals is neutral. However, in the medium-term, particularly in 2040, the impact on the price of emissions in non-ETS sectors is substantial. In that year, the additional supply of emissions results in a reduction in abatement cost in non-ETS from 770 EUR/tCO_2 in the Fit55_nosup scenario to 370 EUR/tCO_2 in the Fit55_agsup scenario. Similar drops are reported for almost all regions. In Germany, the additional supply reduces the cost from 810 EUR/tCO_2 in the Fit55_nosup scenario to 450 EUR/tCO_2 in the Fit55_agsup scenario. Similarly, in France, the additional supply leads to a cost reduction from 770 EUR/tCO_2 in the Fit55_nosup scenario to 390 EUR/tCO_2 in the Fit55_agsup scenario. By 2050, the differences in non-ETS prices disappear in almost all regions. The result is based on the assumption that backstop technology exists, which limits the price in non-ETS sectors to 1000EUR/tCO_2 eq.

137. The simulations suggest that afforestation would have a negligible impact on the prices of EU ETS and ETS2.

138. The decrease in mitigation costs in non-ETS has the same macroeconomic effects on Fit55_agsup as a decrease in EUA price in Fit55_besup scenario, but the effect size is smaller at the EU level. The difference in GDP of the EU+UK between the two scenarios is negligible in 2040 and 2050.

139. In 2040, consumption for the EU+UK is 0.1% higher than in Fit55_nosup scenario. In 2050, the difference in consumption between the two scenarios increases to 0.6%. However, investment is almost identical in both scenarios. The positive macroeconomic impacts can be explained in the same way that those described in the case of Fit55_besup scenario: lower price in non-ETS has less distortionary impact on the economy and allow firms to save resources that would otherwise need to be dedicated to costly mitigation options.

140. For Poland, there are small differences between the Fit55_agsup and Fit55_nosup scenarios in 2040. However, in 2050, the Fit55_agsup scenario shows a 0.2% increase in GDP, a 0.3% increase in investment, and a 2.2% increase in consumption. Large positive impact in Poland can be explained with a relatively large role of agriculture in Polish production. In the scenario where afforestation removals cannot be utilized, the non-ETS sectors, including agriculture, must dedicate substantial resources to abate emissions and absorb the residual emissions with the costly backstop technologies. Afforestation allows to significantly reduce this burden.

Alteration in the level of support

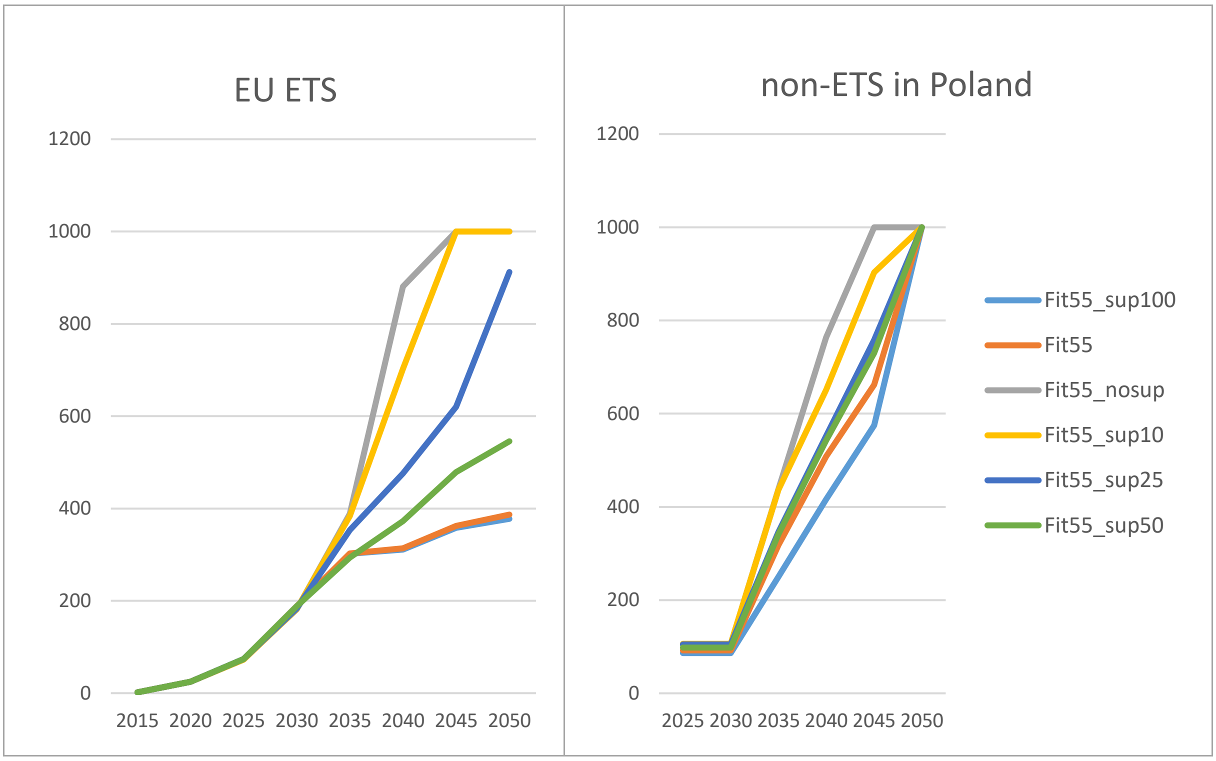
141. The analysis considers scenarios with alternative levels of pricing for removals. Specifically, we examine a set of three scenarios: Fit55_sub10, Fit55_sup25, and Fit55_sup50. In these scenarios, negative emissions from BECCS can be sold at a price equal to 10%, 25%, and 50% of the price of emissions in the EU ETS, and negative emissions from afforestation can be sold at a price equal to 10%, 25%, and 50% of the price of emissions in the non-ETS sector of the country in which they were generated.

142. Additionally, we examine the Fit55 scenario, which prices negative emissions from BECCS at 100% of the EU ETS price and those from afforestation at 50% of the non-ETS price in the relevant country. For comparison, we also present the results for the Fit55_sup100 and Fit55_nosup scenarios in Figure 9. Throughout this and subsequent sections, we use Fit55 as the reference scenario due to its political feasibility.

143. The prices of EU ETS in the Fit55 scenario are very similar to those in the Fit55_sup100 scenario, with values in the former scenario at the level of 310 EUR/tCO_2 in 2040 and 390 EUR/tCO_2 in 2050. When pricing removals at the 50% level (Fit55_sup50), the prices increase to approximately 370 EUR/tCO_2 in 2040 and 540 EUR/tCO_2 in 2050. In the Fit55_sup25 scenario, where support is decreased to 25%, the EU ETS price increase to approximately 480 EUR/tCO_2 in 2040 and 910 EUR/tCO_2 in 2050. A further decrease to 10% results in levels of 700 EUR/tCO_2 in 2040 and 1000 EUR/tCO_2 in 2050. However, even in this scenario, the value in 2040 is still significantly lower than the 880 EUR/tCO_2 in the Fit55_nosup scenario.

144. The impact of alternative pricing levels on non-ETS prices varies between countries. In Poland, the Fit55 scenario leads to a price of 510 EUR/tCO_2, which is similar to the price in the 50% pricing scenario (540 EUR/tCO2). 25% pricing leads to a non-ETS emission price of 550 EUR/tCO_2 and 10% pricing leads to a price of 650 EUR/tCO_2 in 2040. Recall that the Fit55_sup100 scenario produces a price of 420 EUR/tCO_2. In 2050, prices in all scenarios reach the level of 1000 EUR/tCO_2.

Figure 9. Left panel: Price of carbon [EUR/tCO_2] in EU ETS under alternative levels of pricing removals. Right panel: Price of carbon in non-ETS in Poland under alternative levels of pricing removals



Source: CAKE/KOBiZE

145. The differences in macroeconomic performance under the alternative price scenarios are shown in Figure 10. For each scenario, we show the macroeconomic outcomes relative to the Fit55 scenario, which we have chosen as the reference scenario. Both at the EU level and in Poland, the differences between the Fit55_sup100 and Fit55 scenarios are clearly negligible and barely noticeable in the figure. In the other scenarios associated with lower pricing, GDP is lower, investment needs are higher and consumption is lower. The differences between the scenarios change almost linearly with the price level.

Figure 10. Impact on GDP, investment and consumption with respect to Fit55 scenario under alternative levels of pricing removals in 2040 (left panel) and 2050 (right panel) for the EU (top) and Poland (bottom)

Source: CAKE/KOBiZE

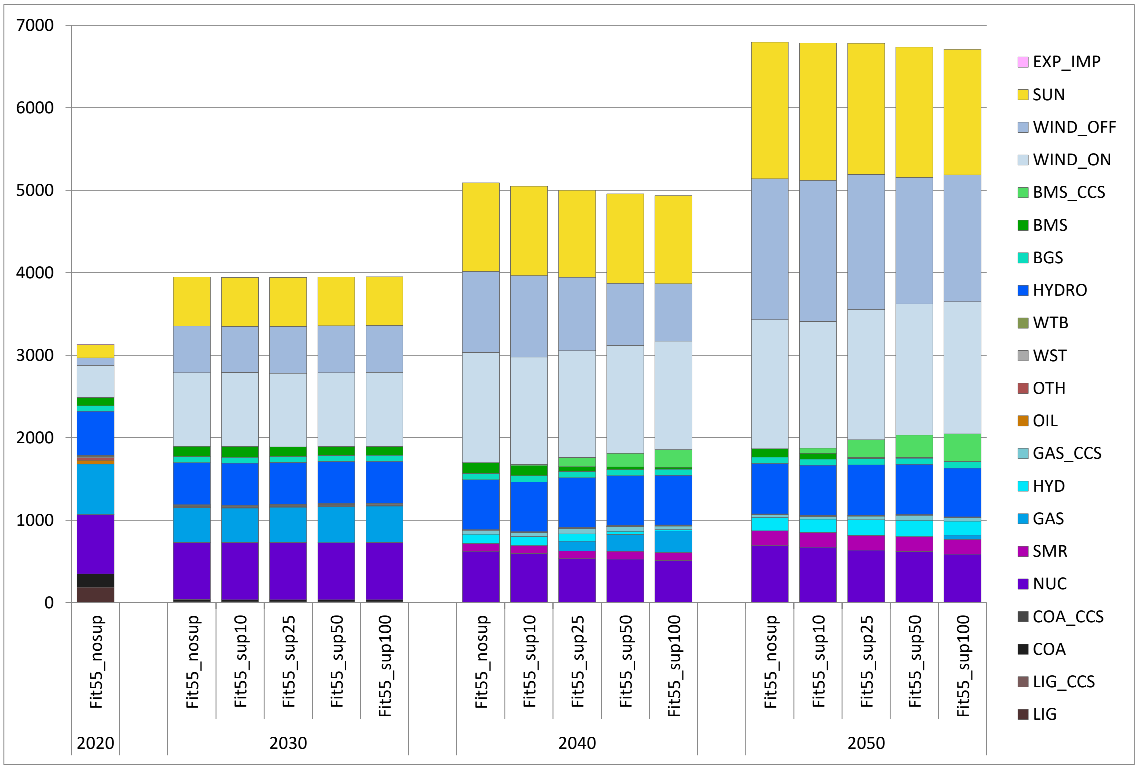
8.1.2 Energy sector

146. The Fit55 scenario assumes that BECCS units will be covered by the EU ETS system, and the installations will obtain revenue determined by multiplying the achieved negative emissions by the EU ETS price. However, the purpose of the analyses described in this chapter was to examine how different levels of negative emission revenues would affect the results. Therefore, a sensitivity analysis was performed and

the results were compared for scenarios in which there are no revenues from negative emissions and revenues at the level of 10%, 25%, 50% and 100% of the emissions cost in the EU ETS (the Fit55_sup100 scenario is practically identical to the Fit55 scenario from an energy system perspective, therefore the conclusions for Fit55_sup100 also apply to the Fit55 scenario). As the percentages refer to the cost of allowances obtained in a given scenario and these vary significantly (see Figure 11), these figures do not reflect absolute differences in the amount of revenue for negative emissions.

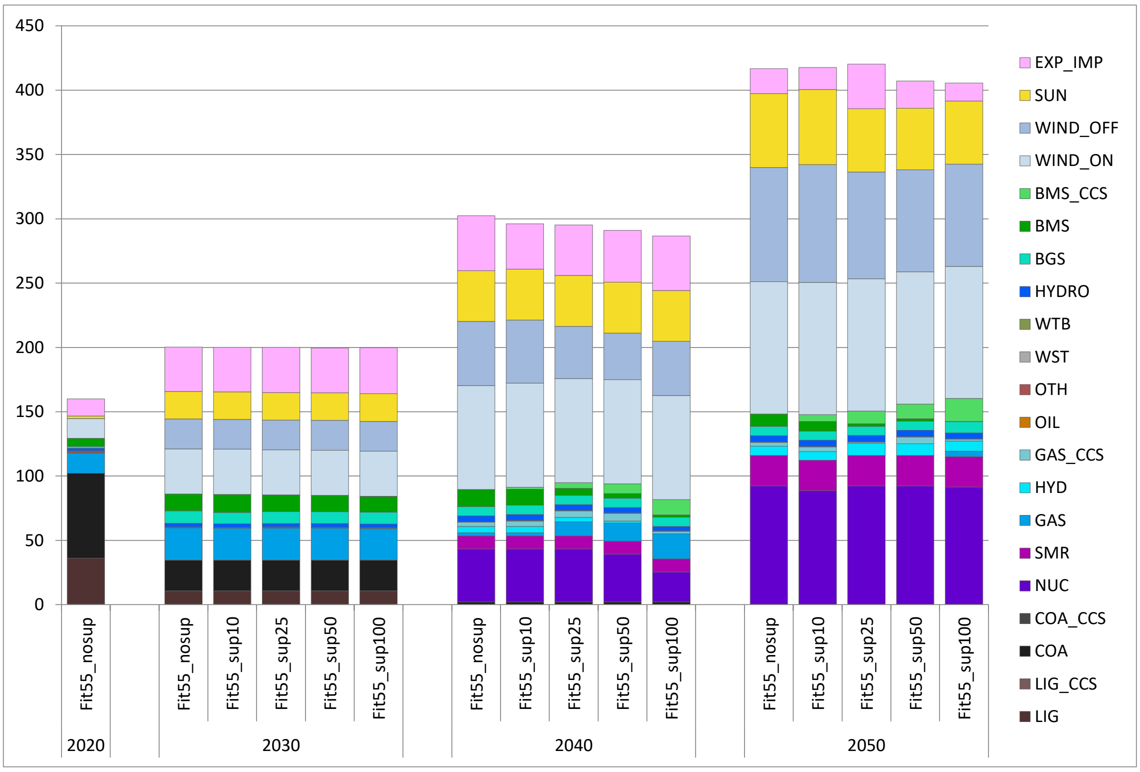
147. Although the carbon prices in individual scenarios differ significantly, the results from the perspective of the power sector are at first sight quite similar, at least in terms of the energy mix.

Figure 11. Electricity generation mix in the EU+UK+EFTA [TWh]



Source: CAKE/KOBiZE

Figure 12. Electricity generation mix in Poland [TWh]

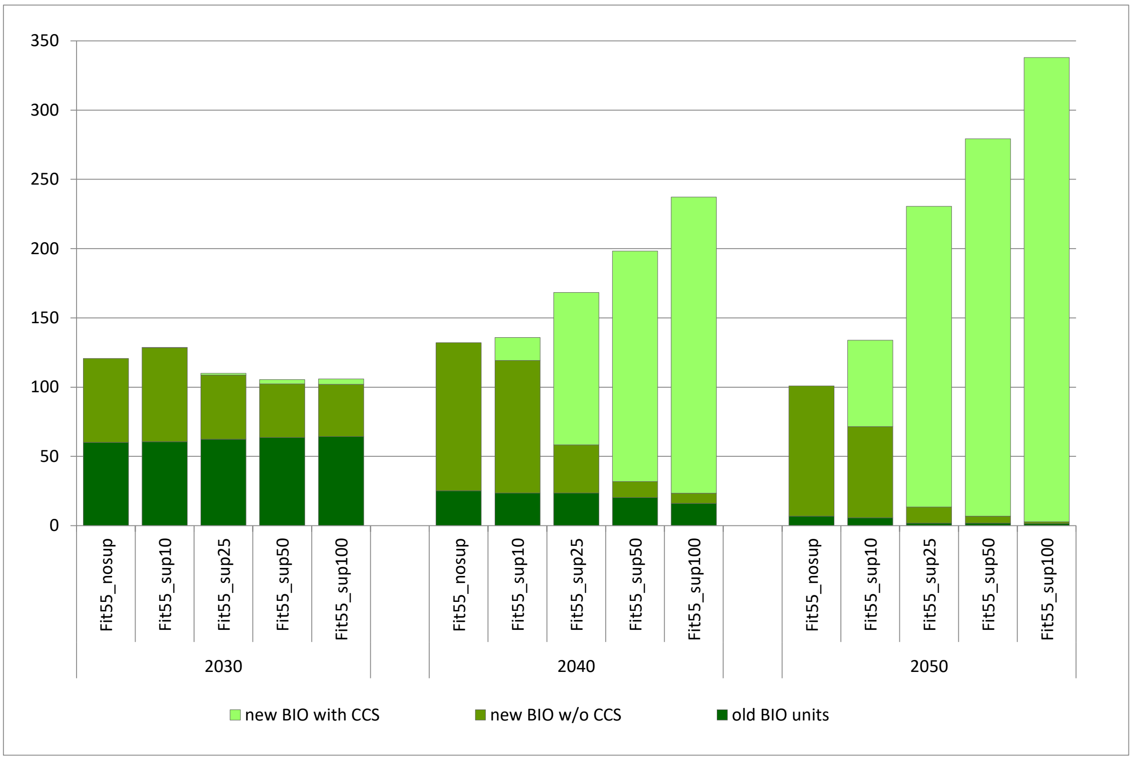


Source: CAKE/KOBiZE

148. The structure of electricity generation is similar in all scenarios - rapid phase-out of fossil fuels, dynamic development of wind farms and photovoltaics and a slight increase in the use of nuclear energy. The general direction of change for Poland is similar, with a slightly slower phase-out of coal and a higher share of nuclear in the energy mix than the EU average.

149. However, a closer look reveals some significant differences between the scenarios, especially in the level of biomass use and the extent to which BECCS technology is developed.

Figure 13. Electricity generation by biomass with and without CCS, in the EU+UK+EFTA [TWh]



Source: CAKE/KOBiZE

150. In the Fit55_sup100 scenario, the BECCS technology grows dynamically thanks to the fact that it receives the full revenue for the absorbed emissions in line with the emission price in the EU ETS. This financing model makes BECCS very competitive compared to other technologies, but its development is still limited by factors such as biomass availability, CO_2 storage options and other technical and social barriers. In terms of total energy production, BECCS technologies do not represent a significant share, accounting for around 5% of electricity generation and 13% of district heating in the EU (similar proportions for Poland). However, in a situation where most generating units are emission-free thanks to renewables and nuclear power, BECCS has a very significant impact on the emissions balance of the energy sector and thus on the carbon price in the EU ETS.

151. In the Fit55_nosup scenario, where BECCS receives no additional revenue for the emissions it absorbs, these technologies do not develop at all. They are uncompetitive due to lower efficiency and higher production costs compared to biomass technologies without CCS. This clearly shows that the lack of revenues for CO_2 absorption will limit the development of this technology and lead to an increase in CO_2 emissions from the sector.

152. It is interesting to note that in the Fit55_sup100 scenario, the main source of CO_2 emissions in the power sector are gas units, which complement the electricity balance, especially during the winter peak hours on days with low production from wind farms. Negative emissions from BECCS allow the CO_2 emissions from these technologies to be offset. On the other hand, in scenarios without BECCS (Fit55_nosup) and at the same time with very high carbon prices, gas-fired power plants start to use hydrogen, which, despite its much higher price, becomes competitive with natural gas.

153. In the Fit55_sup50 scenario, in which BECCS receives revenue worth half the value of the EU ETS emission allowance for each unit of CO_2 absorbed, there is a significant decrease in the deployment of BECCS technology compared to the Fit55_sup100 scenario. As the magnitude of the changes is different for power plants and combined heat and power plants, it is best to illustrate these differences in terms of the amount of CO_2 absorbed rather than the amount of energy produced. In the Fit55_sup50 scenario, the amount of emissions captured by BECCS technologies is almost 20% lower than in the Fit55_sup100 scenario. It should be noted here that in the Fit55_sup50 scenario, reduced CO_2 absorption leads to an increase in the carbon price in the EU ETS to around 550 EUR/tCO_2, compared to around 380 EUR/tCO_2 in the Fit55_sup100 scenario. Therefore, the absolute level of revenue per unit of negative emissions is about 30% lower in the Fit55_sup50 scenario compared to Fit55_sup100, not 50%. Nevertheless, this shows that a reduction in reimbursement does not necessarily lead to a proportional reduction in BECCS deployment.

154. It is also clear that the lower the revenues for negative emissions, the lower the BECCS deployment. The results for the Fit55_sup25 and Fit55_sup10 scenarios show a gradual decrease in biomass generation with CCS.

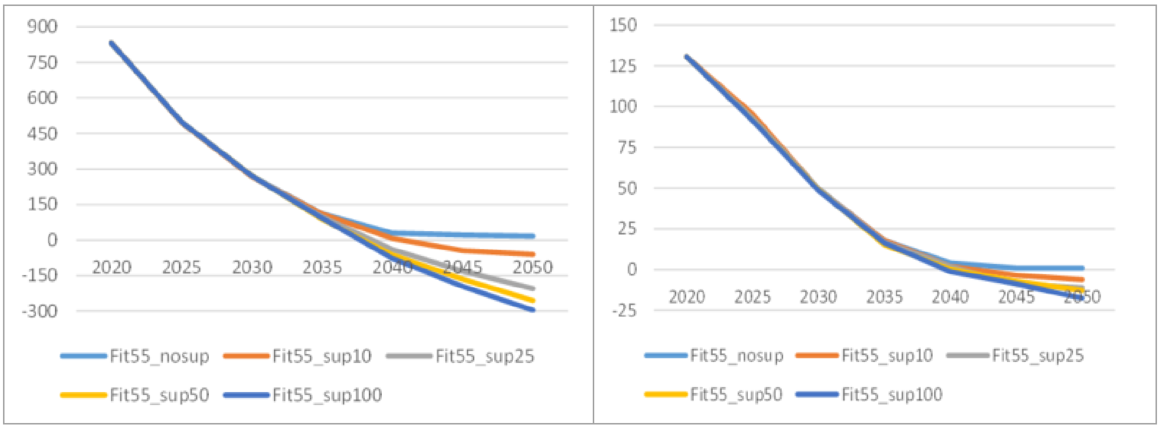
155. One question that may arise concerns the economics of BECCS. If this technology is already appearing in the energy mix, albeit on a small scale, with support at the level of 10% of the carbon price (in absolute terms this means revenues of 100 EUR/tCO_2 of negative emission), when the required level of support increases as the use of this technology increases, do we not then have excessive profits from these installations? In fact, the need for increased support is driven by the rising cost of agricultural biomass, which competes with food production and whose prices are rising rapidly as biomass use increases. As the demand for biomass increases, so do its prices, necessitating greater financial incentives for BECCS operations.

156. In most regions, energy costs are higher in the scenario without rewarding BECCS CO_2 absorption (Fit55_nosup) than in the scenario with rewarding BECCS CO_2 absorption (Fit55_sup100). These differences vary by region and year, but are particularly pronounced in the years 2035-2040, where they can be as high as 20%, presumably due to the still relatively high share of natural gas in electricity generation in these years

and the significant emission costs. Between 2045 and 2050, the differences in energy costs between the scenarios decrease.

157. The level of funding absorption for BECCS technologies has a significant impact on total emissions from the sector. The emissions for each scenario analysed are presented below.

Figure 14. Net emissions from the power sector in the EU+UK+EFTA (left) and Poland (right) [Mt CO_2]



Source: CAKE/KOBiZE

158. The results show rapid emission reductions in the power sector for the EU as a whole. In the scenarios with higher BECCS support, the power sector achieves carbon neutrality for the EU before 2040. In the case of Poland, the process is only slightly slower. In 2050, net emissions from the power sector are negative in all scenarios except the scenario with no support for BECCS.

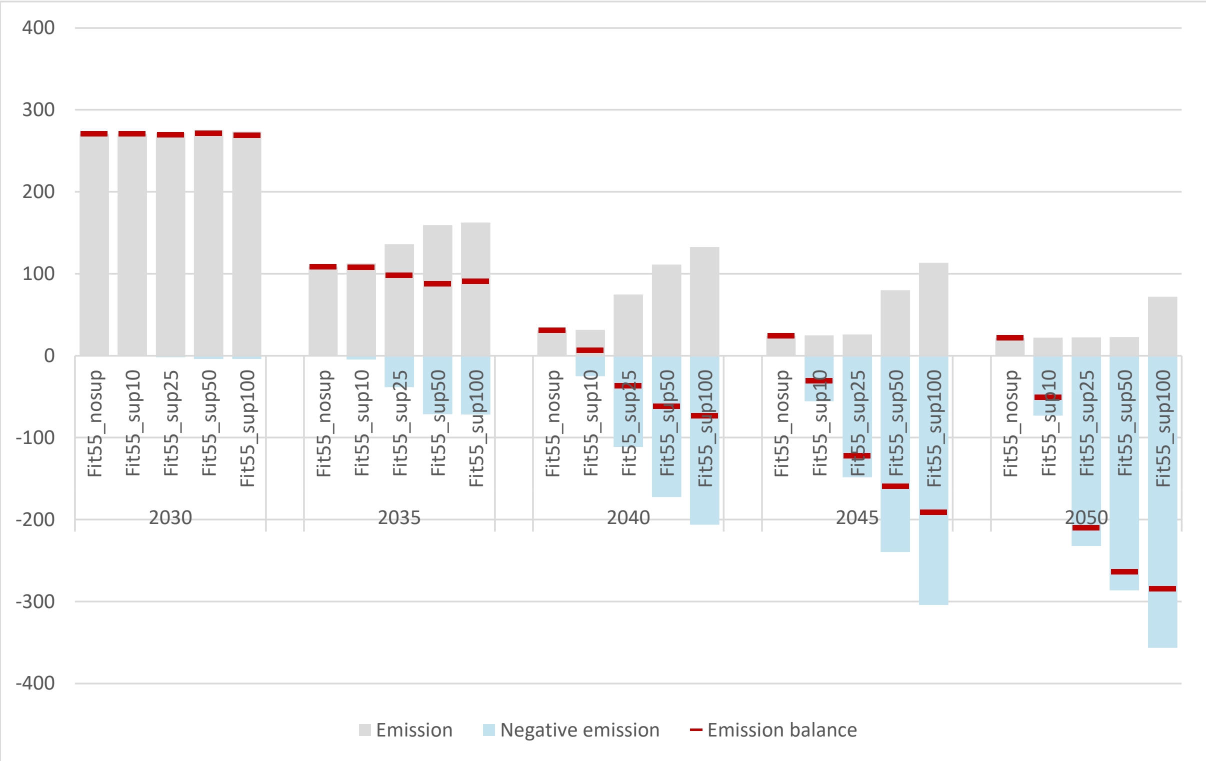
Table 7. Net emissions from the power sector for particular scenarios for the EU+UK+EFTA and Poland [Mt CO_2 eq.]

	2030	2040	2050
EU+			
Fit55_nosup	270	29	16
Fit55_sup10	268	7	-61
Fit55_sup25	271	-40	-204
Fit55_sup50	271	-62	-254
Fit55_sup100	270	-77	-296
Poland			
Fit55_nosup	50	4	1
Fit55_sup10	49	2	-6
Fit55_sup25	50	2	-11
Fit55_sup50	49	0	-13
Fit55_sup100	48	-1	-18

Source: CAKE/KOBiZE

159. The same results are presented below in a slightly different way. Figure 15 shows actual CO_2 emissions, negative emissions, and the emission balance (in red) in the power sector for the EU+UK+EFTA in 2030-2050.

Figure 15. Power sector emission balance for the EU+UK+EFTA [Mt CO_2].



Source: CAKE/KOBiZE

160. The figure above also shows that actual CO_2 emissions in the scenarios with BECCS are slightly higher than without BECCS because these emissions can be offset by the negative emissions.

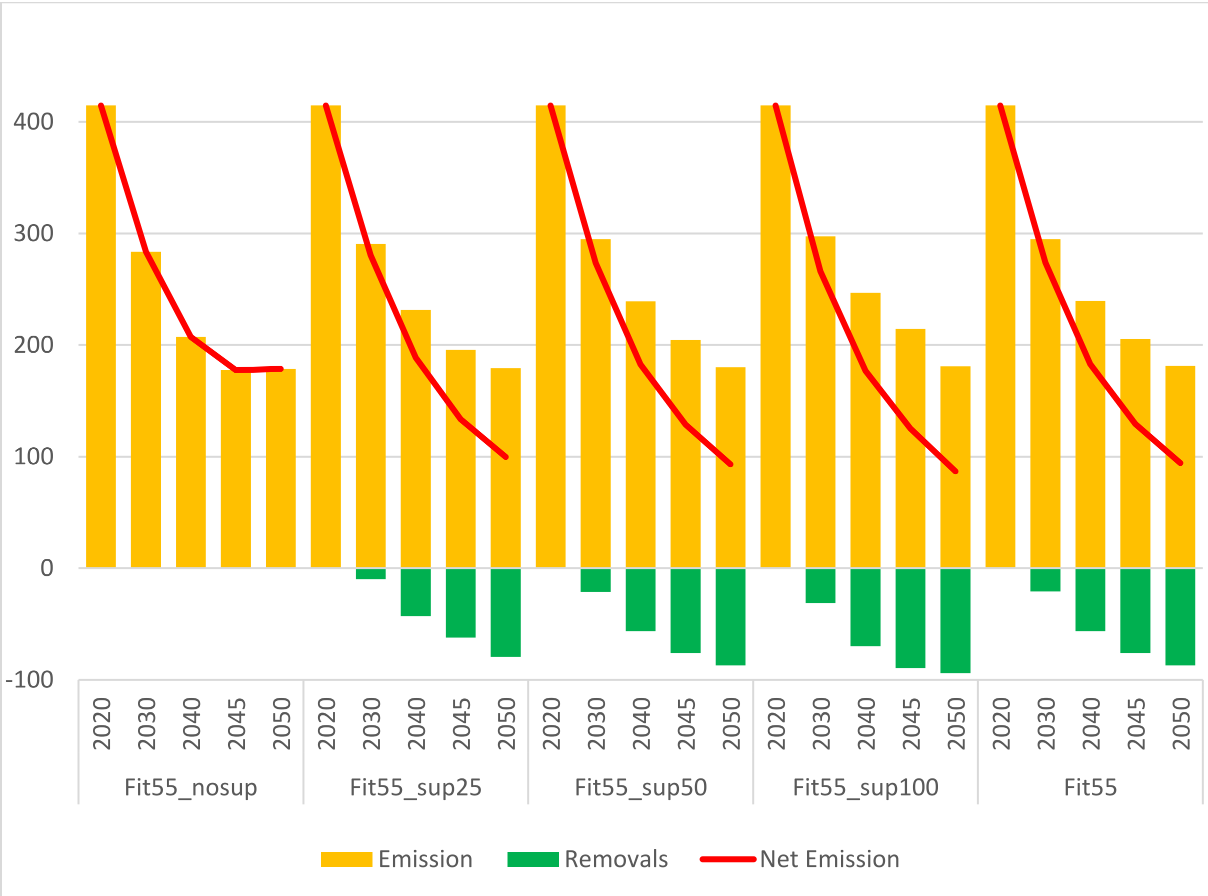
161. The real importance of BECCS technology can be seen by comparing how the amount of negative emissions achieved in the power sector affects the carbon prices in the EU ETS as a whole (see Figure 15). In Fit55_nosup and Fit55_sup10 the carbon price reach 1000 EUR/tCO_2 in 2050, but in 2040 it is about 180 EUR/tCO_2 lower in the scenario with revenues for BECCS (700 EUR/tCO_2 vs. 880 EUR/tCO_2). The impact of increasing subsidies on carbon prices in the EU ETS in 2050 is even more pronounced in scenarios with higher revenues: 910 EUR/tCO_2 in Fit55_sup25, 550 EUR/tCO_2 in Fit55_sup50 and 380 EUR/tCO_2 in Fit55_sup100.

162. The power sector is almost fully decarbonised in 2050, so the high cost of emissions does not significantly affect this sector, but it seems that the presence of BECCS technology is more important for other sectors of the economy included in the EU ETS, where emission reductions are much more difficult and expensive. It therefore seems sensible to introduce financial and legal mechanisms to support the development of BECCS technology. BECCS appears to be an important element of the overall system. Without large-scale implementation of BECCS technology, it would be difficult to achieve negative emissions in the power sector and thus fail to meet the ambitious climate targets set for 2050. The results point to the need to develop this technology to offset GHG emissions from other sectors (in some sectors it may be impossible to reduce GHG emissions to zero). The electricity and district heating sectors are the only ones where negative emissions are possible on a large scale, except for afforestation and inventions aimed at capturing CO_2 from the air (which are currently still at an experimental stage, i.e. DACCS).

8.1.3 Agriculture

163. Simulation for the agricultural sector shows that the amount of greenhouse gases that can be absorbed by afforestation of arable land compared to emissions from the sector cannot be balanced. The net GHG emissions calculated by the difference between emitted and absorbed GHG are represented by the red line in the **Błąd! Nie można odnaleźć źródła odwołania.**.

Figure 16 Agricultural GHG emissions and removals for EU+UK in Fit55_sup scenarios [Mt CO_2 eq.].



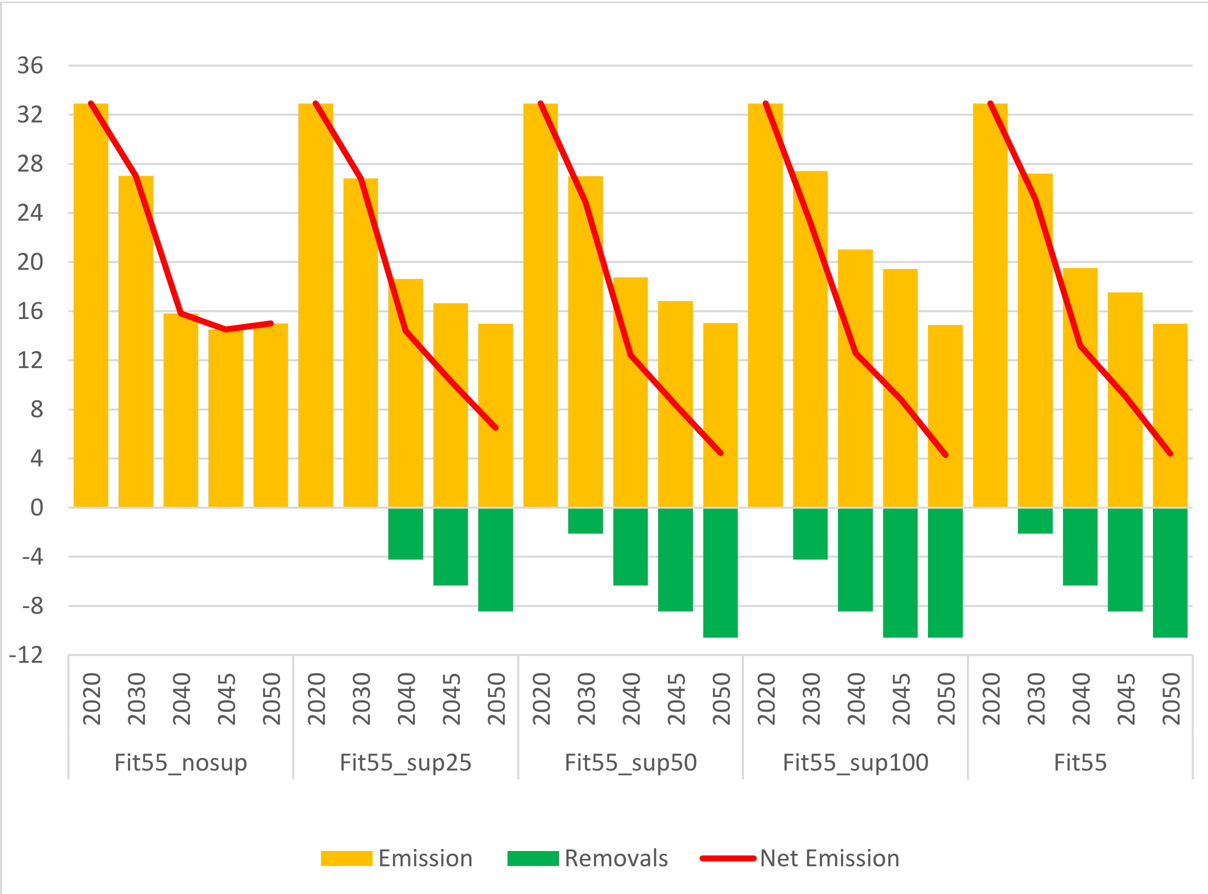
Source: CAKE/KOBiZE

164. Based on the presented chart, it is evident that the GHG emission level depends some extent on the level of support. Without support, the final emission level is reached in 2045, and remains in 2050, although this scenario incurs higher costs, which will be explained later. In contrast, net GHG emissions remain unchanged when the support level of GHG removals is set at or above 25% of the carbon price. This outcome results from the maximum afforestation areas assumed in the scenarios. The implemented restrictions reflect the limited availability of high-quality nursery material and the labor-intensive nature of forest establishment. The findings suggest that increasing payments

beyond 25% of the assumed carbon price does not significantly enhance the GHG removal rate by the agricultural sector.

165. Upon analyzing the probable impact of climate policy scenarios on emission levels in Poland, we can observe more profound changes. An increase in the level of support accelerates the reduction of greenhouse gas emissions. However, there are differences in the amount of GHG removals between the Fit55_sup50 and Fit55_sup100 scenarios. Specifically, in the scenario where subsidies are at the level of 100% carbon price, the maximum GHG removals will be achieved by 2045. This indicates that there is a much greater justification for subsidizing GHG removals in Poland, as demonstrated in Figure 17.

Figure 17. Agricultural GHG emissions and removals for Poland in Fit55_sup scenarios [Mt CO_2 eq.]



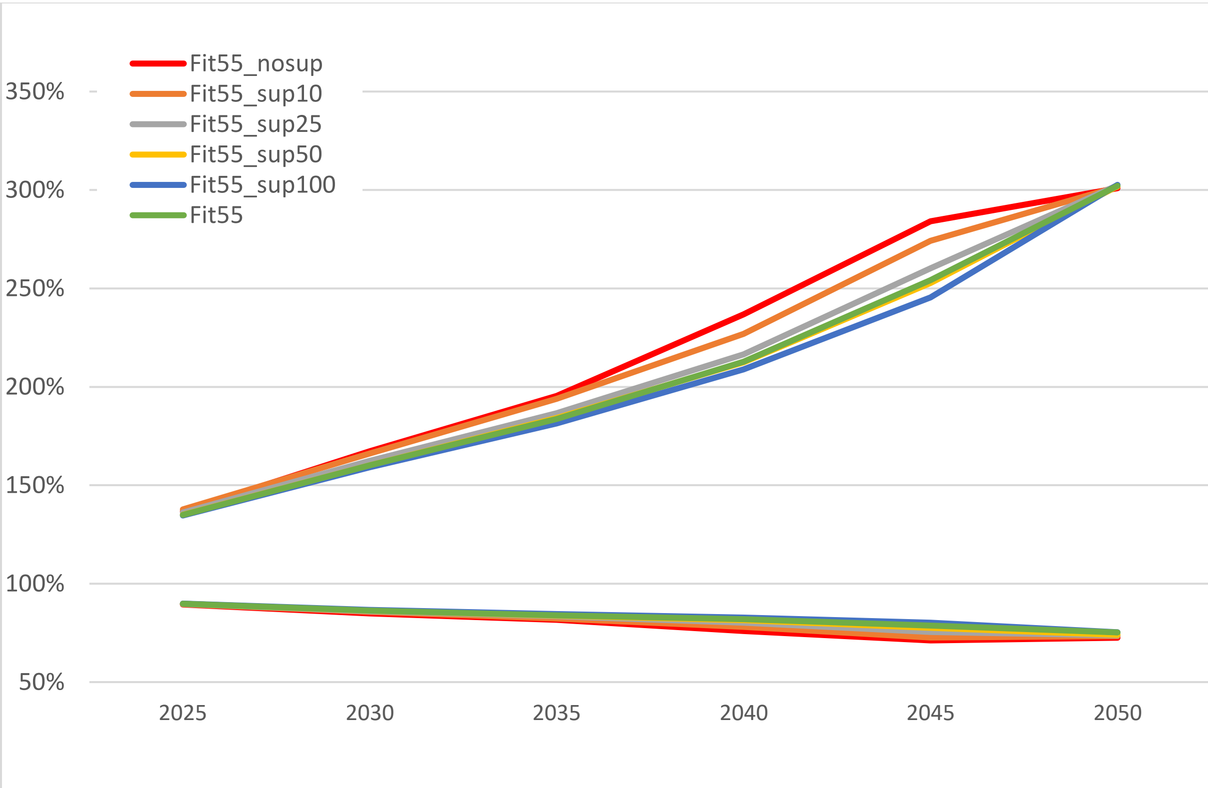
Source: CAKE/KOBiZE

166. According to results, the reduction in greenhouse gas (GHG) emissions in Polish agriculture will be more significant than the average in the EU. Under the baseline scenario (Fit55), the net GHG emissions from agriculture will decrease from 32 Mt CO_2 eq. in 2020 to 4.4 Mt CO_2 eq. in 2050, resulting in a reduction of GHG emissions to

13.4% of the 2020 GHG emissions (the corresponding emission reduction at EU level is 25%).

167. From the EU perspective, cutting GHG emissions in the agricultural sector by 50% and achieving a 75% reduction in net emissions in the period 2020-2050**Błąd! Nie można odnaleźć źródła odwołania.**, results in major changes on the market. Reducing emissions in this sector can be challenging and might necessitate a decrease in agricultural production. Given the inelastic demand for food, a 25% drop in production by 2050 comparing to 2020 could cause a significant increase in agricultural product prices. In fact, results shows that food prices could potentially triple over the 2020-2050 period [Figure 18]. Although the scenarios vary in the paths of changes between 2020 to 2050, the final output by 2050 is quite similar across all scenarios. This similarity is due to the assumptions of using the backstop technology, which sets maximum carbon price in non-ETS sector at 1000 EUR/tCO_2 eq.

Figure 18. Agricultural production (lower lines) & farm gate prices (upper lines) in Fit55_sup scenarios for UE27+UK [2020=100%]

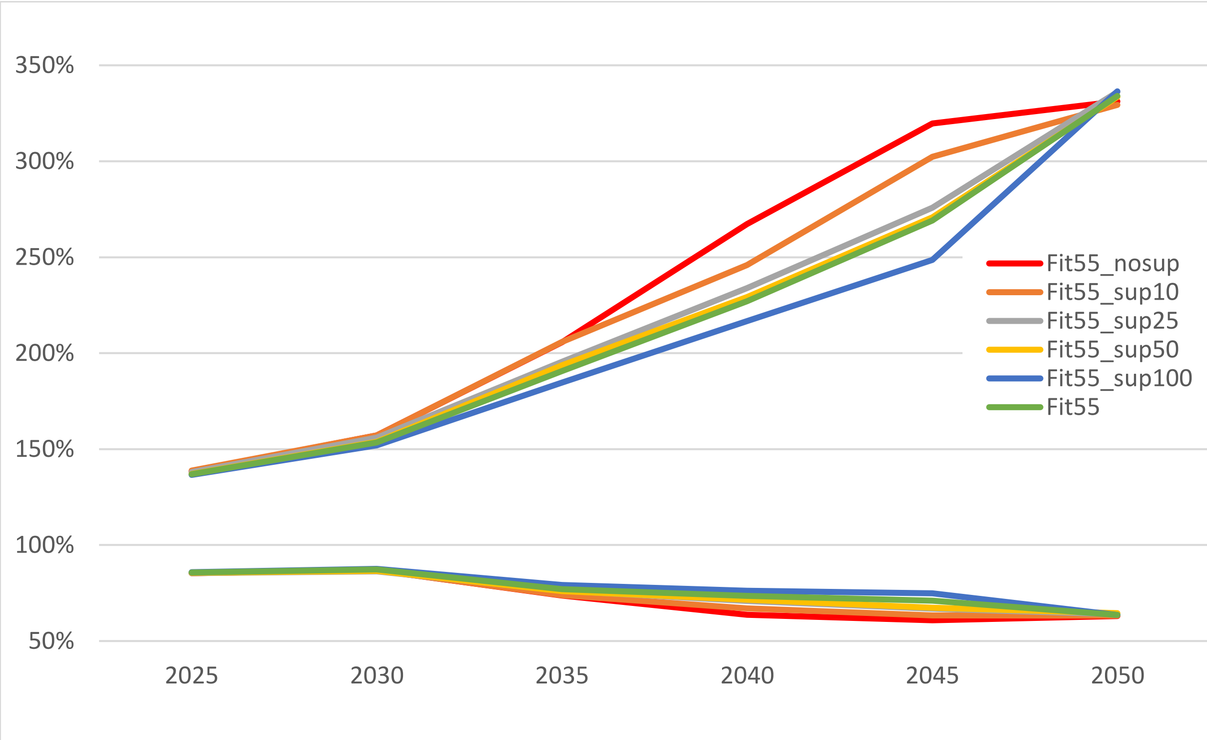


Source: CAKE/KOBiZE

168. The overall market situation is accurately reflected by the average price increase. Upon analyzing the outcome for each product group, it has been observed that the price hike in beef may go as high as 800%. On the other hand, the cost of vegetables and fruits is expected to rise by a minimum of 20% as compared to the base year (2020).

169. The reduction of GHG in Poland has a significant impact on the food market. This impact is more noticeable as the reduction becomes more profound than the EU average, as shown in Figure 19. The rate of GHG emissions reduction varies with different support levels, which leads to diverse paths to the target price level. The target price level is the same for all considered scenarios by 2050. The scenario without subsidies, Fit55_nosup, achieves the target level of prices and production in 2045. On the other hand, the Fit55_sup100 scenario (blue line in the Figure 19) experiences slower production reductions and price increases until 2045.

Figure 19. Agricultural production (lower lines) & farm gate prices (upper lines) in Fit55_sup scenarios for Poland [2020=100%]

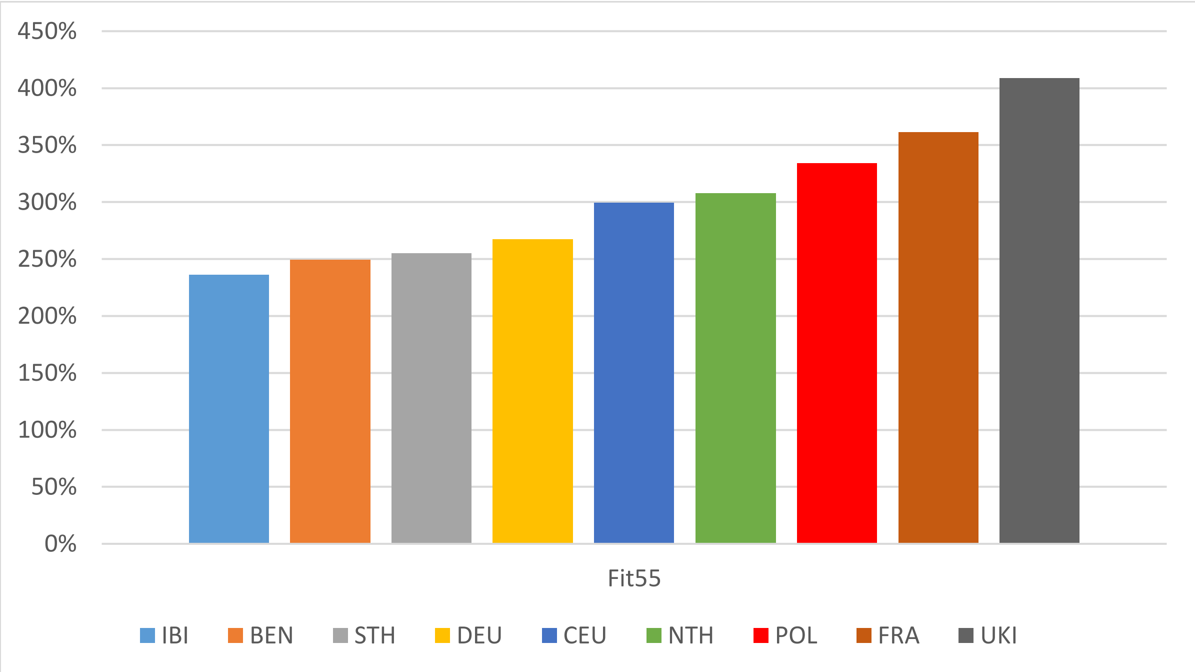


Source: CAKE/KOBiZE

170. By 2050, agricultural production in Poland will decrease to around 63% of its current (2020) level, while the EU average will drop to 75%. This indicates that Polish agriculture is more sensitive to more ambitious GHG reduction targets. As a result, there will be a larger increase in agricultural product prices on the local market. By 2050, agricultural product prices in Poland will reach 334% of the current (2020) level, which is an increase of 34 percentage points higher than the average for the EU27+UK. This increase can be partly explained by the slightly lower starting point of agricultural product prices in Poland. However, it also highlights the greater sensitivity of Polish agriculture to the ambitious assumptions of the GHG emission reductions in the European Green Deal.

171. In the context of the GHG reduction assumptions, changes in the agricultural product market lead to variations in the prices and quantity of agricultural production across different countries. It is important to note that the increase in agricultural product prices will not be uniform across different levels of the GHG removals support. By 2050, the cost of reducing emissions in the agricultural sector will drive all agricultural product prices to the same high level, regardless of the GHG removals support level. However, it is evident that in 2030 and 2040, food products prices will increase more rapidly in scenarios with less support for GHG removal (see red line in the Figure 18 presenting results for Fit55_nosup scenario). This trend is particularly noticeable in 2040. By 2050, the increase in agriculture products prices compared to 2020 level will be nearly the same in all scenarios, as shown only in the Fit55 results. However, this uniformity does not extend to all countries, with prices rising much faster in some, such as Poland, France, Great Britain and Ireland [Figure 20].

Figure 20. Increase of agricultural prices by EU regions in Fit55 scenario [2020=100%]



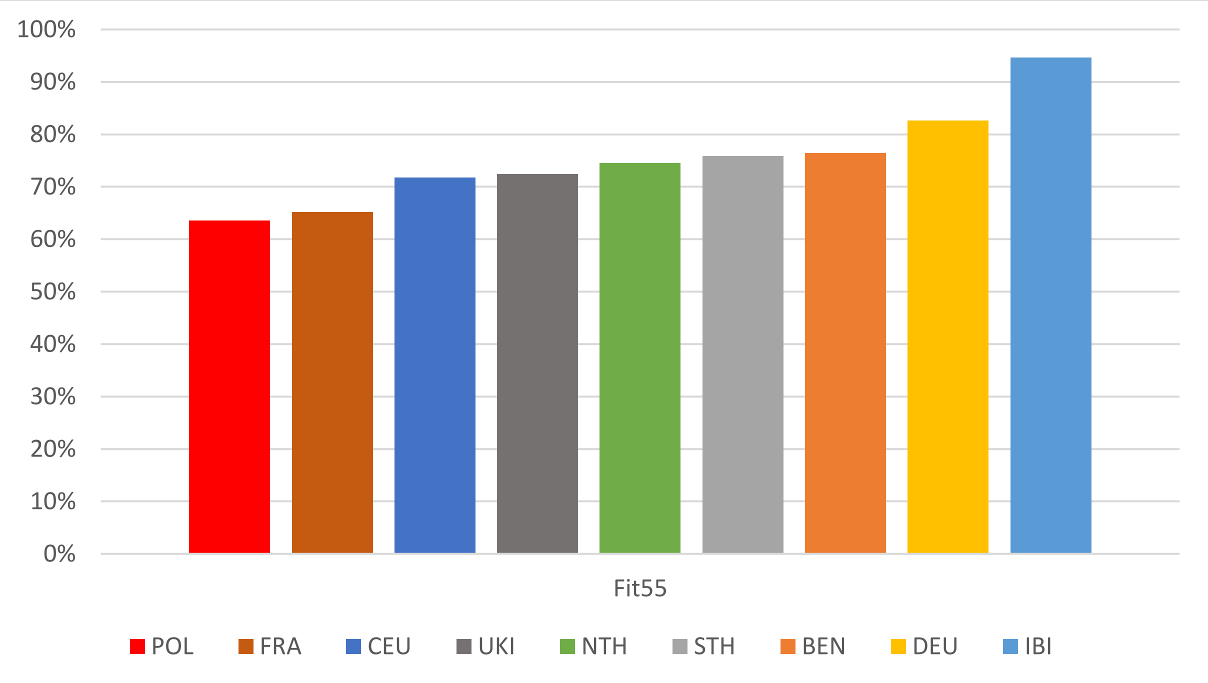
Source: CAKE/KOBiZE

172. France and Poland, with an anticipated price increase of around 350% (Poland slightly less), follow UK & Ireland closely. Although the nature of changes in these countries is slightly different, the resulting net emissions are expected to drop in Poland to approximately 13% of the 2020 level in 2050. Notably, the share of GHG removals in Poland is slightly higher than in France. In contrast, the southern countries (IBI & STH) and the Benelux countries are expected to experience an average price increase in 2050 of approximately 250% of the level in 2020.

173. The fluctuations in price displayed above are closely linked to the agricultural sector's response to the GHG reduction assumptions. On a continental scale, it is observed that the acceleration in prices is proportional to the decline in production. As a result, in scenarios with low support for GHG removals, farmers show slightly greater willingness to decrease the production of agricultural goods. This trend is particularly evident in 2040.

174. However, it is noteworthy that individual countries react differently to the emission reduction targets, leading to varied degrees of production reductions [Figure 21]. Similarly as in case of prices there are nearly no differences between scenarios, thus only Fit55 results are presented on the figure.

Figure 21. Relative level of agricultural productions by EU regions in 2050 in Fit55 scenario [2020=100%]

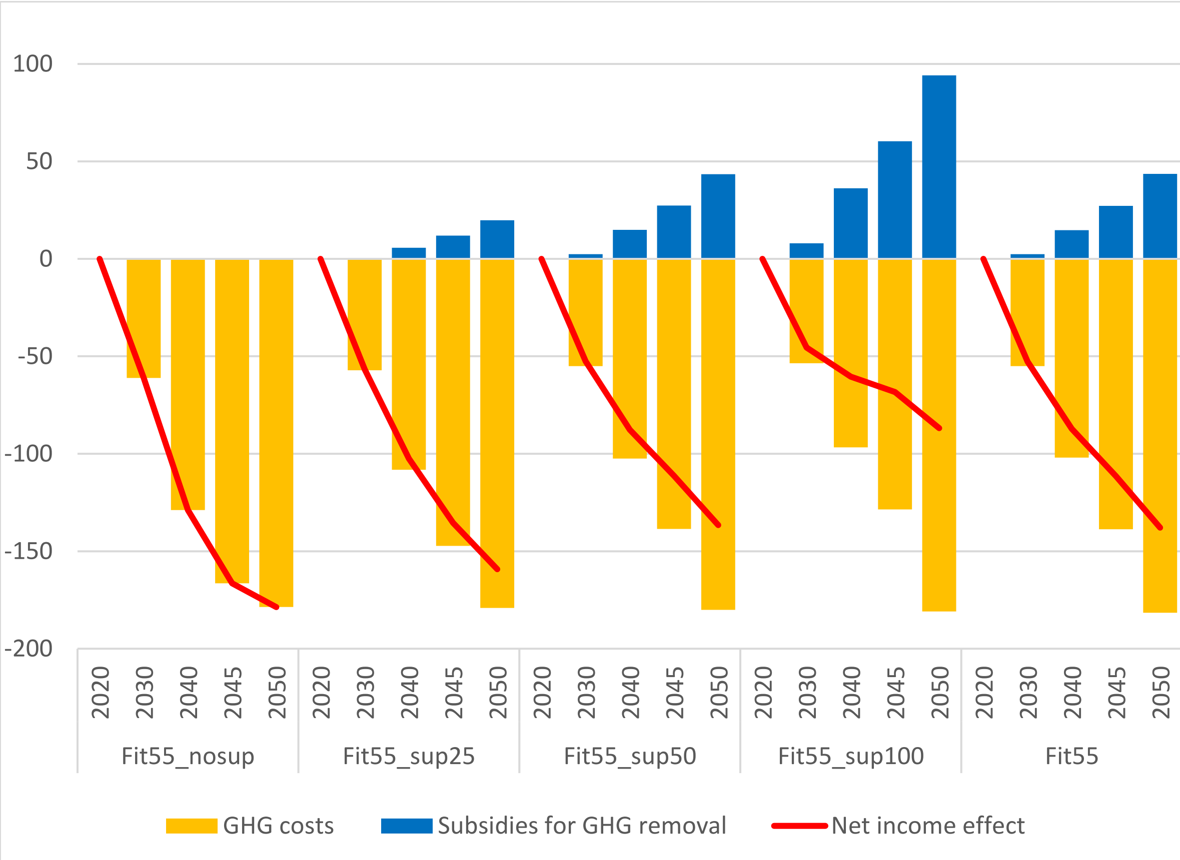


Source: CAKE/KOBiZE

175. Spain and Italy demonstrate the smallest reductions in agricultural production, primarily due to their production structure, where permanent crops and fruits and vegetables play a vital role, and hence, respond the least to GHG emission reduction requirements. The German agricultural sector demonstrates a slight decline in production, thanks to measures implemented by German farmers in recent years, which limited fertilizer usage without significantly affecting yields. This translates to lower unit emissions of agricultural production, leading to less drastic cuts in production than observed in other countries. Conversely, Poland and France experience the highest decline in agricultural production, approximately 30% in France and 35% in Poland compared to the base year.

176. Imposing price on GHG emissions from the agricultural sector will have serious financial consequences. Under the Fit55_nosup scenario, the total annual cost of carbon prices payments for compliance in EU agriculture would reach a horrendous amount of EUR 180 billion by 2050. This is due to EU agriculture GHG emitting less than 190 Mt CO_2 eq. with carbon prices reaching the upper limit in 2050 of 1000 EUR/tCO_2 eq. The use of GHG removals allows to reduce the level of income deterioration of EU agriculture due to the implementation of the EU climate policy. However, the removals of GHG are triggered by subsidies, in scenarios with low levels of removals support like Fit55_sup10 they are negligible and thus omitted from the figure. The values are presented in Figure 22.

Figure 22. Costs of GHG emissions & Subsidies in agriculture EU27+UK in Fit55_sup scenarios [bln EUR]



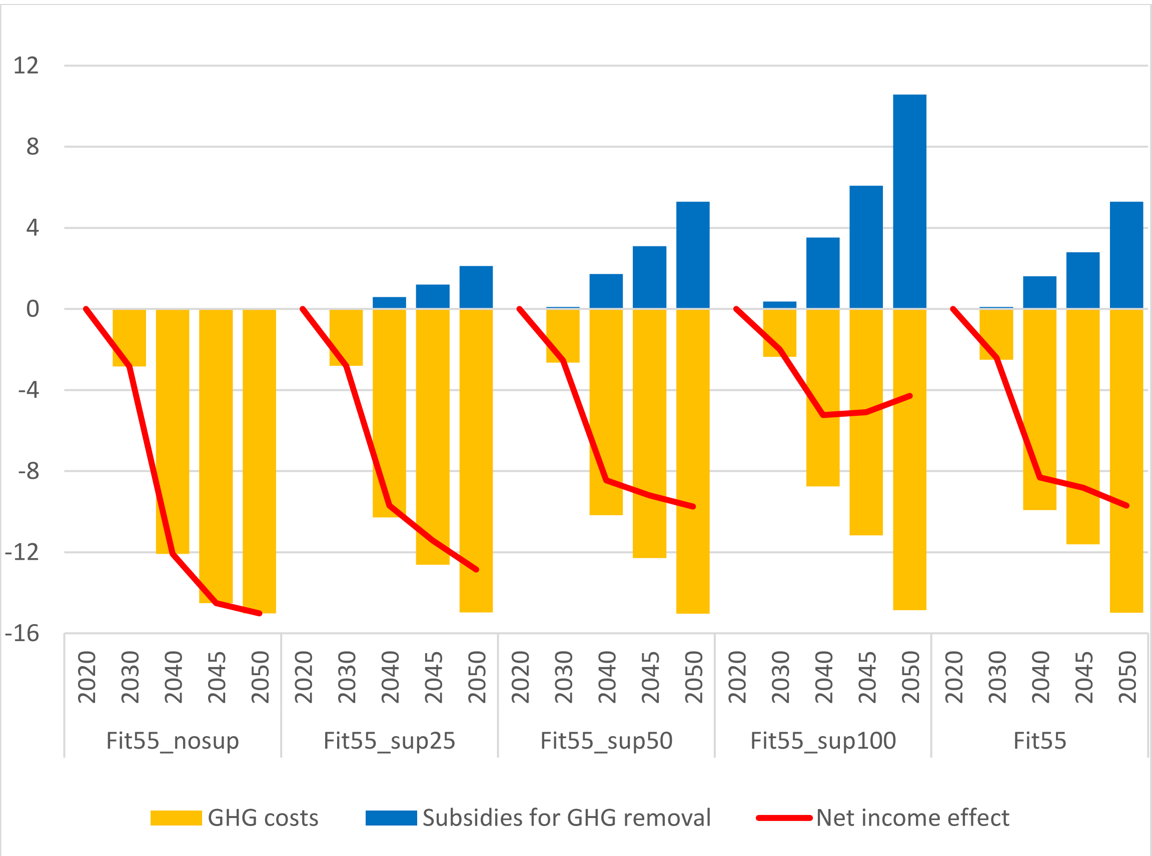
Source: CAKE/KOBiZE

177. The scale of GHG absorbing measures used depends on the level of support. However, as previously noted, increasing the level of subsidies for GHG removals above 25% of the CO_2 eq. emission rate does not result in an increase in afforestation, but only alleviates the financial consequences for farmers. However, even in the most favorable Fit55_sup100 scenario for farmers, in which tons of CO_2 eq. are removed from the atmosphere, the net GHG income effect of the agricultural sector puts a huge financial burden on European farmers. It should be noted here that the annual CAP budget is

approximately EUR 55 billion, while net costs of climate policy (after deducting GHG removals subsidies) in the most favorable scenario would amount to EUR 87 billion in 2050. Bearing in mind that in 2020, CAP subsidies (~ EUR 55 billion) accounted for 60% of farmers' income, it should be clearly stated that the sector, which is part of the global market for agricultural products, is not able to bear such a financial burden and compete on the World market. It can be assumed that charging agriculture for the generated GHG emissions would lead to a significant reduction in agricultural activity across Europe. Likely, only sectors that generate significant added value while emitting low levels of GHG would survive. Examples of such sectors might include specialized horticultural farms, vineyards, ect.

178. The impact of GHG emission reduction on the economic situation of the agricultural sector in Poland is similar to that of the entire EU (Figure 23). Scenarios that burden the sector with the costs of GHG emissions with the simultaneous lack or negligible support for GHG removals significantly worsen the income situation of farmers by burdening the sector with costs that significantly exceed the support received by farmers under the Common Agricultural Policy (25 bln EUR for the period 2023-2027, i.e. approx. 5 bln EUR per year).

Figure 23. Costs of GHG emissions & Subsidies in agriculture in Poland for Fit55_sup scenarios [bln EUR]



Source: CAKE/KOBiZE

179. However, with increased support for GHG removals, the negative impact of the GHG emission reduction, although still very significant, is gradually decreasing. The previously described decline in agricultural production offers the opportunity to afforest some of the unused land, which partially offsets the costs associated with reducing GHG emissions in the agricultural sector through subsidies. In the most favorable scenario for farmers, Fit55_sup100, the net income effect of the GHG reduction reaches its minimum in 2040, approximately minus EUR 5 billion. Then from this point the net income starts to slightly increase due to the slightly faster rate of increase in GHG removals than the rate of increase in the unit costs of GHG emissions in Poland. Only in this scenario would the sector as a whole not incur negative income effect of GHG emission reduction greater than CAP subsidies. However, it should be assumed that even in this scenario, the income situation of farmers would significantly deteriorate. Similarly like in the EU only the farms with lowest emissions per unit of income could afford covering costs of GHG emission reduction.

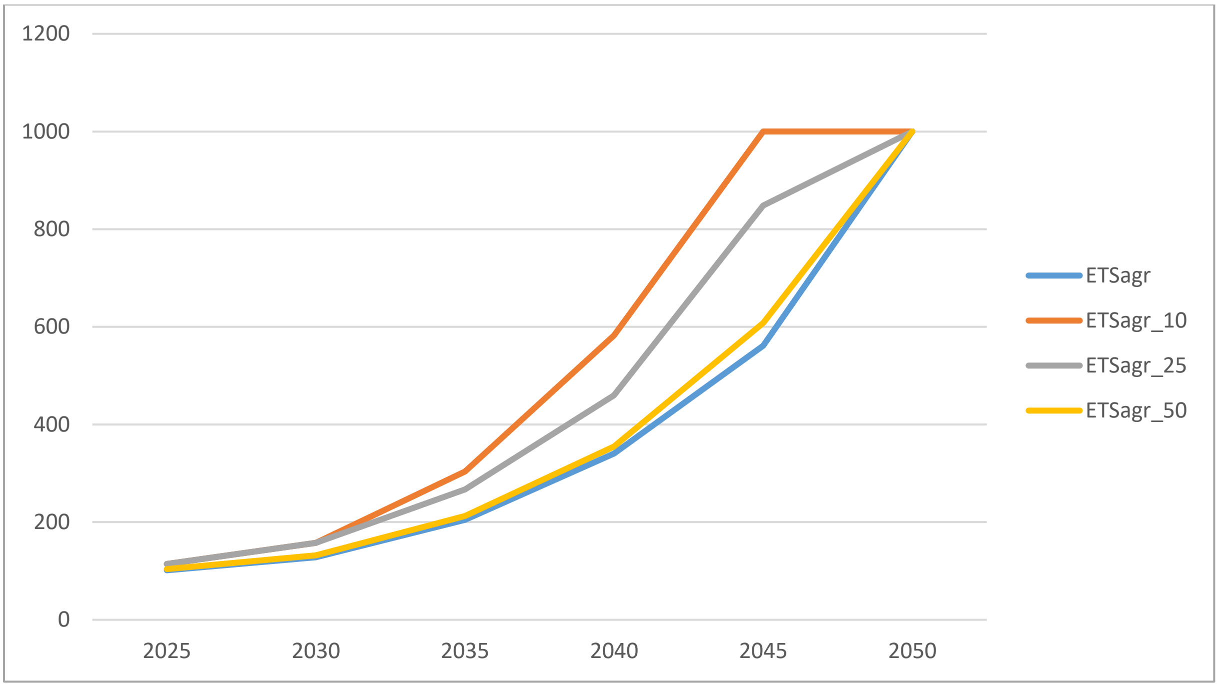
8.2 Common non-ETS carbon price at EU level (ETSagr)

180. The analysis then moves to the scenarios that consider the introduction of a European ETS system for all sectors not covered by the EU ETS or the ETS2 system. In previous scenarios, including the Fit55 scenario, carbon pricing is also applied to agriculture and other non-ETS sectors, but annual emission limits cannot be traded between countries, so these prices remain country-specific. In this scenarios the integration of national systems into the common European system adds flexibility to shift emission reductions to regions with lower marginal abatement costs. Due to the nature of the policy, the focus is on impacts at the macroeconomic level and in the agricultural sector. In the other sectors, the impacts are negligible.

8.2.1 Macro Effects and Pricing in the EU ETS

181. If negative emissions from afforestation receive 100% of the price in this system (ETSagr scenario), the equilibrium level of this price would be 340 EUR/tCO_2 eq., in 2040. If the support is reduced to 50% of the price, the equilibrium price in the new system rises slightly to 350 EUR/tCO_2 eq. Further reductions in support to 25% and 10% lead to a significant increase in the price to levels of 460 EUR/tCO_2 eq., and 580 EUR/tCO_2 eq., respectively. In 2050, the price would converge to the level of 1000 EUR/tCO_2 in all scenarios, as we assume that backstop technology will deliver abatement at this cost.

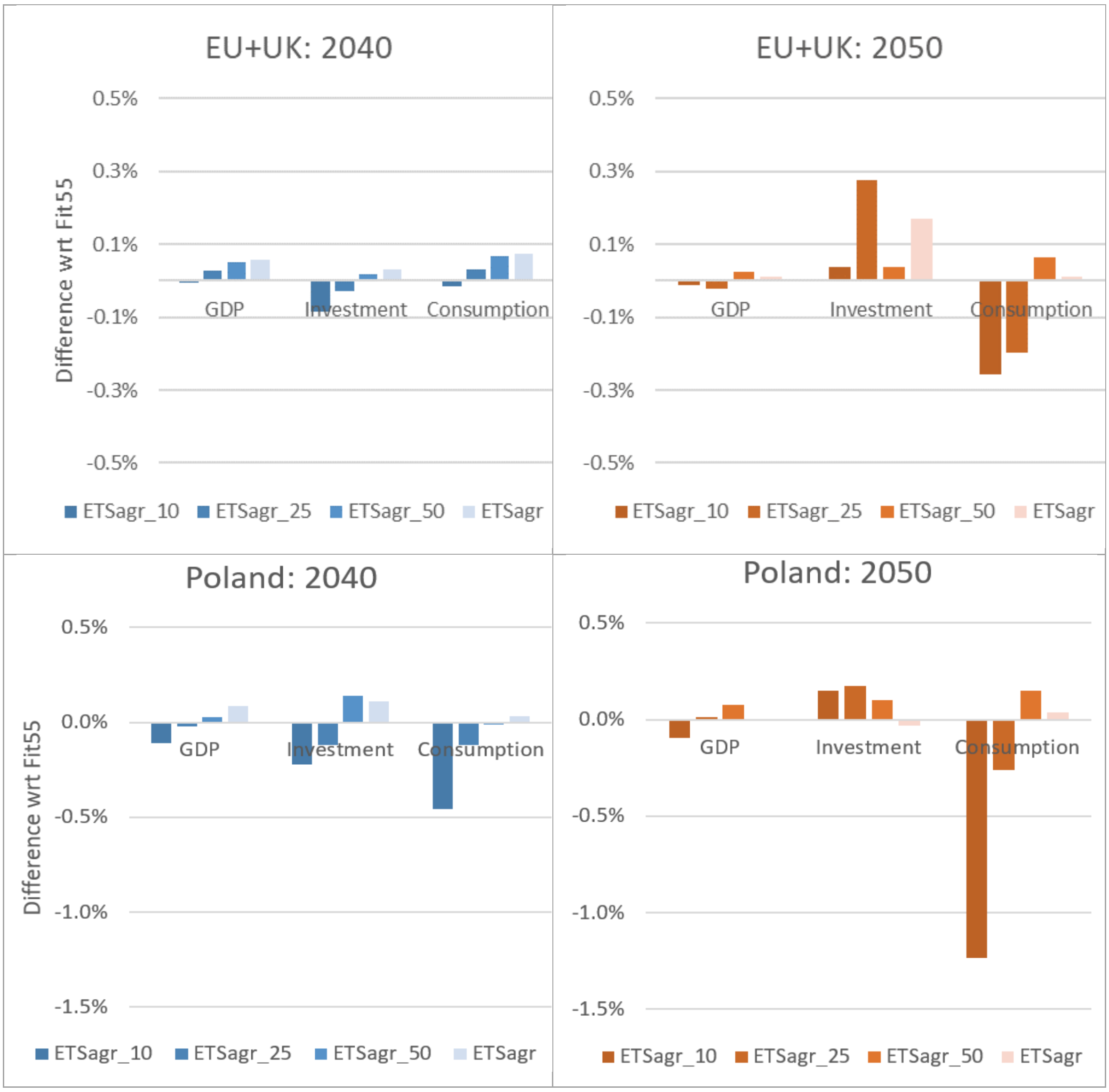
Figure 24. Price of carbon [EUR/tCO_2 eq.] in the ETSagr (for agriculture and other sectors not covered with EU ETS and ETS2) under alternative levels of pricing removals



Source: CAKE/KOBiZE

182. In general, the introduction of the ETSagr has a negligible macroeconomic impact. In 2040, at the EU level and in Poland, all macroeconomic variables in all scenarios are almost at the same level as in the Fit55 scenario. At EU level, in 2050, the scenarios with 100% and 50% support have the same GDP and consumption and slightly (less than 0.2%) higher investment. The 25% and 10% scenarios have the same GDP as Fit55 scenario, but slightly lower consumption, by about 0.2%. The low consumption is due to the need to finance mitigation through backstop technology, which is required when farmers have insufficient incentive to invest in afforestation. Also in Poland the macroeconomic variables in 2050 do not differ between the scenarios. In terms of consumption, the only scenario that differs significantly is ETSagr_10, which is characterised by a consumption value that is 1.2% lower than Fit55 in 2050.

Figure 25. Impact on GDP, investment and consumption with respect to Fit55 scenario under alternative scenarios of pricing removals in scenarios with ETSagr in 2040 (left panel) and 2050 (right panel) for the EU (top) and Poland (bottom)



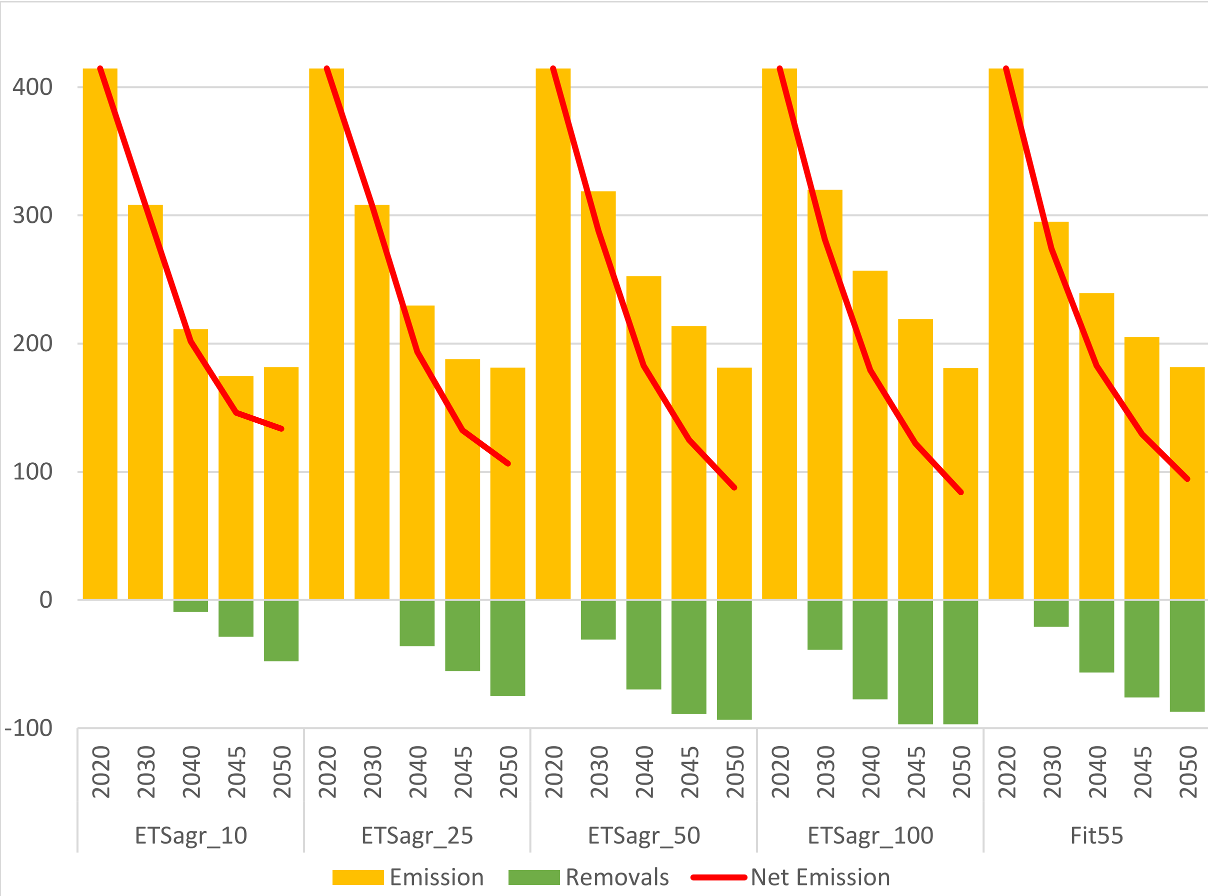
Source: CAKE/KOBiZE

8.2.2 Agriculture

183. The implementation of a new emission trading system ETSagr for agriculture and other sectors that are not under the scope of the EU ETS and ETS2 will lead to a more balanced distribution of the financial burden across all EU regions, comparing to the Fitfor55 scenario. However, it is worth noting that as we approach 2050, the maximum carbon price in our simulations for one tonne of CO_2 eq. equal to 1000 EUR is actually

reached. The introduction of the ETSagr will not result in significant changes in this regard. However, it is important to highlight that setting the uniform carbon price at the EU level in all countries will result in slightly deeper emission reductions in individual scenarios compared to having different prices for different regions. However, the reduction of GHG emissions and its financial impact will be similar to the scenarios discussed in the previous chapter, but the path to achieving these results in 2050 may differ slightly. Please refer to Figure 26 for further details.

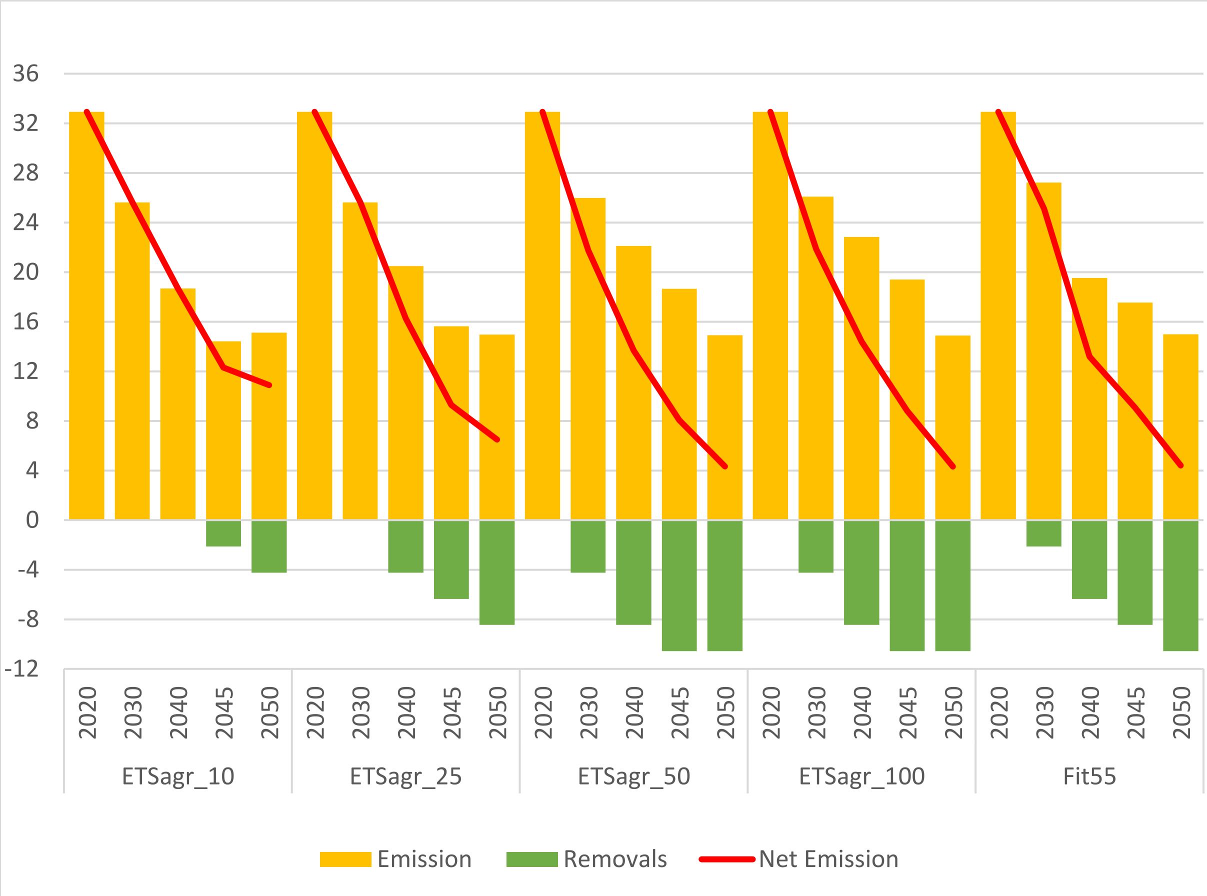
Figure 26. Agricultural GHG emissions and removals for EU27+UK in ETSagr scenarios [Mt CO_2 eq.]



Source: CAKE/KOBiZE

184. In the Scenario ETSagr_100 the full removals level is reached already in 2045, while in ETSagr_50 is very close to the final level. Thus it might be concluded that common ETS system for agriculture speed up achieving final GHG emission reduction, even the differences between Fit55 and ETSagr_50 &ETSagr_100 in 2050 are not very relevant

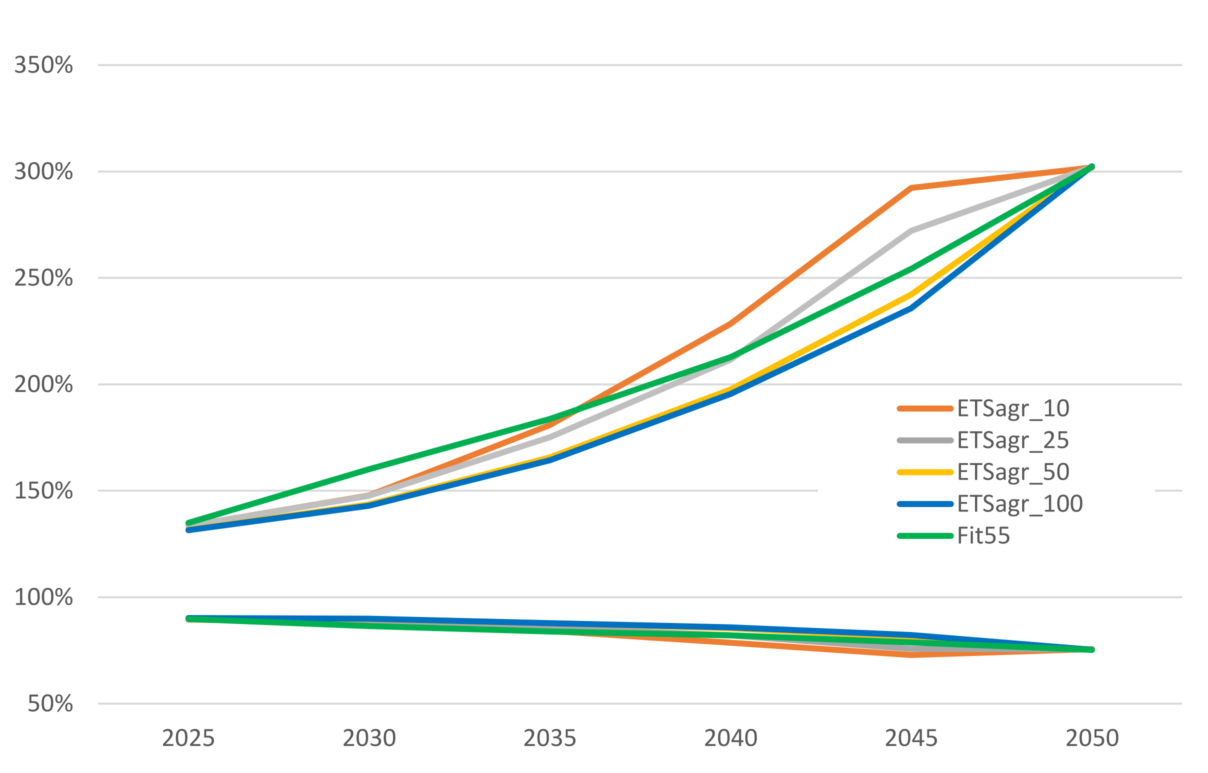
Figure 27. Agricultural GHG emissions and removals for Poland in ETSagr scenarios [Mt CO_2 eq.]



Source: CAKE/KOBiZE

185. Equalizing GHG carbon price across the agricultural sector can promote diverse strategies for achieving the 2050 target. This may result in a reduction in agricultural production or an increase in product prices by 2050, as illustrated in Figure 28.

Figure 28. Agricultural production (lower lines) & farm gate prices (upper lines) in UE27+UK for ETSagr scenarios [2020=100%]

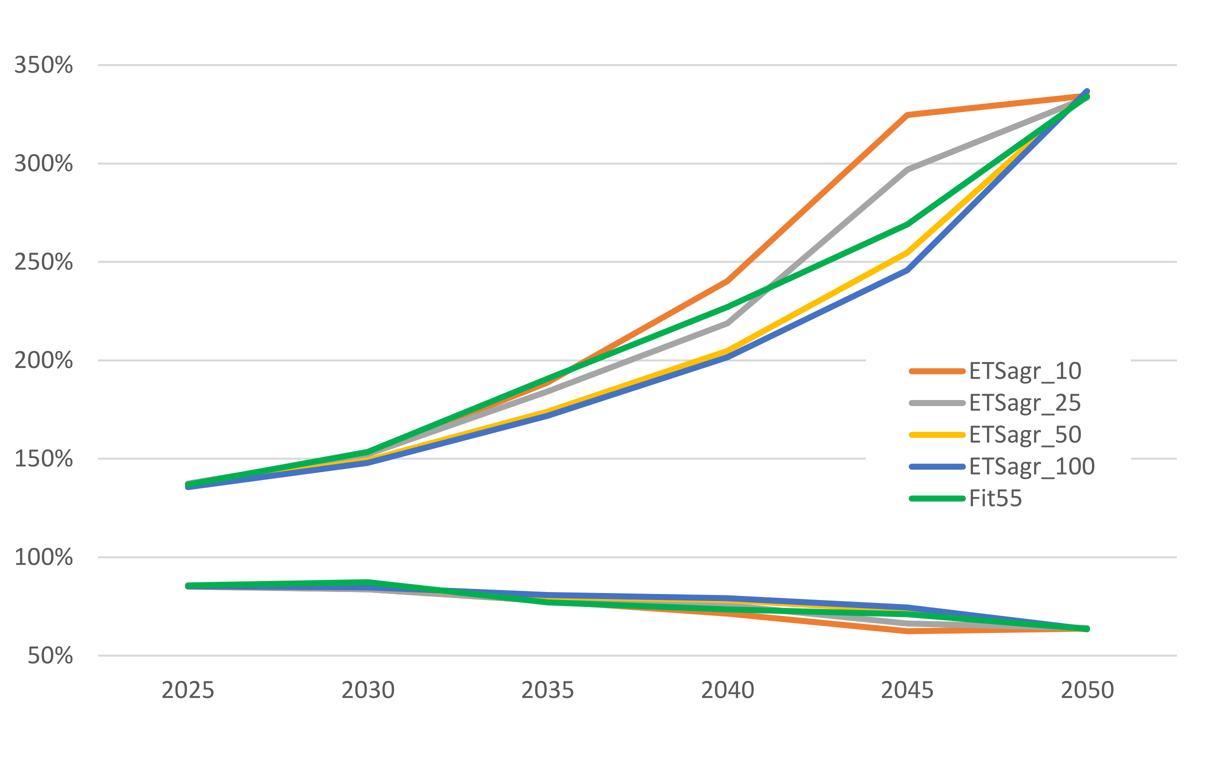


Source: CAKE/KOBiZE

186. Although the initial decline in production and price increase may be slow under the ETSagr scenario comparing to the Fit55 scenario, both are likely to accelerate after 2035. By examining the ETS agr_10 scenario (bottom orange line on the Figure 28), we can see that a comparable outcome to the 2050 target can be achieved as soon as 2045.

187. At the other end of the scale, the ETSagr_50 and ETSagr_100 scenarios should be indicated. The comparison of the results shows, similarly to the high levels of support in the Fit55_sup50 and Fit_sup_100 scenarios, increasing the level of subsidies above a certain level does not cause significant changes on the agricultural markets.

Figure 29. Agricultural production (lower lines)& farm gate prices (upper lines) in Poland for ETSagr scenarios [2020=100%]



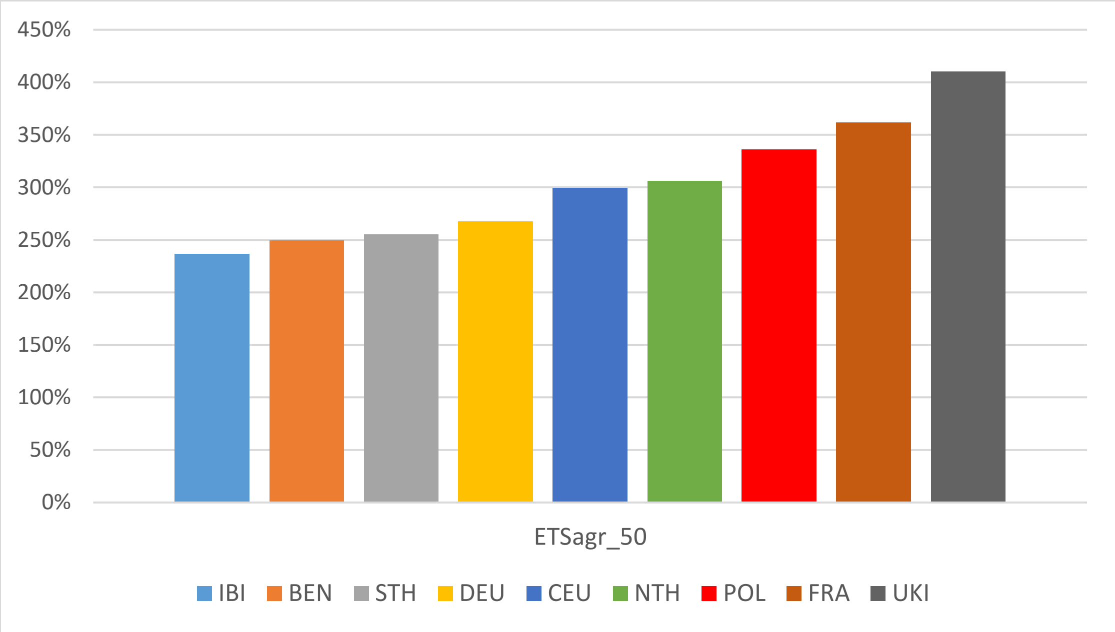
Source: CAKE/KOBiZE

188. The ETSagr scenarios have led to comparable changes in Poland and the EU27. However, it's important to note that GHG reduction is more substantial in Poland, resulting in more significant market changes. Additionally, the level of support has a slightly greater impact on the pace of reaching the final price and volume level than in the EU27+UK. To gain a better understanding of this, please refer to Figure 29, which illustrates the adjustment of production levels and prices in Poland. It is worth noting that in ETSagr_10 scenario already in 2045 the production and prices reach level which all analysed scenarios reach in 2050.

189. The price and production changes observed in the analyzed regions of the EU in ETSagr scenarios are comparable to those in the previously analyzed Fit55_sup scenarios. Furthermore, the final outcomes in terms of price and production changes in 2050 are very similar in both cases as they have achieved a comparable level of carbon price. Thus the output agricultural prices and production changes for the 2050 are presented on the figures Figure 30 and Figure 31 only for ETSagr_50 scenario as the results for other scenarios in 2050 are nearly identical.

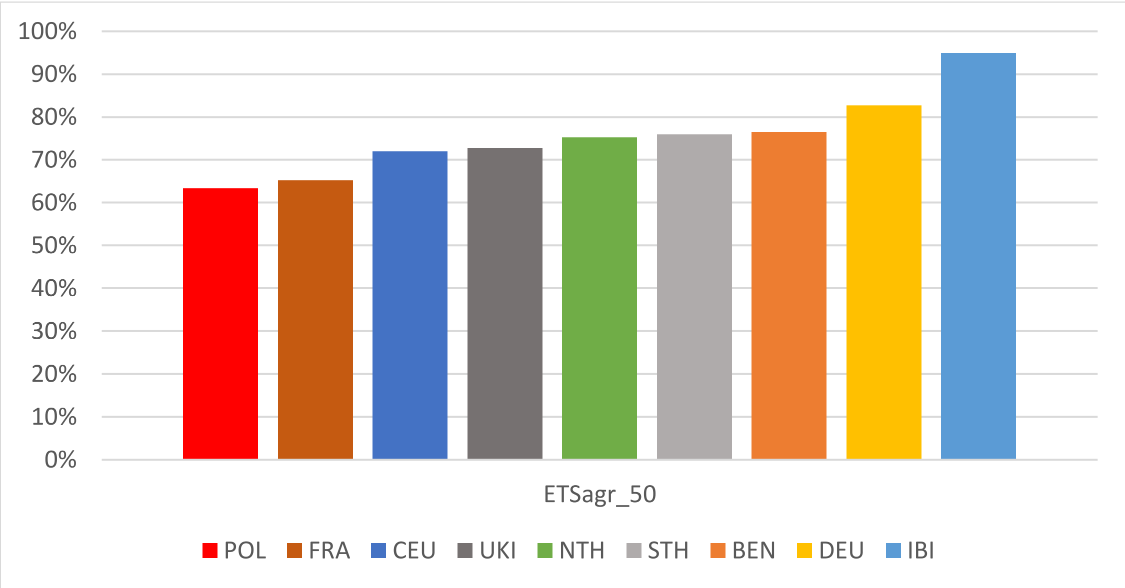
190. The highest increase in prices could be observed in the UK, Poland and France, where GHG reduction leads to the highest decline in agricultural production.

Figure 30. Relative level of agricultural prices by EU regions in 2050 in ETSagr_50 scenario [2020=100%]



Source: CAKE/KOBiZE

Figure 31. Decrease of agricultural production by EU regions in 2050 in ETSagr_50 scenario [2020=100%]



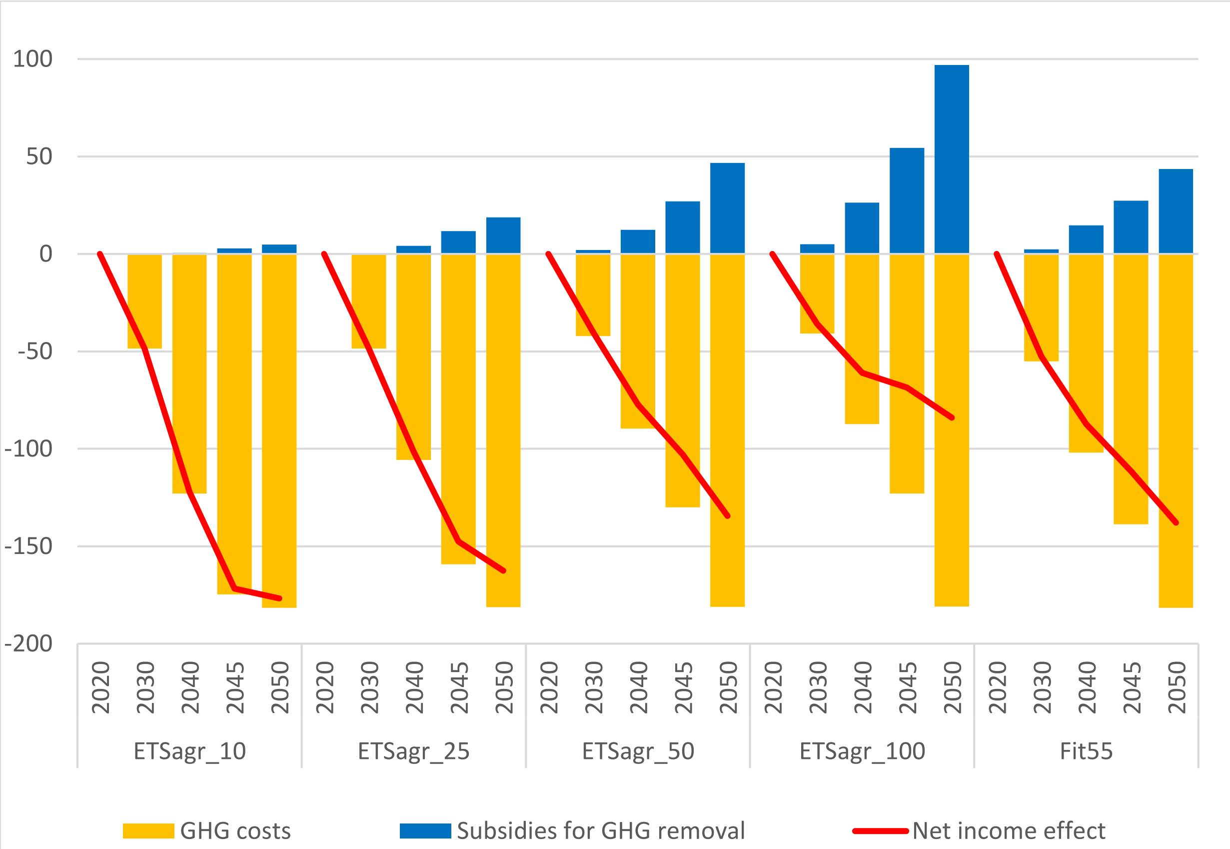
Source: CAKE/KOBiZE

191. In terms of agricultural production and prices, we can observe a slight difference between the ETSagr and Fit55 scenarios by 2040. The Fit55sup scenarios have a stronger impact on the market, leading to a greater increase in prices and a deeper reduction in production. However, the differences at the EU level do not exceed 2-3

percentage points and are would be barely visible on the figures. These differences are due to a more balanced approach to reducing GHG emissions pricing in the agricultural sector in the ETSagr scenarios. Common carbon price prevent rapid changes in emission pricing in single regions or countries, which leads to lower dynamics in affected regions. Despite this, the effects in 2050 for both scenarios are very similar.

192. Similar to the scenarios previously described, the introduction of carbon price for emissions in the agricultural sector places a significant financial strain on farmers. Due to the rapid attainment of maximum levels of pricing for GHG emissions, financial pressure arises more quickly and is slightly more severe. See Figure 32 for details.

Figure 32. Costs of GHG emissions & Subsidies in EU27+UK agriculture in ETSagr scenarios [bln EUR]

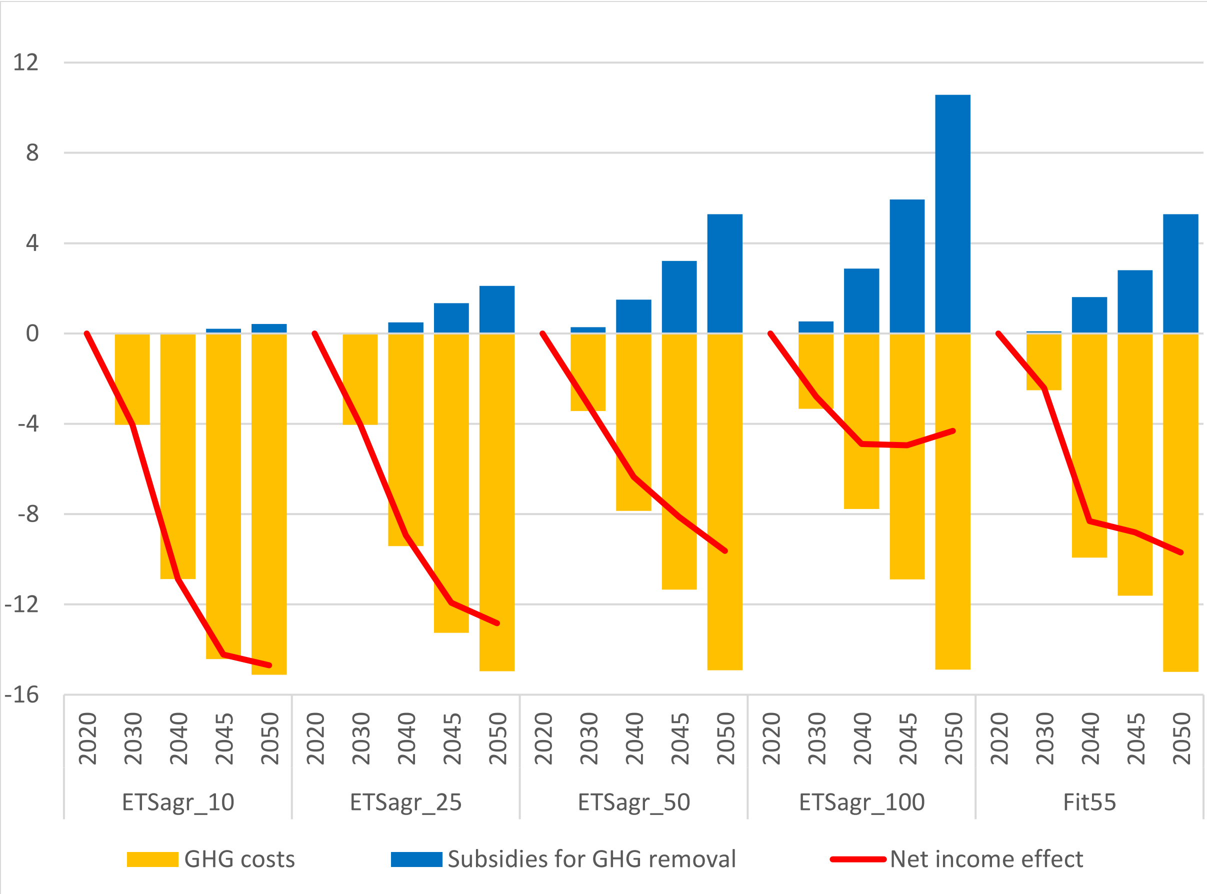


Source: CAKE/KOBiZE

193. In the EU27 scale ultimately, by 2050, due to higher payments for removals the burden on the agricultural sector is comparatively lower than in the previous chapter's analyzed scenarios. In the ETSagr_100 scenario, net income effect in the agricultural sector due to carbon pricing total minus EUR 84 billion. While this is EUR 3 billion less than the Fit_sup100 scenario, it remains true that such a level of income deterioration on European agriculture would result in a drastic reduction of farms number in the EU.

194. Regarding the situation in Poland, the differences between Fit55sup and ETSagr scenarios in 2050 are very similar. The differences in the final net income effect in 2050 are negligible. However, in the ETSagr scenarios, the negative impact of GHG reduction has higher dynamics. The negative net income effects in 2025 and 2030 are greater as the carbon prices for all EU in ETSagr scenarios are higher in that period than the cost of emissions in the domestic carbon pricing system [Figure 33]. Similarly, like in Fit55 scenario, the payments for removals positively impact the net income effect. Thus, increasing the role of afforestation in 2045 and 2050 in ETSagr_100 decreases the economic burden of climate policy on the agricultural sector.

Figure 33. Costs of GHG emissions & Subsidies in Polish agriculture in ETSagr scenarios [bln EUR]



Source: CAKE/KOBiZE

195. It's important to note that the non-ETS sector, and consequently ETSagr, comprises more than just agricultural emissions. As shown in Table 8, agriculture accounted for about 50% of the GHG emissions in the non-ETS sector. If more ambitious climate policy targets are introduced without support for emission removals, the share of agriculture emissions in the non-ETS increases. This suggests that reducing non-agricultural GHG emissions in the non-ETS sector is comparatively easier.

Table 8. Reduction efforts of agricultural sector and total non-ETS

	Mt CO2 eq.	2020	2025	2030	2035	2040	2045	2050
AGRI GHG	ETSagr_50	414.7	332.4	319.9	290.7	255.9	212.3	189.9
	Fit55	414.7	324.4	291.9	265.2	234.3	205.4	190.1
Non-ETS GHG	Mt CO2 eq.	2020	2025	2030	2035	2040	2045	2050
	ETSagr_50	846.4	727.5	662.3	553.4	458.4	376.3	335.2
	Fit55	846.4	708.7	633.8	531.0	437.0	370.3	336.9
AGRI GHG in non-ETS	Share Agri in non-ETS/ ETSagr	2020	2025	2030	2035	2040	2045	2050
	ETSagr_50	49.0%	45.7%	48.3%	52.5%	55.8%	56.4%	56.7%
	Fit55	49.0%	45.8%	46.1%	49.9%	53.6%	55.5%	56.4%

Source: CAKE/KOBiZE

8.3 Hydrogen Subsidies

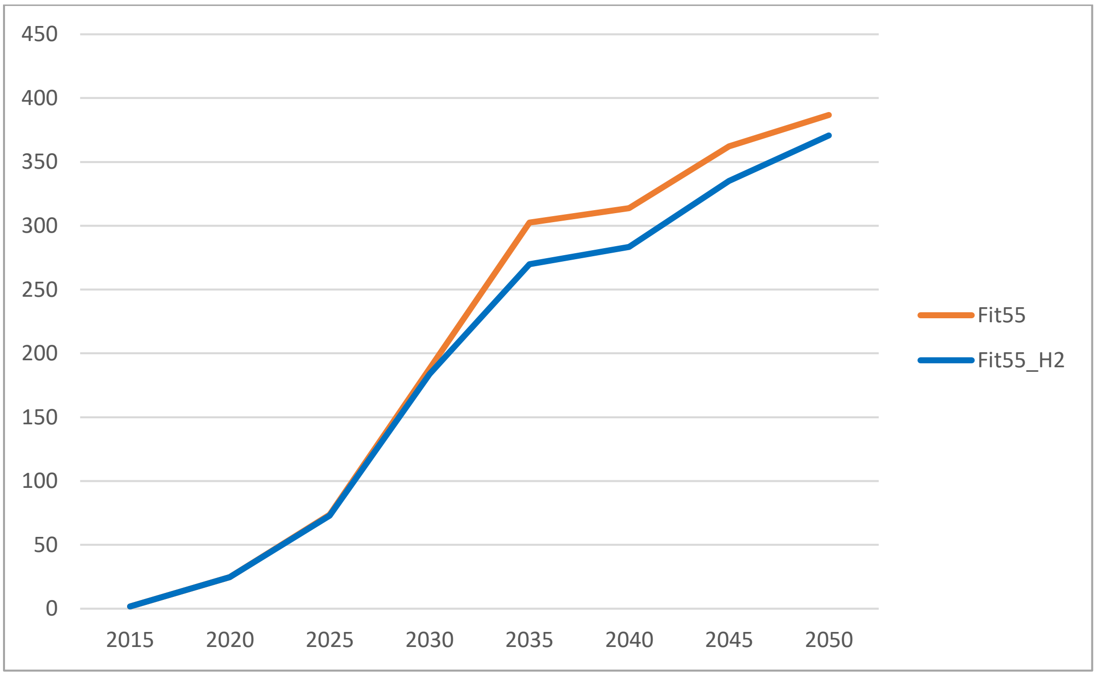
196. In this subsection the report analyse the impact of introducing subsidies to hydrogen. We present the results at the macroeconomic level as well, as consequences for energy sector, transport sector and energy-intensive industries.

8.3.1 Macro Effects and Pricing in the EU ETS

197. The effect of subsidising the use of hydrogen has non-trivial consequences for the price of emissions in the EU ETS. On the one hand, it incentivises the substitution of fossil fuels, mainly natural gas and oil, with hydrogen, thereby reducing the demand for emission allowances in the EU ETS. This puts downward pressure on the carbon price. On the other hand, the subsidy increases the demand for hydrogen and electricity. The increase in demand in the electricity sector then leads to a higher demand for allowances, putting upward pressure on their price. The simulation suggests that the former effect dominates in the European economy and the hydrogen subsidies introduced in the Fit55_H2 scenario lead to lower prices in the EU ETS market compared to the Fit55 scenario.

198. The prices in the two scenarios diverge significantly in 2035: in this year the EU ETS price reaches the level of 270 EUR/tCO_2 in Fit55_H2, which is 30 EUR lower compared to 300 EUR/tCO_2 in Fit55 scenario. In the following years the price difference between the two scenarios becomes slightly smaller - 30 EUR/tCO_2 in 2040 and 20 EUR/tCO_2 in 2050. The impact of subsidies on hydrogen use has a negligible effect on emission prices in the ETS2 and non-ETS sectors.

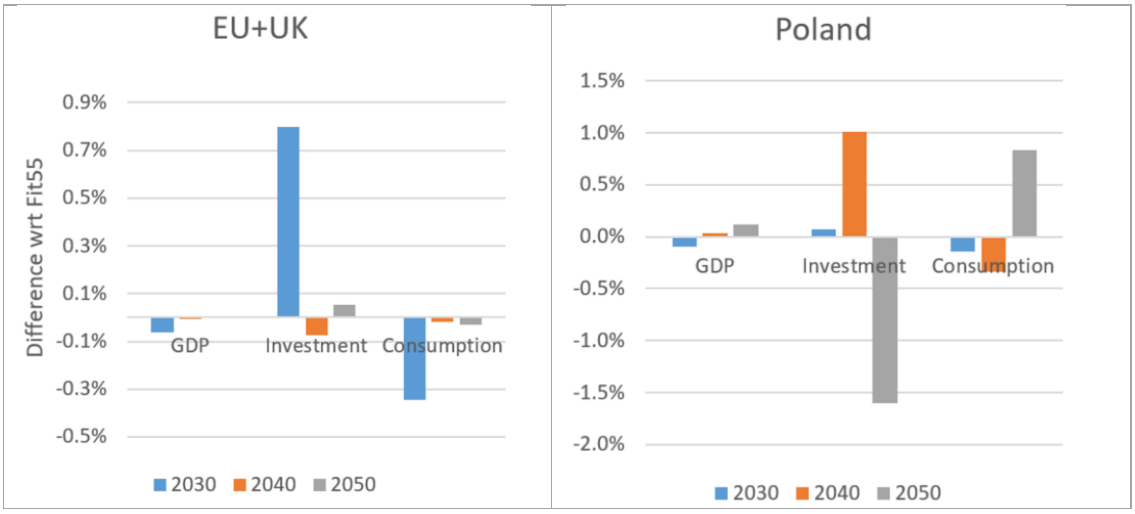
Figure 34. Price of carbon [EUR/tCO_2] in EU ETS under Fit55 scenario (no subsidies to hydrogen) and Fit55_H2 scenario (subsidies to hydrogen)



Source: CAKE/KOBiZE

199. As expected, the introduction of hydrogen subsidies leads to a reduction in GDP and consumption, almost throughout the time horizon. The loss can be explained by the distortionary effect of overlapping policies highlighted by the analytical studies (see the literature review in Chapter 2) an explicit carbon price that automatically adjusts to a given emission reduction target ensures that firms choose a mix of inputs that reduces their emissions while minimising the loss of output. Any policy that distorts this price will lead to a sub-optimal choice of inputs and thus a greater loss of output.

Figure 35. Impact on GDP, investment and consumption with respect to Fit55 scenario under scenario with hydrogen subsidies in 2040 and 2050 for the EU (left) and Poland (right)



Source: CAKE/KOBiZE

200. The simulations suggest that subsidies lead to a small reduction in EU+UK GDP of less than 0.1% in 2030. The fall in consumption in that year is 0.3%, which is larger than the fall in GDP due to increased investment (0.8%). In 2040 and 2050, GDP, consumption and investment are almost identical in the Fit55_H2 and Fit55 scenarios. In Poland, the impact on GDP is negligible and the impact on consumption changes over time: in 2040, consumption falls by 0.3% due to the large increase in investment, but in 2050, consumption is pushed up by 0.8% due to the fall in investment, which is driven by the price fall in the EU ETS.

8.3.2 Energy sector

201. The hydrogen subsidies analysed in this chapter significantly increase hydrogen production in the EU and Poland. Figure 36 shows the difference between the Fit55 scenario, which can be used as a reference, and the Fit55_H2 scenario, which includes hydrogen subsidies.

Figure 36. Green hydrogen production in the EU+UK+EFTA (left) and Poland (right) [PJ]

Source: CAKE/KOBiZE

202. Before 2030, the level of green hydrogen use is negligible in both scenarios, partly due to limited demand and partly due to the low availability of green hydrogen and electrolysers. In the 2030-2035 period, the pace of development of green hydrogen production is strongly dependent on subsidies - in the Fit55 scenario, hydrogen is still minimally used, whereas with subsidies in the Fit55_H2 scenario, green hydrogen technologies start to be used as early as 2030 and the initial pace of development of these technologies accelerates significantly.

203. In the decade of the 2030s, the use of green hydrogen is much higher thanks to the subsidies introduced. However, the differences between the scenarios gradually decrease and by 2050 hydrogen production in the subsidised scenario is only about 15% higher than in the unsubsidised scenario. A number of factors influence the results obtained. Firstly, the technology for green hydrogen production will gradually develop, the cost of renewable energy sources and overall electricity prices will decrease, which means that green hydrogen will become cheaper and the competitiveness of hydrogen-based technologies will increase. Secondly, it was assumed that subsidies for green hydrogen would be high in the initial period to give an impetus to the development of this technology, and then gradually reduced as the technology develops (the level of subsidies is gradually reduced from 50% in 2025 to 10% in 2050 - as described in Chapter 6.3). This brings the two scenarios closer together in 2050.

204. However, it should be emphasised that the model results are primarily based on the economics of competing technologies and do not take into account possible additional effects related to the technology learning curve. In our calculations, the change in technology costs is determined on the basis of literature (e.g. Primes Reference Scenario 2020 assumptions) and does not depend on the level of penetration of a given technology. In fact, it is very likely that subsidies at an early stage of development would

have an even greater impact on achieving technical maturity of hydrogen technologies (both on the production and use side), and the actual effects of subsidies would be more significant even in the long term. Nevertheless, this result confirms the appropriateness and effectiveness of subsidies for the use of hydrogen, as well as the positive impact on the reduction of carbon prices in the EU ETS. In the period 2035-2040, the carbon price in the Fit55_H2 scenario is about 10% lower than in the Fit55 scenario, in 2045 this difference is still 7% and only decreases to about 3% in 2050.

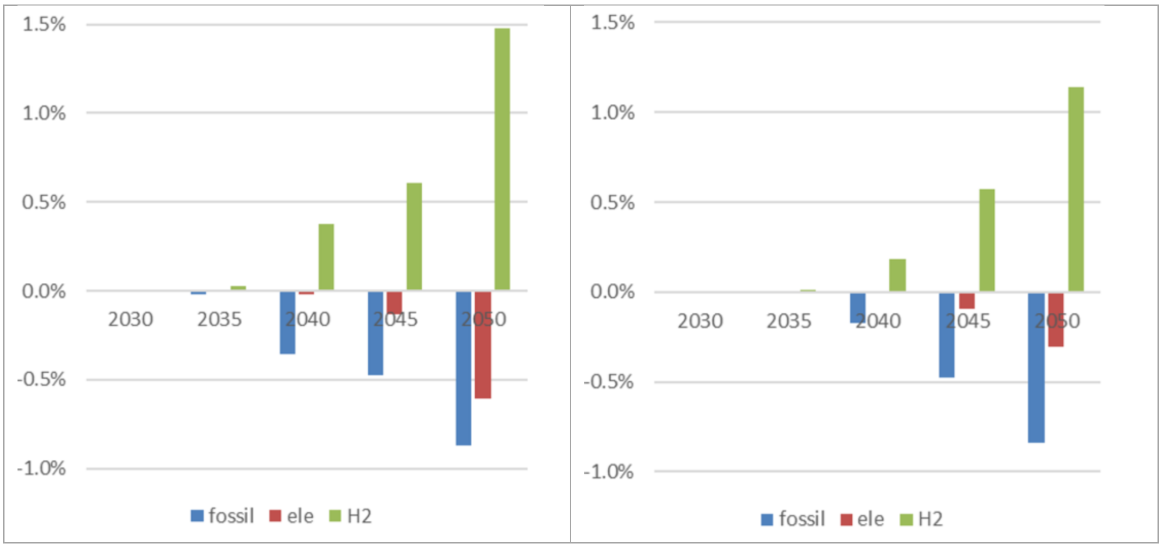
205. The differences between the scenarios do not have a major impact on the energy mix, but it is worth noting that the faster development of hydrogen technologies influences the development of wind farms and photovoltaics, which together reach about 6-5% higher electricity production in the EU in 2035-2045 in the Fit55_H2 scenario. Again, the difference decreases in the following years, but in 2050 production from this group of renewable sources is still about 4% higher in the scenario with green hydrogen subsidies.

8.3.3 Transport

206. The impact of hydrogen subsidies on the transport sector's development is limited, particularly when compared to the effects of emission standards. Lower hydrogen costs moderately incentivise the uptake of hydrogen heavy-duty vehicles. As illustrated in Figure 37, the share of hydrogen vehicles in the fleet increases by up to 1.5 percentage points in Poland and 1.2 percentage points in the EU+UK area. Furthermore, this increase comes at the expense of not only fossil fuel vehicles. The policy also has the tendency to crowd out purchases of electric-powered heavy-duty trucks, although this effect is smaller than the fall in diesel trucks. The reduction in emissions is also modest, with the relative drop reaching a maximum of slightly above 1% for both the EU+UK and Poland in 2050. In absolute numbers, the reduction is 0.7 Mt CO_2 across the EU.

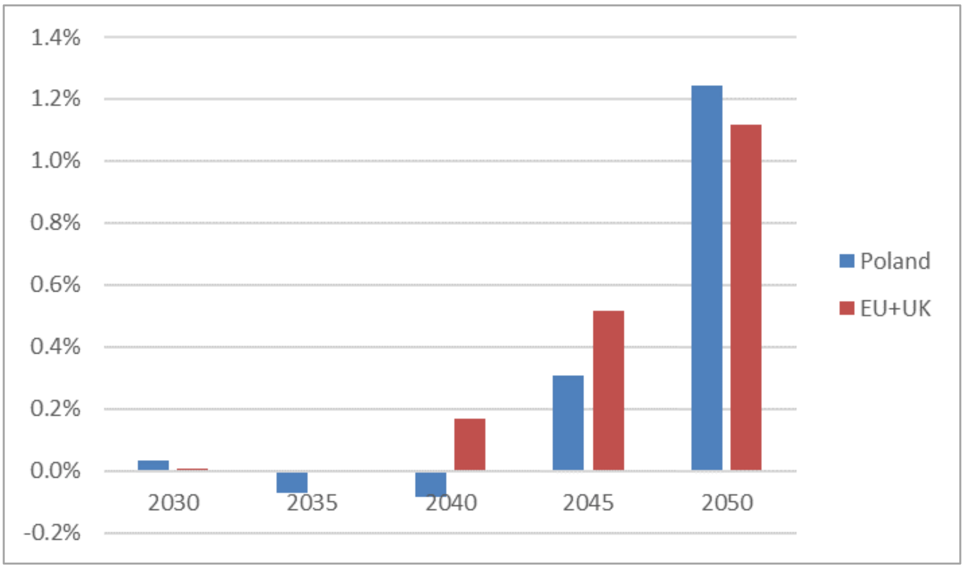
207. The impact of hydrogen subsidies on the structure of the passenger car fleet and on their emissions is close to zero. The changes in the number of EV vehicles and emissions with respect to the Fit55 scenario is less than 0.1%, even for the year 2050. This result is driven by the fact that the reduced cost of hydrogen for end users does not make the total cost of ownership low enough that it becomes a viable alternative to EV vehicles.

Figure 37. Change in structure [in p.p.] of heavy duty vehicle fleet in Poland (left panel) and EU+UK area (right panel) in Fit55_H2 scenario relative to Fit55 scenario



Source: CAKE/KOBiZE

Figure 38. Relative decrease in emissions from heavy duty vehicles in Fit55_H2 scenario relative to Fit55 scenario in Poland and EU+UK



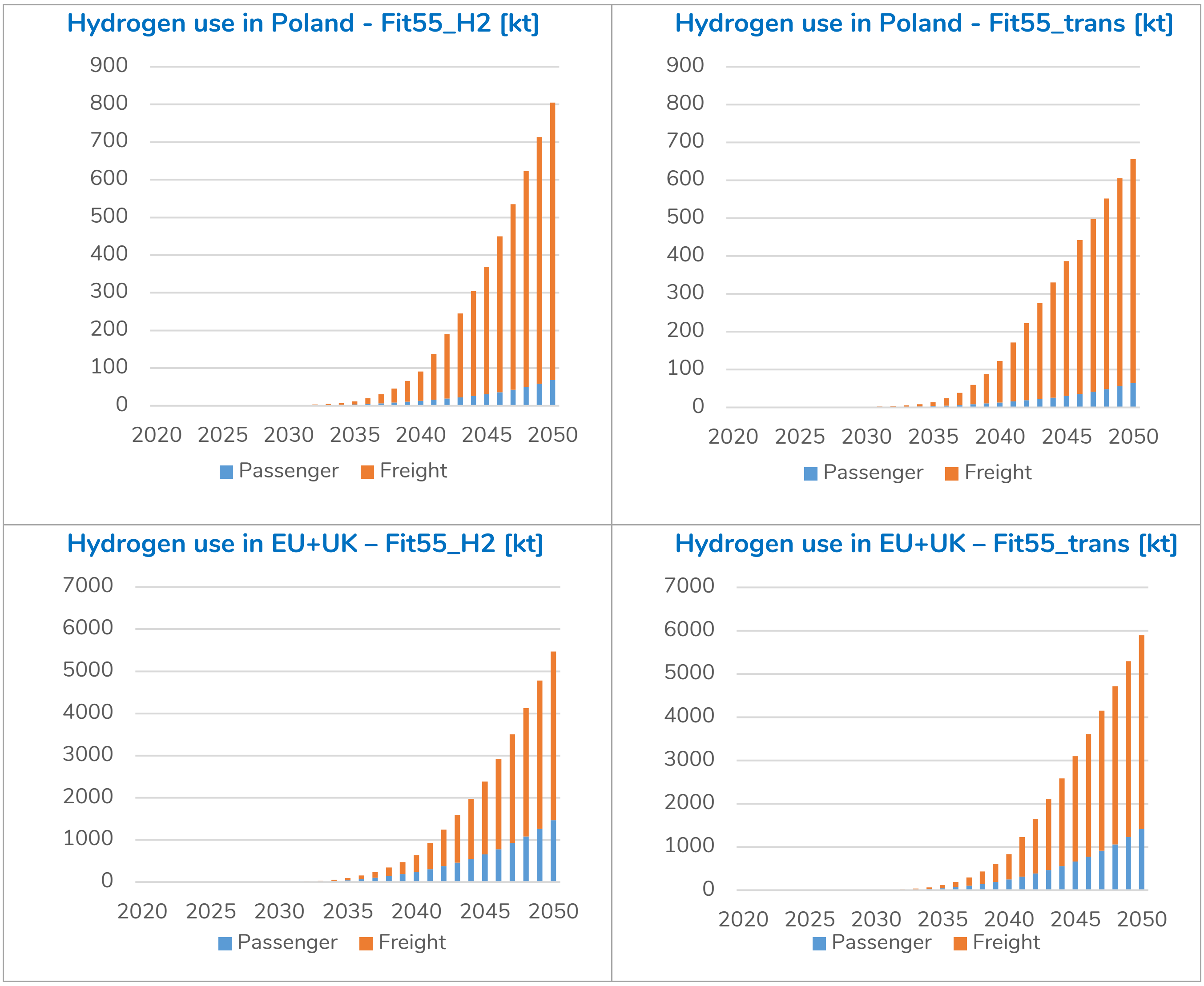
Source: CAKE/KOBiZE

208. The impact of hydrogen subsidies on its consumption and the comparison with the hydrogen consumption in the Fit55_trans scenario are shown on Figure 39. Hydrogen consumption in Poland and EU+UK for passenger and freight transport has been

compared. Hydrogen consumption in Poland will grow exponentially after 2035, reaching 91 kt hydrogen in 2040, less than 370 kt in 2045 and about 800 kt in 2050 (Fit55_H2 scenario). A slightly different path for hydrogen demand is shown in the Fit55_trans scenario - more linear. Hydrogen consumption in this scenario will be slightly higher (5%) in 2045 than in the subsidised hydrogen scenario and 18% lower in 2050. The structure of hydrogen consumption in Poland is only 10% for passenger transport and 90% for freight transport.

209. The situation is different in the EU+UK countries, where hydrogen consumption in passenger transport accounts for about 25-30% of the total consumption and the remaining 70-75% in freight transport. In 2045, the consumption in the Fit55_H2 scenario is about 2400 kt and in the Fit55_trans scenario about 3000 kt. In 2050 the consumption will be about 5500 and 5900 kt respectively.

Figure 39. Hydrogen use in Poland and EU+UK in Fit55_HS and Fit55_trans scenario

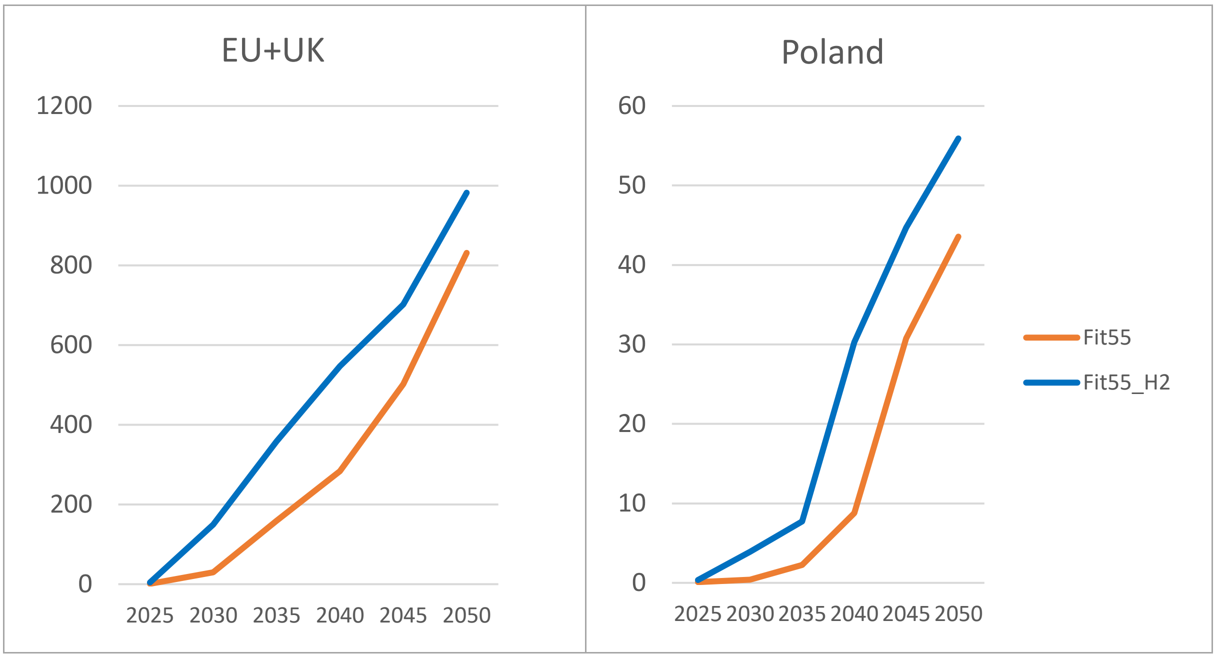


Source: CAKE/KOBiZE

8.3.4 Other sectors

210. Subsidies significantly accelerate the substitution of fossil fuels by hydrogen in industrial sectors. In the energy-intensive industry, which includes chemicals, iron and steel, non-metallic minerals and paper, subsidies lead to hydrogen use of 150 PJ in 2030, compared to only 30 PJ in the nonsubsidised scenario. In 2040 and 2050, hydrogen use in the subsidised scenario Fit55_H2 is 550 PJ and 980 PJ respectively, compared to 280 PJ and 830 PJ in the unsubsidised scenario Fit55.

Figure 40. Use of hydrogen [PJ] in heavy industry (chemicals, iron and steel, non-metallic minerals and paper) in Fit55_H2 and Fit55 scenarios



Source: CAKE/KOBiZE

8.4 Impact of Transport Policies

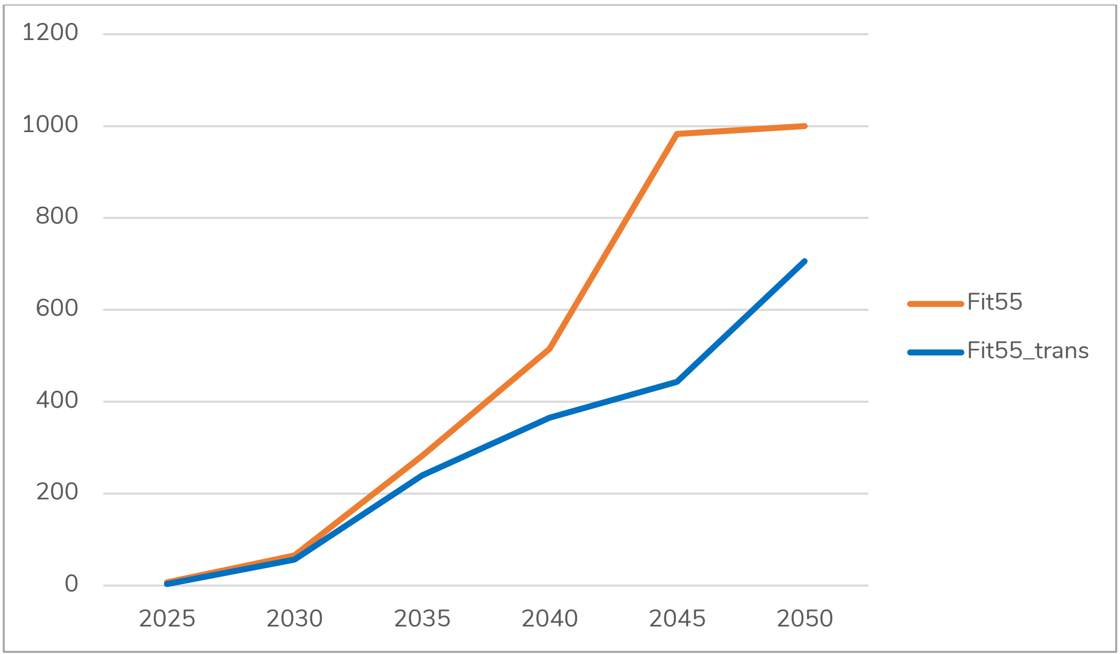
211. This section of the report proceeds to analyse the Fit55_trans scenario, which allows for an examination of the effects of measures in the transport sector, such as the implementation of more stringent emission standards for heavy-duty freight transport vehicles and trailers, as well as an increased scrappage rate for fossil fuel-powered passenger cars. The impact of these policies was assessed not only on transport. Additionally, we delve into the consequences of implementation of these policies measures on macroeconomic variables, energy and agriculture sectors.

8.4.1 Macro Effects and Pricing in the EU ETS System

212. The main effect of the additional measures in the transport sector is a decrease of the emission price in ETS2. In 2030, the price in the Fit55_trans scenario is 60 EUR/tCO_2 compared to 70 EUR/tCO_2 in the Fit55 scenario. In 2040, the price in Fit55_trans is 370 EUR/tCO_2, almost 30% lower than 520 EUR/tCO_2 in Fit55. In 2050 it reaches 710 EUR/tCO_2 in the Fit55_trans scenario and 1000 in the Fit55 scenario. A simple explanation for this effect is that emission standards for heavy duty vehicles as well as higher scrappage rates accelerate the replacement of combustion engine vehicles and thus reduce the demand for emission allowances in the ETS2 market. The impact of emission standards and the scrappage rate on the EU ETS emission price is negligible.

213. Interestingly, measures in the transport sector affect the marginal cost of abatement in non-ETS sectors in some regions. For example, in 2050 in Poland the cost reaches the level of 530 EUR/tCO_2 in the Fit55_trans scenario, while it reaches 1000 EUR/tCO_2 in the Fit55 scenario. In the same year in Central Europe the non-ETS cost is 780 EUR/tCO_2 in Fit55_trans and 1000 in the Fit55 scenario. The effect on the cost of non-ETS emissions can be explained by the endogeneity of the non-ETS emissions target: in all Fit55 scenarios considered, we set an exogenous target for all sectors not covered by the EU ETS. This broad set of sectors includes both non-ETS sectors and ETS2. If the demand for ETS2 falls in a given country, more emission units will be available for the non-ETS sectors. This leads to a reduction in the marginal cost of abatement in these sectors.

Figure 41. Price of carbon [EUR/tCO_2] in ETS2 under the Fit55 scenario (no additional measures in transport) and Fit55_trans scenario (with additional measures in transport)



Source: CAKE/KOBiZE

214. The emission standards and an increase in the scrapping premium have a negligible impact on GDP and lead to a slight increase in investment, while the impact on consumption varies between the short and long term. The impact on GDP is less than 0.1% at EU level and in Poland the impact is small and negative (by 0.3%) in both, 2040 and in 2050. In the years 2040 and 2050, investment in the Fit55_trans scenario is higher than in the Fit55 scenario by 0.3% and 0.1% at EU level due to higher investment needs in the transport sector. In Poland investment is higher in 2040 (by 1.5%) and lower in 2050 (by 1%). The reason is that in the case of Poland, high replacement rate in 2040s reduces purchases of new vehicles in 2050. Consumption in the two scenarios is almost the same in 2040, but in 2050 it is higher in the Fit55_trans scenario by 0.6% at EU level and by 3.9% in Poland.

215. An increase in consumption could be explained by three effects: first, emission standards incentivise early adoption of low-carbon vehicles, which means that in 2050, when the price of emissions in ETS2 rises dramatically, it has less negative impact on household consumption than in the Fit55 scenario, where households that do not receive an incentive in the 2030s and 2040s postpone the transition. This model effect is based on the assumption that, under the Fit55 scenario, households and firms during the 2030s and 2040s do not anticipate or consider the high fuel prices in 2050 when making their vehicle choice decisions. If they were to take these future fuel prices into

account, they would likely opt for zero-emission vehicles regardless of the emission standards. Second, in our simulations, the relatively low emissions in the Fit55_trans scenario are associated with a low use of backstop negative emission technologies, which in our simulations is associated with a decrease in imports, putting downward pressure on exports and therefore upward pressure on consumption. Finally, the change can be explained by terms of trade effects: an increase in the demand for capital leads to an increase in the cost of capital, which results in higher production costs for some traded goods, such as chemicals. This in turn leads to a further fall in exports, allowing consumption to rise.

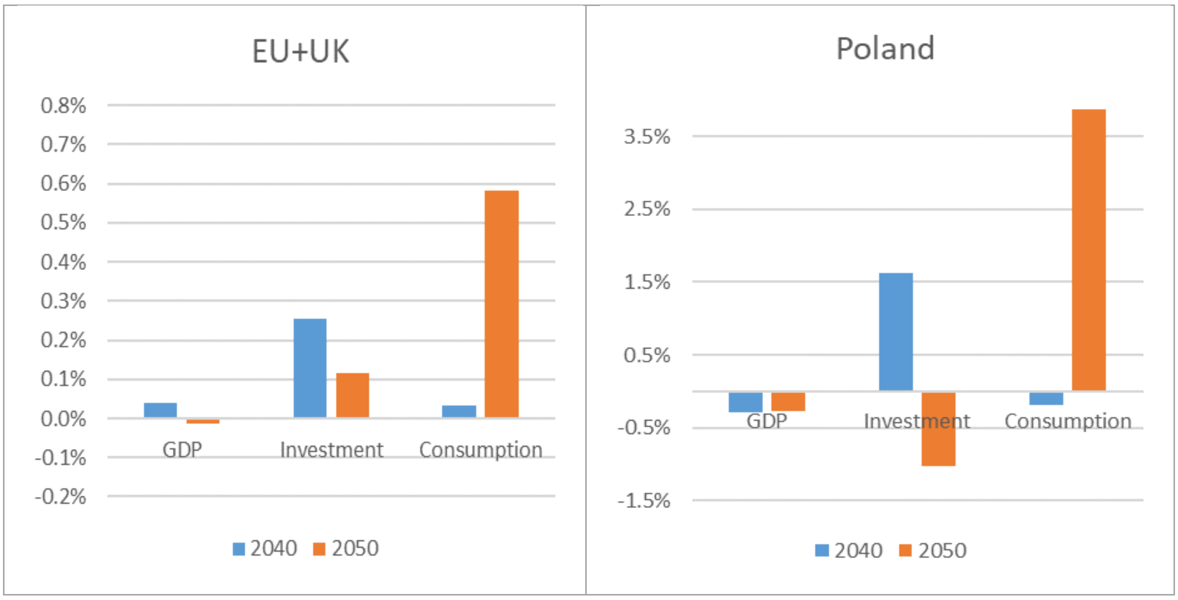
216. Importantly, the positive impact on consumption is overestimated because technically the more stringent emission standards are imposed in the transport model through subsidies to zero-emission HDVs, which are not reflected in the macroeconomic model. Therefore, our macroeconomic model does not take into account that the financing of increased purchases of HDVs can have long-term costs for consumers. The total cost of subsidies is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. A rough correction to the consumption figures could be made by subtracting the cost of subsidies from the value of household consumption in the Fit55_trans scenario. If we do this, the difference between consumption in the Fit55_trans scenario and in the Fit55 scenario in 2050 becomes smaller, although it remains positive (see **Błąd! Nie można odnaleźć źródła odwołania.**).

Table 9. Value of subsidies in Fit55_trans scenario and the difference in consumption between Fit55_trans and Fit55 scenarios [bln EUR]

Category	value of subsidies	difference in consumption	corrected difference in consumption	corrected difference [%]
EU				
2040	8.9	4.1	-4.7	-0.04%
2050	10.9	82.0	71.1	0.51%
Poland				
2040	2.8	-0.9	-3.7	-0.77%
2050	2.5	20.5	18.0	3.40%

Source: CAKE/KOBiZE

Figure 42. Impact on GDP, investment and consumption with respect to Fit55 scenario of the measures in the transport sector (Fit55_trans scenario)



Source: CAKE/KOBiZE

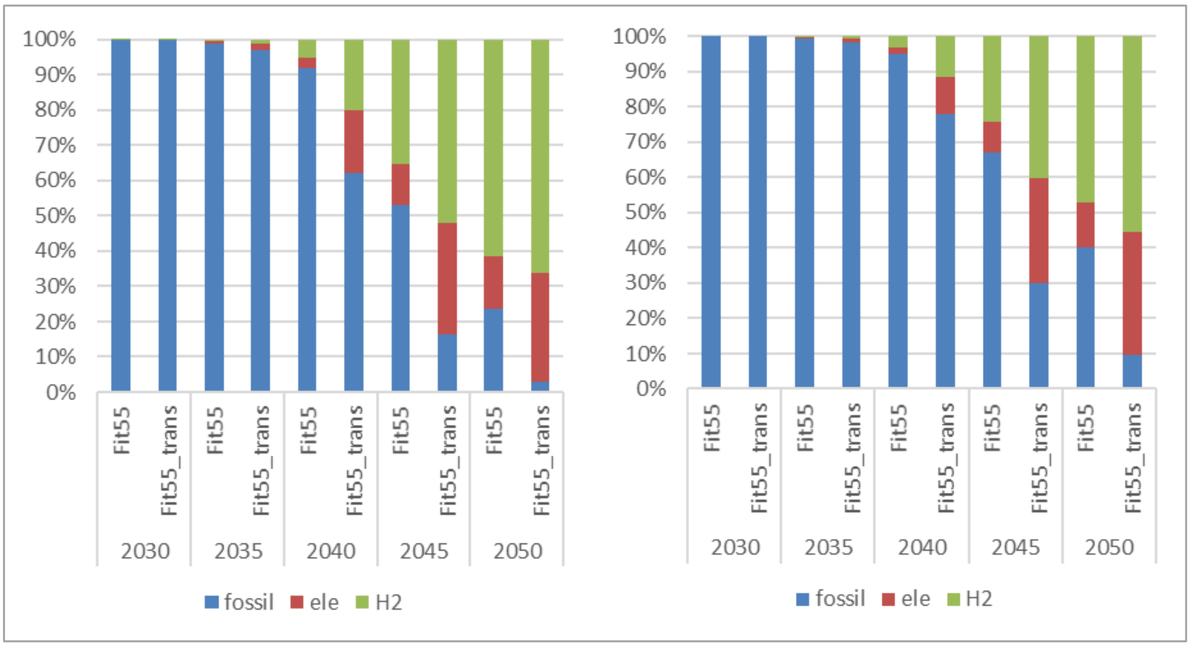
8.4.2 Transport

Impact on freight transport

217. The adoption of increased emission standards for new heavy-duty vehicles has a significant impact on the evolution of freight transport in both Poland and the EU+UK area. Simulation results, shown in Figure 43, indicate that the fleet of HDVs will undergo a much faster transformation when the measure is adopted. In the scenario without it, fleet development is approximately 5 years behind. Under the Fit55 scenario, the transformation of the fleet of HDVs only begins in 2040. However, under the Fit55_trans scenario, in 2040 more than 30% of the fleet in Poland is composed of zero-emission trucks, while the value for the EU+UK area is over 20%. If emission standards are not introduced, a substantial number of trucks powered by fossil fuels can be expected to operate by the year 2050. However, if the transport sector is compelled to primarily acquire zero-emission vehicles, the fleet will mainly comprise of electric and hydrogen-powered trucks by 2050. In Poland, the proportion of diesel trucks is anticipated to be less than 5%, while for the EU+UK, it is expected to be below 10%. The zero-emission fleet will comprise a combination of remaining technologies, with hydrogen being slightly more prevalent. Overall, the price impact caused by ETS2 may not be a strong enough incentive to completely abandon fossil fuel-powered trucks, so policymakers should provide a clear signal in the form of emission standards to facilitate the transformation of heavy-duty transportation.

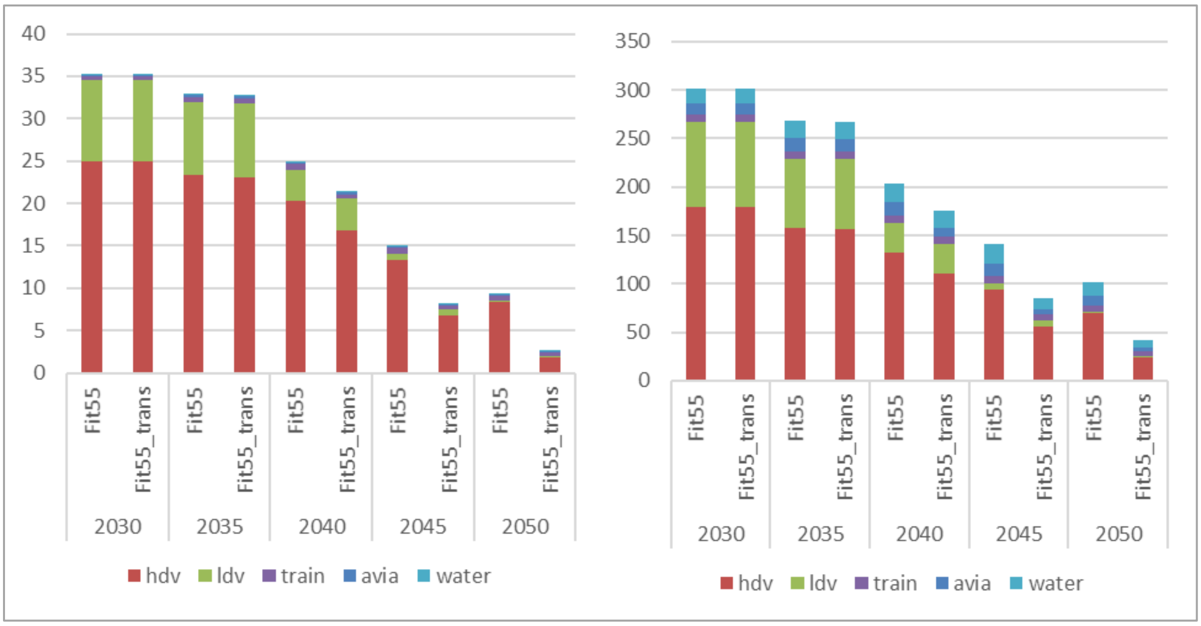
218. The rapid transformation of the heavy-duty vehicle fleet will significantly accelerate the reduction of CO_2 emissions from road freight transport, as demonstrated in Figure 44. Additionally, since the majority of freight transport emissions originate from HDVs, this measure will make a substantial contribution to the overall decarbonisation of freight transport. Under the Fit55_trans scenario, emissions from HDVs in Poland could decrease by more than 10 times between 2030 and 2050, reaching approximately 1.9 Mt CO_2, with total freight emissions amounting to 2.6 Mt CO_2. Without this measure, emissions would decrease by roughly 66%, and the freight transport sector would emit 9.3 Mt CO_2 in 2050. Under the Fit55_trans scenario, total freight transport emissions in the EU+UK also decrease more rapidly. By 2050, emissions are projected to be only 40% of what they would be under the Fit55 scenario. The significant reduction is primarily due to nearly 90% decrease in emissions from HDVs from 2030 to 2050. By mid-century, the entire freight transport sector is expected to emit 41.7 Mt CO_2, with road transport being the largest contributor.

Figure 43. Structure of heavy duty vehicle fleet in Poland (left panel) and EU+UK area (right panel)



Source: CAKE/KOBiZE

Figure 44. Emissions [Mt CO_2] in freight transport in Poland (left panel) and EU+UK area (right panel)



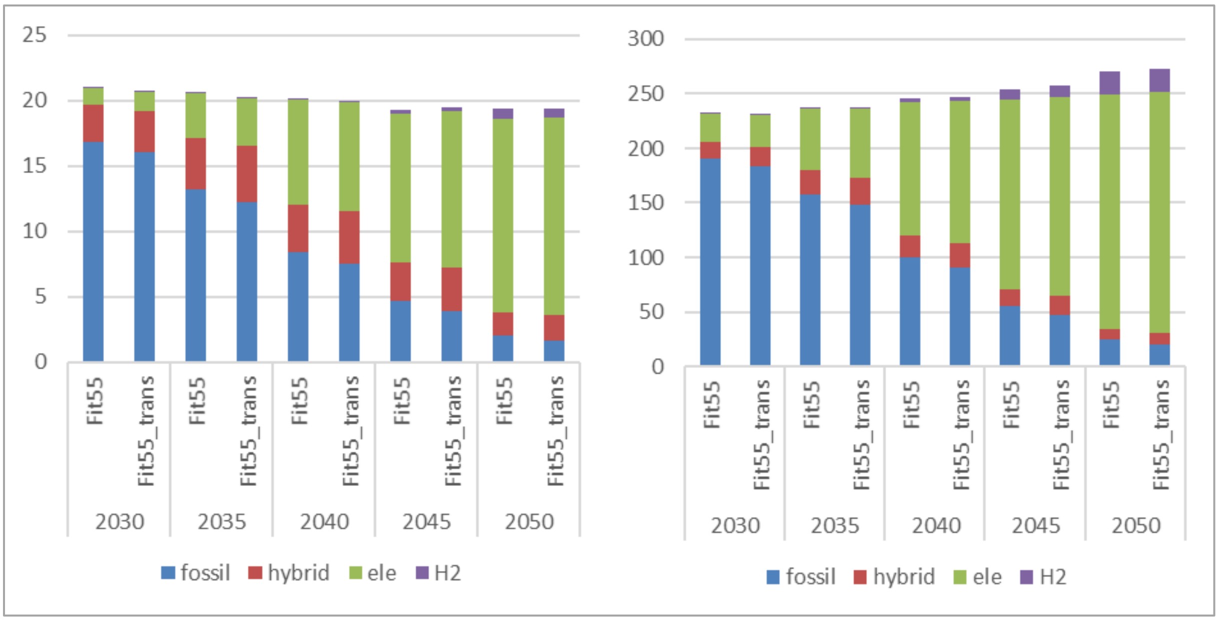
Source: CAKE/KOBiZE

Impact on passenger transport

219. The increase in the scrappage rate of fossil fuel powered vehicles has a relatively small impact on developments in the passenger transport sector. Decarbonisation of this sector is primarily driven by measures introduced as part of the ‘Fit for 55’ package, which are already included in the Fit55 scenario. As illustrated in Figure 45, the fleet of passenger cars in Poland and the EU+UK region is expected to gradually transition to zero-emission vehicles between 2030 and 2050. Consequently, by 2050, over 80% of vehicles are expected to be powered by electricity and hydrogen, even without additional measures. The increased scrappage rate is expected to further reduce the share of fossil fuel-powered passenger cars by approximately 2 percentage points.

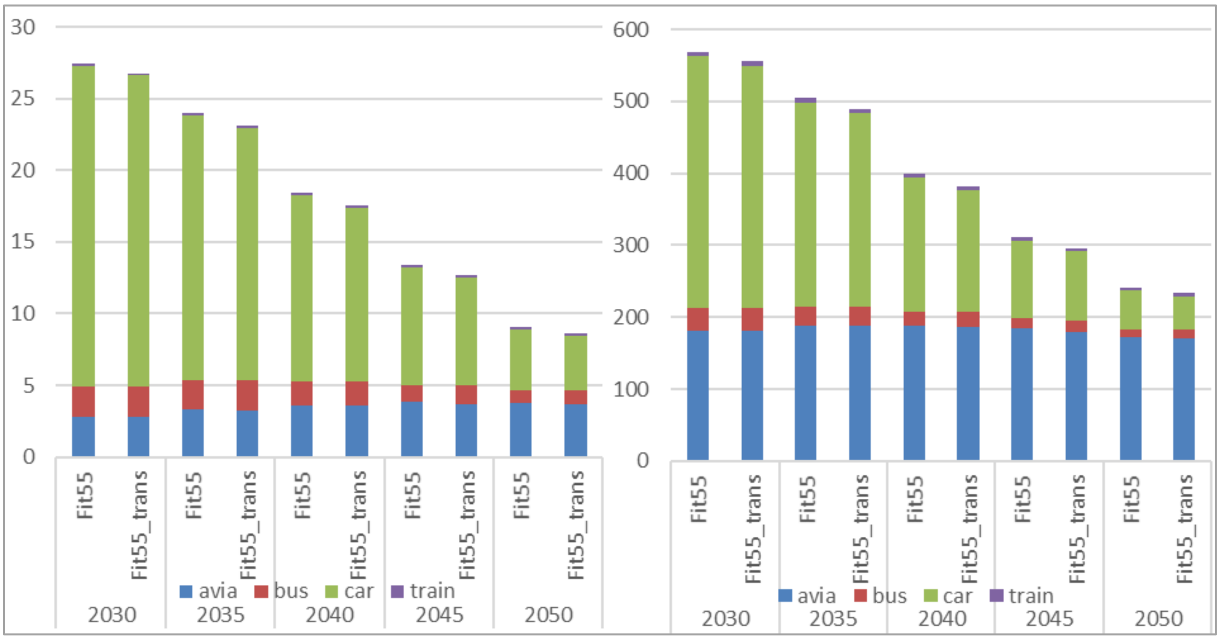
220. As illustrated in Figure 46, increasing the scrappage rate of fossil fuel-powered cars can contribute to a reduction in emissions from passenger cars by 0.5 Mt CO_2 and 6.8 Mt CO_2 in 2050 in Poland and the EU+UK area, respectively. Therefore, it can be argued that this measure should be viewed as an attractive supplement to further promote the decarbonisation process of individual transport. Furthermore, additional measures similar to this one should be proposed and implemented to complement the ‘Fit for 55’ package and remove the remaining internal combustion engine (ICE) cars from our roads.

Figure 45. Structure of passenger car fleet [mln vehicles] in Poland (left panel) and EU+UK area (right panel)



Source: CAKE/KOBiZE

Figure 46. Emissions [Mt CO_2] in passenger transport in Poland (left panel) and EU+UK area (right panel)

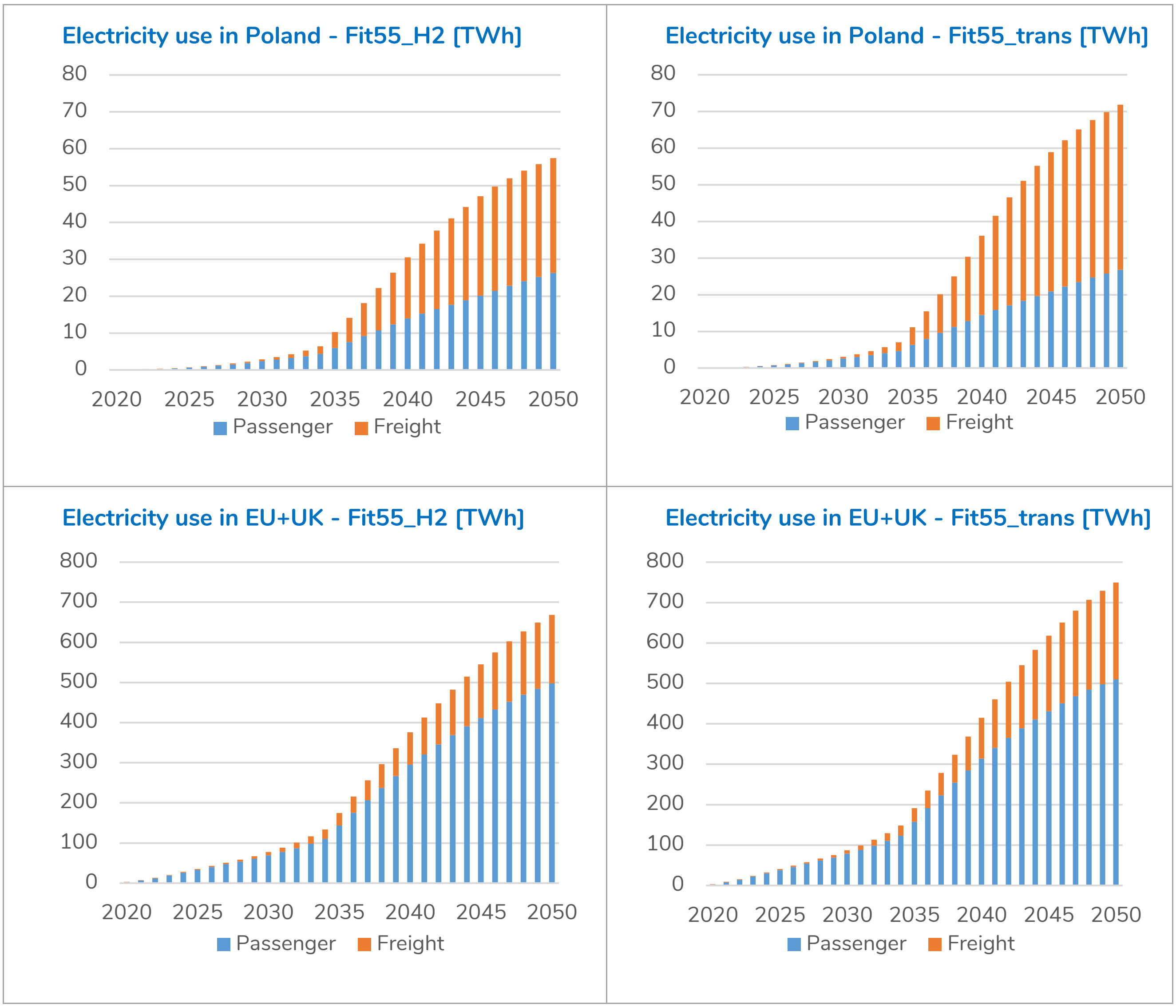


Source: CAKE/KOBiZE

221. In the Fit55_H2 scenario, the demand for electricity in Poland is projected to reach 31 TWh in 2040 and 57 TWh in 2050. Meanwhile, the Fit55_trans scenario predicts a 20% increase in demand due to higher electrification of freight transport. The share of electricity demand in the total demand is expected to be around 55% and 60% in the Fit55_H2 and Fit55_trans scenarios, respectively.

222. In the EU+UK countries, transport is projected to consume 376 TWh in 2040 under the Fit55_H2 scenario and 669 TWh in 2050. The Fit55_trans scenario predicts a demand that is approximately 10% higher. It is important to note that road freight transport accounts for only 20-25% of the total electricity demand in transport, with the remaining 75-80% being consumed by passenger transport (passenger cars and buses).

Figure 47. Electricity use in Poland and EU+UK in Fit55_HS and Fit55_trans scenario



Source: CAKE/KOBiZE

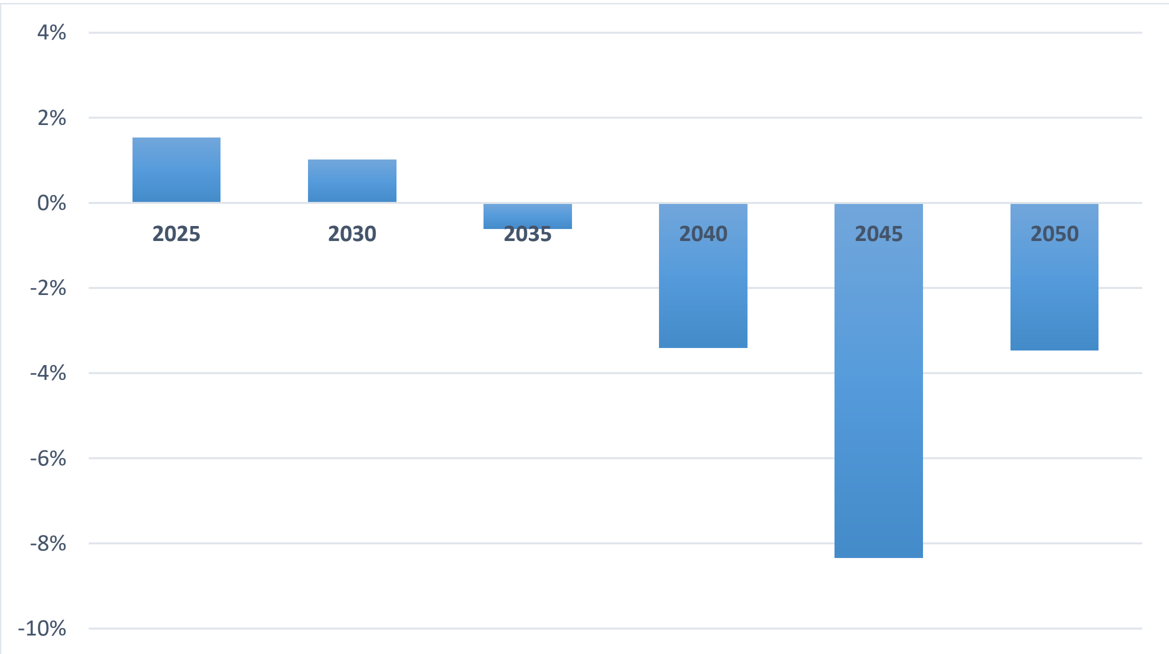
The change in the total costs (cars and buses) of the transport system on the example of Poland

223. The cost of using a vehicle comprises the purchase cost, maintenance expenses (including repairs), and fuel costs. This applies to both consumers (for cars) and enterprises (for buses). Opting for more energy-efficient vehicles, despite their higher purchase cost, can result in lower total operating costs due to reduced fuel consumption. Changing an internal combustion vehicle to an electric or hydrogen one may provide additional benefits if the cost of electricity or hydrogen for power supply is lower than that of petroleum-based fuels.

224. The variation in total cost of ownership (TCO) between passenger transport by car and bus is due to differences in their structure. Consumers tend to opt for technologies with lower TCO, such as those that run on electricity or hydrogen, which also have lower maintenance costs.

225. During the initial period of consumption of the zero-emission fleet between 2025 and 2030, user costs in Fit55_trans are only 2-3% higher than the Fit55 scenario. The benefits of using zero-emission technologies will become apparent after 2035, with the highest profits expected around 2045, reaching up to 8%. By 2045 and 2050, the total cost of ownership for these vehicles in Poland is expected to be lower by 3.5%.

Figure 48. Changes in total cost of ownership (TCO) in passenger transport in Fit55_trans scenario vs. Fit55



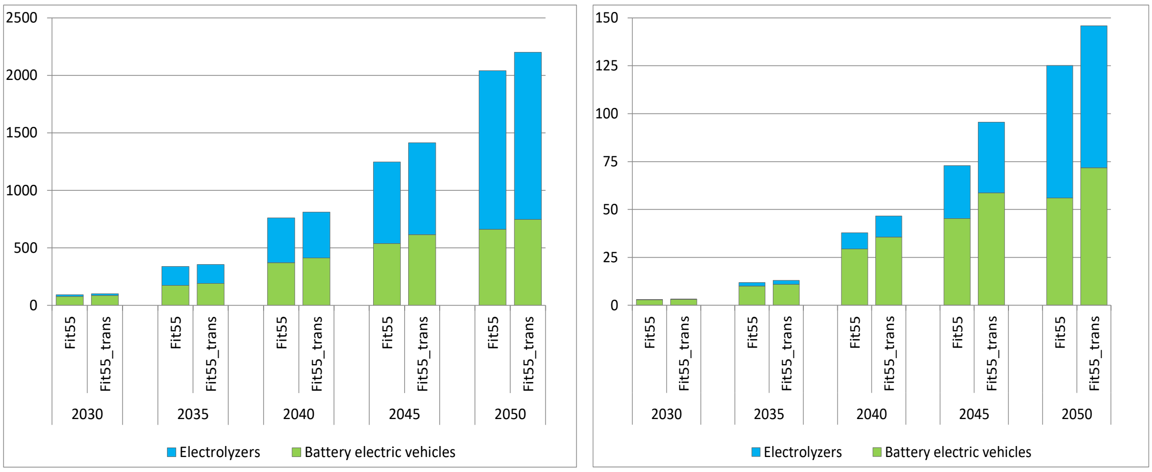
Source: CAKE/KOBiZE

8.4.3 Other sectors

8.4.3.1 Energy

226. The policies introduced in the transport sector have an impact on the electricity sector mainly by generating additional demand for electricity, either directly, by charging electric cars, or indirectly, by increasing the use of hydrogen in heavy-duty vehicles, since green hydrogen is also produced by electricity. In both cases, this not only means an increase in the average annual electricity consumption, but also influences the structure of the daily load curves and the balance of the energy system. Therefore, the impact of implementing additional transport policies on the electricity sector has been assessed mainly in terms of increased electricity consumption for charging electric cars and for hydrogen production. The results are presented below for the scenario with additional policies i.e. Fit55_tran and the Fit55 scenario.

Figure 49. Electricity consumption for BEV and electrolysers in the EU+ (left) and Poland (right) [TWh]



Source: CAKE/KOBiZE

227. For the EU as a whole, the impact of the additional transport policies analysed on the energy sector is relatively small. The electricity demand of BEVs in the Fit55_trans scenario is about 13% higher than in the Fit55 scenario over the whole period analysed. The electricity consumption of electrolyzers in the period 2030-2050 is more than 6% higher in the Fit55_trans scenario than in the Fit55 scenario. Overall, the increase in final electricity demand in the Fit55_trans scenario compared to Fit55 for the EU is only slightly more than 1%.

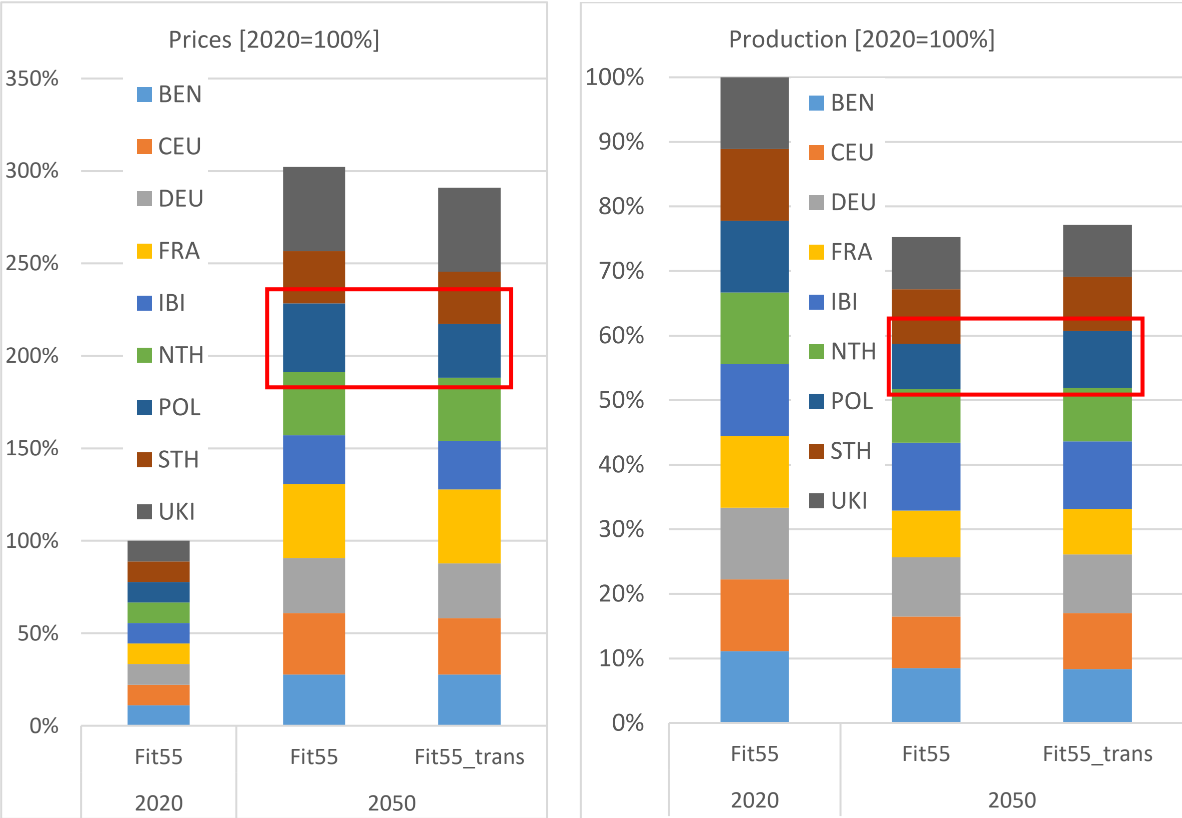
228. In Poland, however, the impact of the analysed transport policies is more evident. The total electricity demand for charging electric cars in the Fit55_trans scenario is about 25% higher in the period 2030-2050 than in the Fit55 scenario. This is a significant change. Also, the total electricity demand for electrolysers in the period 2030-2050 is about 16% higher in the scenario with additional transport policies. Overall, the electricity demand in this period is more than 4% higher than in the Fit55 scenario, which does not look very impressive, but it is already a noticeable change. It affects the structure of the energy supply - we can see, for example, a faster introduction of nuclear units into the system and an increase in electricity imports in 2050.

229. These changes will also affect the electricity consumed by electric car chargers and electrolysers. The magnitude of this impact depends strongly on the electric car charging scheme adopted, but even on the optimistic assumption that there will be an efficient system that optimises the distribution of electric car charging over time - it could be around 4-5 GW of additional electricity demand. Paradoxically, this also slightly delays the introduction of battery storage into the system, as surplus electricity in periods of renewable energy overproduction is used more by electrolysers and electric cars, reducing the need for other forms of energy storage.

8.4.3.2 Agriculture

230. It has been observed that changing assumptions regarding the transport sector's situation affect the agricultural sector in Poland and the Central European countries (CEU). This is evidenced through the higher effort of the transport sector to reduce GHG emissions, which puts lower pressures on the agricultural production. Consequently, this leads to lower price increases in Poland and the Central European countries. A visual representation of this phenomenon is provided by the Figure 50.

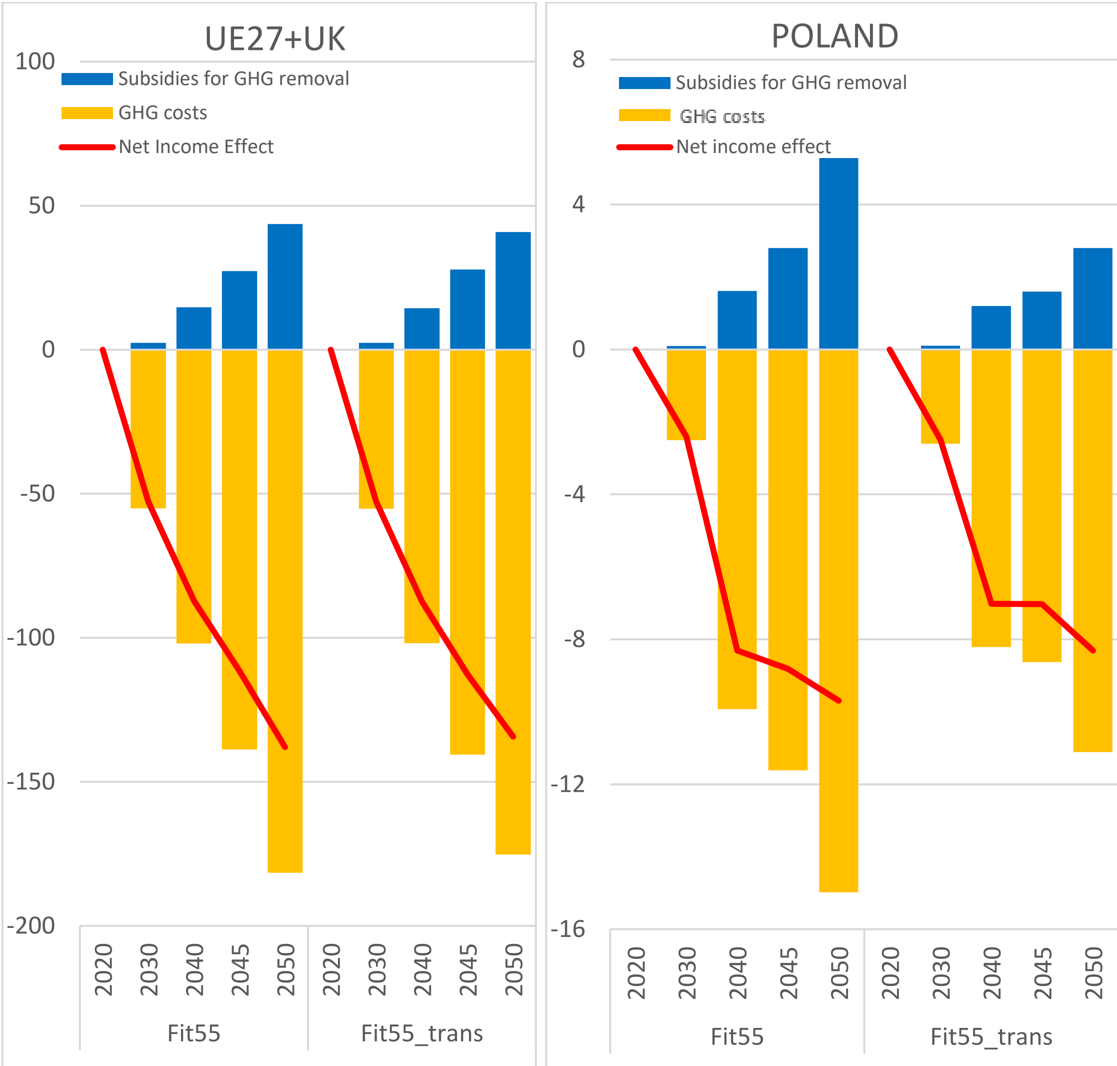
Figure 50. Changes in agricultural production and prices in Fit55_trans scenario in EU regions



Source: CAKE/KOBiZE

231. Significant shifts are evident in Poland as a direct result of implementing the Fit55_trans scenario. The agricultural production reduction is lower by more than 15 percentage points, resulting in a drop to 79% of the 2020 level in Fit55_trans in 2050 year, as opposed to 63.6% in Fit55. Consequently, there is a considerably lower increase in the agricultural products prices, which in 2050 will increase to 262% of the base year level. There is therefore a significant difference from the price increase in the Fit55 scenario of 334% in 2050.

Figure 51. Fiscal effects of Fit55_trans scenario in the agricultural sector in EU and in Poland [bln EUR]



Source: CAKE/KOBiZE

232. The financial results of the sector reflect the changes that have been made. Although the difference in the EU is relatively small (134.4 billion EUR vs. 138 billion EUR), it is already noticeable in Poland. The Figure 51 clearly indicates that due to lower carbon price in non-ETS in Fit55_trans the negative impact of GHG emissions reduction on the agricultural sector's income effect is noticeably lower.

9. European Commission's 2040 Target Proposal for the EU

9.1 Analyzing the EC's ambitious climate targets for 2040

233. The challenge of achieving EU climate neutrality by 2050 is unprecedented and necessitates the development of a complex climate policy framework. As indicated in earlier chapters, the design of this policy framework not only affects the levels of emission reductions achieved but also impacts the health of individual economic sectors and regions. Therefore, the primary objective of this section is to analyse the EC's proposed GHG net emission reduction target of 90% by 2040 compared to 1990 emissions. According to the EC Communication[58], this target is intended to place the EU on a cost-effective and equitable path towards achieving climate neutrality by 2050.

234. The EC considered three main scenarios presented in the Impact Assessment[59] to the Communication with assumed emission reduction targets for 2040 (compared to 1990) as follows Scenario 1 (S1): -78.5%, Scenario 2 (S2): -88% and scenario 3 (S3): -92%. In addition, the EC also presented results for the additional "LIFE" scenario, which aims to show how selected parameters, including reduced consumption and a fully implemented circular economy, would affect emission reductions. The proposed scenarios S1-S3 differ in the level of emissions in 2040, while they essentially aim to reach a similar point by 2050, namely climate neutrality.

235. In the modeling results presented by the EC for each scenario, the key issue is the widespread implementation of technologies that are not yet commercially available, mainly for S2 and S3. This adds to the uncertainty of the modeling results as it assumes that the expected technological developments will actually take place. This mainly concerns the widespread development of the use of synthetic fuels and hydrogen. The optimistic assumptions on the potential for the use of renewable energy sources (RES) are also crucial.

236. The EC's analysis of impacts on macroeconomic indicators such as GDP and output focuses on the overall level, ignoring potential differences between regions/countries. According to the EC, the differences in GDP in 2040 between the scenarios are small - with the highest level of climate ambition (S3), GDP in 2040 is projected to be at best

[58] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, Brussels, 7 February 2024, COM(2024) 63 final.

[59] Commission staff working document Impact Assessment Report accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, EC, SWD(2024) 63 final.

unchanged and at worst 0.8% lower than under S2; with a lower level of ambition by 2040 (S1), GDP is projected to be at best slightly higher (+0.6%) than under S2. However, it is highly likely that the scale of changes is much greater between individual Member States / regions.

237. Therefore, it seemed interesting to compare the modeling results using our modeling toolbox with very ambitious reduction targets for 2040 and 2050, but with the current assumptions in our models, mainly concerning the lack of development of alternative fuels and the assumption that hydrogen fuel will have to compete with gas on the market.

238. Taking into account the absorption level in the LULUCF sector from the Commission's Impact Assessment, i.e. -218 and -316 or -317 Mt CO_2 eq. for scenario S1 and scenario S2 and S3 respectively, the net reduction target for 2040 in our Fit55 scenario would be 79% and 81%. The reduction target we have assumed for 2040 closely aligns with the -78.5% target in scenario S1 of the Impact Assessment. In 2050, the assumed EU absorption level in the LULUCF sector in our Fit55 scenario is about 40% higher (approximately 480 million tonnes CO_2 eq.) compared to 330-340 million tonnes CO_2 eq. in the Impact Assessment. Consequently, our gross emissions target is relatively lower.

239. To assess the macroeconomic consequences of implementing the Commission's proposals, as outlined in the Impact Assessment, we have modified the d-PLACE model. Due to the implementation of more stringent reduction targets, we introduced a mechanism in the model to allows for exceeding emission limits. Specifically, we (i) deactivate backstop technologies which provided unlimited supply of negative emissions at the cost of 1000 EUR/tCO_2 in the basic version of the model and (ii) we assume that sectors are allowed to exceed the targets of emissions if they pay a penalty of 1000 EUR/tCO_2. We assume that the revenue from this penalty is received by the government. This modification enables us to clearly determine the extent to which the emission limit might potentially be exceeded without incurring high capital costs associated with backstop technologies, Previously, backstop technology, which includes various an experimental absorption technologies requiring significant capital investment, was only marginally used in scenarios.

240. The Fit55+ scenario is developed under the assumption that backstop technologies are not available. It includes the same emission reduction pathways as the previous Fit55 scenario for EU ETS, ETS2, and non-ETS. However, it allows for the exceeding of GHG emission limits. Excess emissions occur when the carbon price in a given scheme reaches the level of 1000 EUR'15 per tonne of CO_2 eq. Emitters pay this "penalty" price for excess emission units, but no actual abatement actions are taken.

241. Additional scenarios Fit55_S2+ and Fit55_S3+ have been developed, reflecting the targets included respectively in the S2 and S3 scenarios of Impact Assessment. The scenarios differ from reduction path considered in the Fit55+ in two main ways: (i) they target a faster net reduction in the period 2030 – 2040, achieving net emission reductions of 88% to 92% by 2040 for scenarios for S2 and S3 respectively, and (ii) they aim for a more ambitious gross emission reduction in 2050, aligned with the European Commission's updated assumptions. Although the net reduction by 2050 is nearly identical across all scenarios, they feature varying levels of negative emissions from LULUCF sector. Up to 2030, there is no difference between the Fit55+ and Ft55+_S2 or Fit+_S3 scenarios, they are all based on the 'Fit for 55' package. It is worth noting that while all scenarios ultimately achieve the same reduction target by 2050, the European Commission favored scenario S3 in the Impact Assessment. According to the Commission, this option aligns with the guidelines of the European Scientific Advisory Board on Climate Change (ESABCC)[60].

242. Table 10 shows the different scenarios analyzed, along with the respective emission reduction targets assumed for the EU Member States. The table also provides information on the exceedance of the emission limit value in each scenario.

Table 10. GHG emission reduction targets in Fit55 and Fit55+ scenarios for EU

Scenario	GHG emission reduction target for EU27				LULUCF [mln tCO_2 eq.]	Exceeding the emission limit [mln tCO_2 eq.]
	Total net GHG emission reduction- *including LULUCF* (compared to 1990)	EU ETS (compared to 2005)	non-ETS (compared to 2005)	ETS2 (compared to 2005)		
2040						
Fit55+	83%	82%	66%	68%	-396	1
Fit55_S2+	88%	89%	71%	84%	-316	161
Fit55_S3+	92%	91%	77%	87%	-317	302
2050						
Fit55+	100%	95%	85%	87%	-481	112
Fit55_S2+	101%	96%	87%	98%	-332	363
Fit55_S3+	101%	96%	87%	98%	-333	360

Source: CAKE/KOBiZE

[60] Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050, European Scientific Advisory Board on Climate Change,16 June 2023, DOI: 10.2800/609405. ISBN: 978-92-9480-584-3.

9.2 Macroeconomic results

243. In our modeling framework, we excluded technologies at the experimental stage with highly uncertain future commercial costs (such as e-fuels and DACCS) and considered constraints on the speed of deployment of the remaining technologies. This resulted in limited availability of low-cost abatement options in 2040. In this situation, deep reductions in that year require the deployment of high-cost options, which in turn require a high carbon price. Indeed, our simulations suggest that tight emission targets in the EU ETS in 2040 in Fit55_S2+ and Fit55_S3+ scenarios are associated with a sharp increase of carbon price to the level of 590 EUR/tCO_2 in Fit55_S2+ and 740 EUR/tCO_2 in Fit55_S3+. Interestingly, the carbon price in the EU ETS returns to around 380 EUR/tCO2 in all scenarios in 2050 due to the increasing availability of low-cost options.

244. Compared to the Fit55+ scenario, the scenarios with accelerated decarbonisation (Fit55_S2+ and Fit55_S3+) result in moderate GDP losses at the EU level. However, the impact varies significantly across regions, with some experiencing substantially larger losses than others. Note that the losses occur even if the reduction targets are not met.

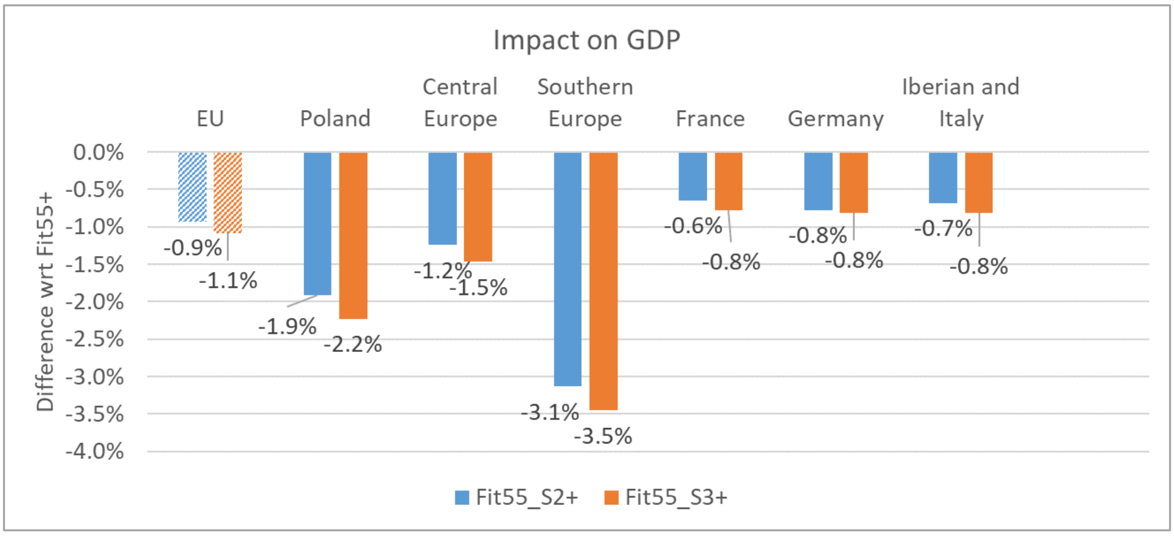
245. In the Fit55_S2+ scenario, GDP in 2040 at the EU level is 0.9% lower than under the Fit55 overshoot scenario. Similarly, in Germany, France, Italy, and the Iberian Peninsula, the difference in GDP is lower than 1%. Meanwhile, in Central and Eastern EU countries, the GDP loss is 1.9% in Poland, 1.2% in Central Europe, and 3.1% in Southern Europe.

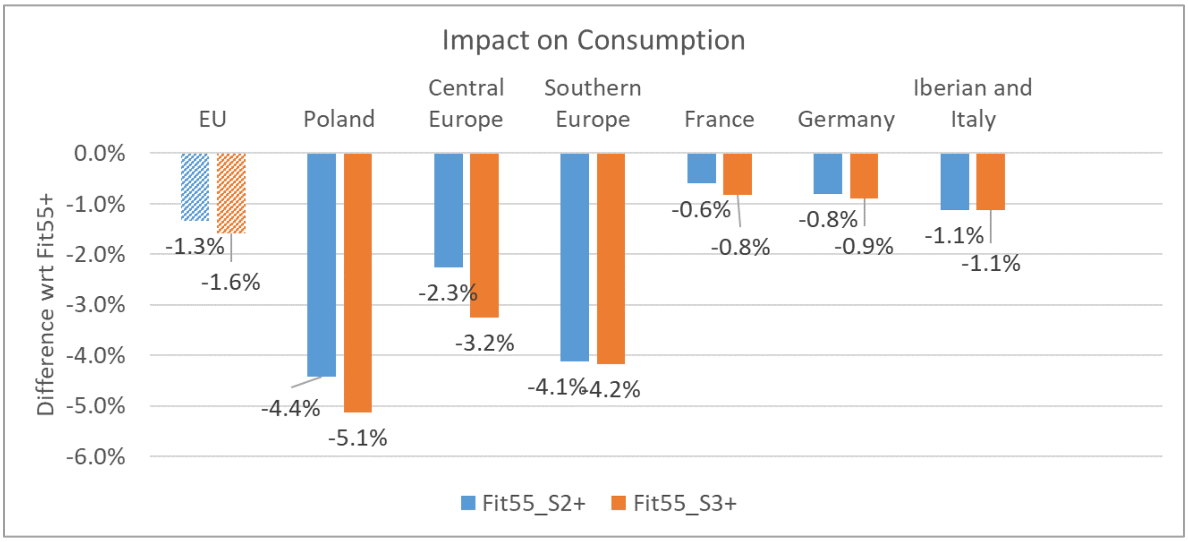
246. In the case of Fit55_S3+, the differences across regions are even sharper. At the EU level, the loss in GDP in 2030 comparing to Fit55+ is 1.1%, and in Western European countries, it is 0.8%. However, in Poland, the loss is 2.2%, in Central Europe, it is 1.5%, and in Southern Europe, it is 3.5%.

247. The estimated loss in terms of consumption is significantly greater than the loss in terms of GDP, especially for new member states. Fast adoption of low-carbon technologies require a substantial increase in investment, leaving fewer resources for consumption. In the Fit55_S2+ scenario, the consumption loss in 2040 amounts to 4.4% in Poland, 4.1% in Southern Europe, 2.3% in Central Europe, and 1.3% at the EU level. The implementation of the most ambitious scenario (Fit55_S3+) leads to a 1.6% reduction in consumption in the EU compared to the Fit55+ scenario and 5.1% reduction in Poland.

248. The economic costs of Fit55+ are high due to the inertia of structural and technological change. Our model considers that low-carbon technology deployment takes time. For each key technology, such as PV, wind and nuclear, annual capacity growth is limited.

Figure 52. GDP and consumption loss in 2040 under scenarios Fit55+, Fit55_S2+ and Fit55_S3+ for selected EU regions





Source: CAKE/KOBiZE

249. In Poland, Southern Europe, and Central Europe, the costs of transitions are higher than elsewhere primarily due to the relatively high emission-intensity of the land transport sector. By 2040, this sector becomes the largest source of emissions in those countries. In Poland, the emission intensity is 0.37 tCO_2/EUR compared to 0.12 tCO_2/EUR at the EU level. In Southern Europe, the emission intensity reaches a value of 0.52 tCO_2/EUR, and in Central Europe, it is 0.21 tCO_2/EUR.

250. In Southern Europe, the slow transformation of maritime transport is a major contributor to the high costs of accelerated transformation. Firstly, it is highly emission-intensive, with Southern Europe emitting 2.63 tCO_2/EUR in 2040 compared to the EU's 1.63 tCO_2/EUR. Secondly, it constitutes a slightly larger portion of Southern Europe's GDP (1.4%) compared to the EU level (1.2%). Maritime transport is the second biggest source of emissions in the region after land transport.

251. The economic costs of the accelerated reduction proposed by the European Commission are an order of magnitude higher than the costs of the most ambitious least-cost path considered by the IPCC. According to the macroeconomic analysis of the total costs of the transition presented in the Sixth Assessment Report (Working Group 3), the difference in consumption growth between the most ambitious scenario (C1) and the BAU scenario is 0.04 p.p. Acceleration of decarbonisation in Poland brings reduction in the consumption growth rate in 2030s by 0.4 p.p. (1.8% annual growth in Fit55_S2+ scenario vs 2.2% in Fit55+), according to our analysis. At the EU level, consumption growth slows down by 0.2 p.p.

9.3 Impact Assessment of the Commission 2040 target proposal

252. The Commission's proposed Impact Assessment[61] fails to consider potential negative effects related to the risk of delay in the development of new technologies and access to alternative fuels, such as e-fuels and hydrogen. Therefore, the potential effects of increasing climate ambitions on the competitiveness of the EU economy and the size of exports may be overstated if there are delays in accessing alternative or zero-emission fuels and technologies. Therefore, rather than a minor effect of climate policy on trade (or even an improvement in the EU's competitiveness in global markets), there is a risk of industrial production and investment relocating outside the EU, resulting in what is known as carbon leakage.

253. Additionally, high costs of energy from fossil fuels (resulting from increased carbon price) can lead to a significant reduction in the standard of living among low-income households (energy poverty). Additionally, some coal-dependent Member States, such as Poland, may need to reduce social transfers due to the high costs of investing in energy transformation. The decrease in disposable income and increase in emission costs could lead to significant social dissatisfaction among those with the lowest incomes. Rapid structural changes may cause the devaluation of equipment and assets in various industries, particularly in the extraction and processing of fossil fuels. It is important to note that these changes may have a significant impact on society. Ambitious goals may also require consumers to replace durable goods more quickly and prioritize home renovations. Workers who possess sector-specific human capital, such as experience, education, and training, may face difficulty utilizing their skills and may

[61] Commission staff working document Impact Assessment Report accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, EC, SWD(2024) 63 final.

experience wage cuts. To address these issues, active labour market policies are necessary, which may require increased public spending. However, this may be limited due to investment and military needs.

254. The authors of the Impact Assessment, in explaining the results, argue that early investments in low-emission technologies build a "competitive advantage" over the rest of the world, allowing for increased production. With such an assumption, the results are rather optimistic. Without this effect, GDP in scenario S3 would probably be significantly lower than in scenarios S2 and S1. At the same time, this assumption has a very weak theoretical and empirical basis. The "building a competitive advantage" argument overlooks the fact that the rest of the world can copy and improve on technological innovations introduced in the EU, which can quickly erode the competitive advantage of European companies. In the past, investments in low-emission technologies have not allowed for the creation of a competitive advantage, for example in the market for photovoltaic panels.

255. Although small changes in employment are suggested, the lack of consideration of the need for capital and labour reallocation among member states may lead to underestimation of unemployment growth in some regions of the EU and social consequences of transformation.

256. Finally, the different scenarios S1, S2 and S3/LIFE assume a diverse range of sectors covered by a common emissions price (this is evident from the analysis of Table 4. Ad02). This variation in the way the scenarios are formulated makes it difficult to accurately assess the projected abatement costs with different reduction targets. In particular, the marginal abatement costs in the EU ETS cannot be determined given the current sectoral scope. Furthermore, in the S3 and LIFE scenarios all sectors are subject to the same emissions price, which would indicate the creation of a single common trading scheme for all economic sectors in the EU in these scenarios. This represents a very significant departure from the current climate policy architecture, where sectors and emission reduction targets are split between the EU ETS and non-ETS (including ETS2). Consequently, it is not possible to compare marginal emission costs solely as a result of implementing different emission reduction pathways in the S1, S2 and S3/LIFE scenarios, which limits the usefulness of the impact assessment.

10. Conclusions

257. As the European Union navigates the complex terrain of climate policy, encapsulated within the ambitious framework of the European Green Deal and the far-reaching targets of achieving climate neutrality by 2050, it confronts multifaceted challenges. Against the backdrop of soaring energy transformation costs and a volatile economic landscape characterized by an energy crisis, high inflation, and geopolitical tensions, the imperative to recalibrate climate policies becomes even more pressing. Among other things, this analysis highlights the key findings and implications of the use of removal units and key sectoral policies for the EU ETS, highlighting the need for nuanced approaches to mitigate negative impacts while advancing sustainability objectives.

Policy scenarios

258. In our scenarios, assuming the cost-efficient path towards climate neutrality in 2050, the EU achieves a 75% reduction in 2040 vs. 1990 levels. However, combined with the LULUCF, the net reduction reaches 83%. This figure differs from the EC's preferred reduction target of 90% for Europe's 2040 climate goal.

259. The details regarding our emission path for 2040 include an 82% reduction for the EU ETS sector and a 66% reduction for the non-ETS sector compared to 2005 emissions levels. For ETS2 covers building and transport, the 2040's target is 68% vs. 2005.

Introducing removals and the new ETS for non EU ETS & ETS2 sectors

260. Carbon removal technologies play a key role in the decarbonisation of the EU economy. Without these technologies, it will be very difficult to achieve climate neutrality, as in some sectors it is not technically feasible to reduce GHG emissions completely. The development of BECCS absorption technologies and afforestation of agricultural land requires the implementation of supporting incentives, such as pricing of negative emissions generated by these technologies.

261. Supporting removals on a large scale presents a favourable trajectory across various dimensions. It results in a significant drop in carbon prices in all EU sectors (the higher the removals support, the lower the carbon prices), enhancing the values of economic indicators such as GDP and consumption, particularly by 2040 and 2050. In contrast, the complete abandonment of pricing removals contributes to the opposite effect: a decline in GDP and consumption. However, what remains to be considered is the impact of the growing share of removals in pricing schemes on the weakening of the incentives for emission reduction.

262. Notably, pricing negative emissions from BECCS and afforestation contributes significantly to consumption gains, with BECCS exerting a more pronounced impact. Pricing afforestation is more important in Poland than for other countries.

263. The introduction of the new ETS system for sectors not covered by EU ETS and ETS2 to reach the equal price for supporting agricultural removals has a negligible effect compared to the current policy architecture with non-ETS national targets. However, the emission reduction by carbon price in agriculture leads to reduced production and a sharp increase in the prices of agricultural products.

Subsidising Hydrogen and Transport Policies

264. Subsidies for green hydrogen production result in lower prices in the EU ETS, albeit with attendant declines in GDP and consumption, albeit relatively modestly.

265. The pace of development of green hydrogen production, especially in the 2030-2035 period, is strongly dependent on subsidies.

266. Demand for hydrogen is mainly in the transport and industrial sectors, but additional hydrogen consumption will occur in the energy sector, where hydrogen will be used as a long-term energy storage and back-up technology to replace natural gas. This additional demand could reach about 30-35% of total hydrogen production in 2050. Demand for charging electric cars increases by around 25% and total electricity consumption in electrolysers increases by around 16% due to additional transport measures.

267. In the transport sector, supplementary measures such as subsidies and emission standards for heavy-duty vehicles demonstrate tangible impacts on emission reduction, albeit with variations in their efficacy across passenger and freight segments, as well as on changing the vehicle mix, particularly as regards heavy goods vehicles (electric and hydrogen cars predominate).

268. Increasing emission standards for heavy-duty vehicles significantly impacts freight transport in Poland and the EU27, accelerating fleet transformation by 5-7 years compared to no standards. Without emission standards, over half the fleet still runs on fossil fuels by 2050. But if the sector adopts mostly zero-emission vehicles, by 2050, the fleet will mainly be electric and hydrogen-powered trucks.

Agricultural Sector Dynamics

269. Attempting to enforce GHG emission reductions in line with principle the polluter pays in agriculture presents formidable challenges, with potential negative income effect in farming sector in EU reaching staggering proportions (3-times exceeding current financial support from EU budget).

270. However, the judicious use of GHG removal subsidies offers a pathway to partly alleviate the financial burdens on the agricultural sector, albeit contingent upon the level of support provided.

271. Climate policy assumptions geared towards carbon neutrality in agriculture precipitate significant market disruptions, with production declines and spikes in price, particularly in Poland.

11. Policy recommendation

272. **Revised Targets:** Considering the discrepancy between the CAKE reduction path projection and the European Commission's (EC) proposed targets, a thorough reassessment of reduction objectives for 2040 is recommended. This involves aligning targets more closely with potential future achievements and ensuring realistic yet ambitious milestones in the pursuit of climate neutrality by 2050. The 2040 target proposed by the EC will require significant energy efficiency improvement and implementation of new technologies, including those currently in the pre-commercial stage (such as e-fuels and DACCS). These technologies have uncertain future commercialisation costs, and their implementation may be delayed. If we adopt the milestones proposed by the EC without vast implementation of these technologies, there's a risk of exceeding emission limits. In this context, to ensure economically acceptable realisation of climate policy, the following actions may include:

- Integration of international emission offsets as per Article 6 of the Paris Agreement to enhance flexibility.
- Increasing the role of carbon removals (BECCS technologies, afforestation of arable lands, and increasing carbon sequestration in the LULUCF sector),
- Linking the EU ETS and ETS2 with other trading systems in other regions outside the EU to enhance market liquidity and cost-effectiveness, ensuring that stringent emissions caps do not lead to economic dislocation.

273. **Enhanced Support for Carbon Removal Technologies:** Recognising the key role of carbon removal technologies, particularly in sectors facing technical challenges, a strategic integration plan should be developed to strengthen incentives for these

technologies. Priority should be given to the pricing of removals, with particular attention to BECCS and afforestation, taking into account country-specific considerations such as the increased importance of afforestation in Poland. Higher pricing for negative emissions and enhanced financial and regulatory support for the deployment of these technologies across the EU, will help lower carbon prices and boost economic indicators such as GDP and consumption.

274. **Implementation of ETS for Other Sectors:** The introduction of the new ETS system for sectors not covered by existing emission schemes (EU ETS, ETS2) in the EU, should be optimized for maximum effectiveness. While recognizing its negligible macroeconomic consequences, careful consideration of both sector-specific and country-specific implications is essential, both at the EU level and, importantly, in Poland.

275. **Establishment of a European Carbon Central Bank (ECCB):** While the removal units ETS trading as well as the agri sector and ETS2 could be integrated with the existing EU ETS, measures addressing potential risks related to market liquidity, stability and coherence seem to be necessary. Establishment of a European Carbon Central Bank (ECCB) that would serve as a regulatory authority, managing the supply and demand for EU allowances and CO_2 removal units, is recommended.

276. **Support for Green Hydrogen Production:** Recognising the dependence of green hydrogen production on subsidies, a sustained and strategic approach is needed to support its development, particularly in the critical period 2030-2035. This includes careful assessment of the impact on GDP and consumption.

277. **Balanced Subsidies and Emission Standards in Transport:** Subsidies and emission standards in the transport sector should be carefully balanced to ensure effective emission reductions. While acknowledging the tangible impacts on emissions, variations in efficacy across passenger and freight segments should be considered, ensuring a comprehensive approach to sustainable transport policies.

278. **Careful Design of GHG Removal Subsidies in Agriculture:** The formidable challenges posed by economic mechanisms for GHG reduction in agriculture necessitate a judicious application of GHG removal subsidies. Financial burdens on the agricultural sector can be alleviated with carefully designed support mechanisms, contingent on appropriate funding levels.

279. **Market Stabilization Measures for Agriculture:** Climate policy assumptions aiming for carbon neutrality in agriculture should be accompanied by measures to stabilize markets, especially in regions like Poland. Balancing production declines and price spikes is crucial, and proactive policies can help mitigate the impact on farmers. However creating an ETS solely for agriculture would be immensely challenging.

It's important to note that while industries covered by the current ETS systems can potentially cut emissions to near-zero, the unique nature of agriculture doesn't offer the same possibility. It wouldn't be feasible to directly impose a carbon price on farms. One alternative could be to pass the cost to food on consumers, though this approach would likely face resistance.

280. **Comprehensive Dialogue and Stakeholder Engagement:** Essentially, as the EU strives for climate neutrality, it faces a delicate balance between environmental sustainability and economic viability. Strategic interventions, encompassing pricing mechanisms, targeted subsidies, and calibrated policy frameworks, are imperative to navigate these challenges effectively. Moreover, fostering robust dialogue and stakeholder engagement, particularly in sectors like agriculture, is indispensable to ensure the equitable distribution of costs and benefits, fostering a transition that is not only environmentally sound but also socially and economically just.

References

1. 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.

2. 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. USA 2019. https://www.jgea.org/ojs/index.php/jgea/article/view/77.

3. Beerling, David (2020-07-08). "Potential for large-scale CO2 removal via enhanced rock weathering with croplands". Nature. 583 (7815): 242–248. Bibcode:2020Natur.583..242B. doi:10.1038/s41586-020-2448-9. hdl:10871/122894. PMID 32641817. S2CID 220417075. Archived from the original on 2020-07-16. Retrieved 2021-02-09.

4. Biochar Market Size, Share & COVID-19 Impact Analysis, By Technology (Pyrolysis and Gasification), By Application (Farming, Livestock, Power Generation, and Others) and Regional Forecasts, 2023-2030 https://www.fortunebusinessinsights.com/industry-reports/biochar-market-100750 .

5. Boratyński J., Pyrka M., Tobiasz I., Witajewski-Baltvilks J., Jeszke R., Gąska J., Rabiega W. (2022). The CGE model d-PLACE. Technical documentation for the model version 2.0. Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_d-PLACE_v.2_d-place-model_documentation.pdf.

6. Boratyński, J., Witajewski-Baltvilks, J., Tatarewicz, I., Pyrka, M., 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 2021. https://climatecake.ios.edu.pl/wp-content/uploads/2021/12/CAKE_Models_Linking_21.12.2021_final.pdf.

7. CFR Common Reporting Format, used by Annex I Parties to report quantitative GHG inventory data – for details see: "Use of the 2006 IPCC guidelines for national greenhouse gas inventories and revision of the UNFCCC reporting guidelines for Annex I Parties to the Convention"; https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements/use-of-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-and-revision-of-the-unfccc .

8. Climate Action Progress Report 2023, European Commission, https://climate.ec.europa.eu/document/download/60a04592-cf1f-4e31-865b-2b5b51b9d09f_en

9. Commission staff working document Impact Assessment Report accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Securing our future: Europe's 2040 climate target and path to climate neutrality by 2050

building a sustainable, just and prosperous society, EC, SWD(2024) 63 final, Strasbourg 2024.

10. Commission Staff Working Document, Implementing the REPowerEU Action Plan: Investment needs, Hydrogen Accelerator and Achieving the Bio-methane targets - SWD(2022) 230 final, Brussels 2022.
11. Communication from the Commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions – Sustainable and Smart Mobility Strategy – putting European transport on track for the future COM/2020/789 final, Brussels 2020.
12. Communication from the Commission to the European parliament, the council, the European economic and social committee and the committee of the regions – Hydrogen strategy for a climate-neutral Europe; COM/2020/301 final, Brussels 2020.
13. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society, Brussels, 7 February 2024, COM(2024) 63 final.
14. Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.
15. Directive (EU) 2023/959 of the European Parliament and of the Council of 10 May 2023 amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union and Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading system.
16. Ehrenfeld, J. G., Kaldor, E. & Parmelee, R. W. Vertical distribution of roots along a soil toposequence in the New Jersey pinelands. Canadian Journal of Forest Research 22, 1929-1936 (1992). Canada 1992.
17. Eshel G, Shepon A, Makov T, Milo R. Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States. Proceedings of the National Academy of Sciences 2014;111:11996-2001.
18. 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 2020.
19. Food and Agriculture Organization of the United Nations (FAO). 2015. Global Forest Resources Assessment (FRA) 2015. How are the World's Forests Changing? Rome: FAO.https://www.fao.org/3/i4793e/i4793e.pdf
20. Frolking S., Talbot J., Jones M.C., Treat C.C., Kauffman J.B., Tuittila E.S., Roulet N. (2011). Peatlands in the Earth's 21st century climate system. Env Rev 19:371–396. https://doi.org/10.1139/a11-014.

21. Fuss S, Lamb WF, Callaghan MW, Hilaire J, Creutzig F, et al. 2018. Negative emissions—Part 2: Costs, potentials and side effects. Environ. Res. Lett. 13:063002.
22. 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. 5850-587.
23. https://climate.ec.europa.eu/document/download/dc751b7f-6bff-47eb-9535-32181f35607a_en?filename=com_2018_733_analysis_in_support_en.pdf
24. https://t2fl.gov.uk/modes/driving/ultra-low-emission-zone/scrappage-schemes
25. https://www.iea.org
26. International Union for Conservation of Nature (IUCN). 2017. Bonn Challenge Barometer of Progress: Spotlight Report 2017. Gland, Switz.: IUCN. https://portals.iucn.org/library/node/47111
27. Joosten H., Couwenberg J., Von Unger M. (2016a). International carbon policies as a new driver for peatland restoration. W: Bonn A., Allott T., Evans M., Joosten H., Stoneman R. (red.). Peatland restoration and ecosystem services: science, policy and practice. Cambridge University Press/British Ecological Society, Cambridge: 291-313.
28. Joosten H., Sirin A., Couwenberg J., Laine J., Smith, P. (2016b). The role of peatlands in climate regulation. W: Bonn A., Allott T., Evans M., Joosten H., Stoneman R. (red.). Peatland restoration and ecosystem services: science, policy and practice. Cambridge University Press/British Ecological Society, Cambridge: 63-76.
29. Kurniawan, Tonni Agustiono; Othman, Mohd Hafiz Dzarfan; Liang, Xue; Goh, Hui Hwang; Gikas, Petros; Chong, Kok-Keong; Chew, Kit Wayne (April 2023). "Challenges and opportunities for biochar to promote circular economy and carbon neutrality". Journal of Environmental Management.
30. Lamb A, Green R, Bateman I, et al. The potential for land sparing to offset greenhouse gas emissions from agriculture. Nature Clim Change 2016.
31. Land-Management Options for Greenhouse Gas Removal and Their Impacts on Ecosystem Services and the Sustainable Development Goals Pete Smith, Justin Adams, David J. Beerling, Tim Beringer, Katherine V. Calvin, Sabine Fuss, Bronson Griscom, Nikolas Hagemann, Claudia Kammann, Florian Kraxner, Jan C. Minx, Alexander Popp, Phil Renforth, Jose Luis Vicente Vicente, Saskia Keesstra Annual Review of Environment and Resources 2019 44:1, 255-286.
32. 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).
33. Offshore Wind Technical Potential in Bulgaria, The World Bank, 2020.
34. Offshore Wind Technical Potential in Romania, The World Bank, 2020.
35. Ontl, T. A. & Schulte, L. A. (2012) Soil Carbon Storage. Nature Education Knowledge 3(10):35.

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

37. P. Renforth, The potential of enhanced weathering in the UK, International Journal of Greenhouse Gas Control, Volume 10, 2012, Pages 229-243, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2012.06.011. https://www.sciencedirect.com/science/article/pii/S1750583612001466

38. 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.

39. Polish Ministry of Climate and Environment; Polish hydrogen strategy until 2030 with an outlook until 2040; https://www.gov.pl/web/klimat/polska-strategia-wodorowa-do-roku-2030.

40. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science 2018;360:987-92.

41. Pyrka M., Jeszke R., Boratyński J., Witajewski-Baltvilks J., Antosiewicz M., Tatarewicz I., Rabiega W., Wąs A., Tobiasz I., Lewarski M., Skwierz S., Gorzałczyński A., Lizak S., Zborowska I., Chodor M., Kobus P., Krupin V., Cygler M., Mzyk P., Sekuła M. (2023). VIIEW on EU ETS 2050: Changing the scope of the EU ETS. Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw. https://climatecake.ios.edu.pl/wp-content/uploads/2023/04/LIFE_VIIEW_Changing-the-scope-of-the-EU-Emissions-Trading-System.pdf.

42. Rabiega, W., Sikora, P., Gąska, J., Gorzałczyński A. (2022). The TR3E Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_TR3E_v.2_transport-model-documentation.pdf

43. Regulation (EU) 2023/839 of the European Parliament and of the Council.

44. Regulation (EU) 2023/857 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement, and Regulation (EU) 2018/1999.

45. Rudy Kahsar, Cara Maesano, Daniel Pike, Isabel Wood From Trees to Tech and Beyond: Carbon Dioxide Removal (CDR) in All Its Variations https://rmi.org/from-trees-to-tech-and-beyond-carbon-dioxide-removal-cdr-in-all-its-variations/.

46. Schuiling, R. D.; Krijgsman, P. (2006). "Enhanced Weathering: An Effective and Cheap Tool to Sequester CO2". Climatic Change. 74 (1–3): 349–54. Bibcode:2006ClCh...74..349S. doi:10.1007/s10584-005-3485-y. S2CID 131280491.

47. Tatarewicz, I.; Lewarski., M.; Skwierz, S. The Model for European Energy System Analysis MEESA. Technical documentation for the model, version 2.0. Available online: https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_MEESA_v.2_energy-model_documentation.pdf.

48. Ten Year Network Development Plan 2018, ENTSO-E, Brussels 2018.

49. Ten Year Network Development Plan 2020, ENTSO-E, Brussels 2020.

50. Thompson, J. A., & Kolka, R. K. Soil carbon storage estimation in a central hardwood forest watershed using quantitative soil-landscape modeling. Soil Science Society of America Journal 69, 1086-1093 (2005).

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

52. Van der Mensbrugghe D. (2018). The Standard GTAP Model in GAMS, Version 7. Journal of Global Economic Analysis, 3(1), 1–83. https://doi.org/10.21642/JGEA.030101AF.

53. Wąs, A., Witajewski-Baltvilks, J., Krupin, V., Kobus, P. (2022). The EPICA Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_EPICA_v.2_agriculture-model_documentation.pdf.

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

Annex I. Brief description of the models and assumptions

CGE model – d-PLACE

281. D-PLACE is a multi-sector, multi-region computable general equilibrium (CGE) model. Its version used in this report distinguishes 29 industries and 11 regions, including 9 EU country regions, EFTA and Rest of World. The model is recursive-dynamic, solved for 5-year time steps. It is calibrated to the GTAP10 database[62], covering global economic, energy and emissions accounts for the year 2014. Model's structure is similar to other global CGE models, such as the standard GTAP model in GAMS[63], with extensions that enable specific analytical requirements - for further information, refer to the documentation[64].

282. As a typical CGE model, d-PLACE represents sector and country-specific production technologies, allowing estimation of the impact of energy and emission prices on the cost of production of individual industries. It tracks how changes in production costs translate to international competitiveness, inducing changes in exports and imports. By considering inter-industry dependencies, the model ensures consistency of sectoral output structure projections. Agents are myopic in the model, so their behaviours are based on current price incentives, rather than on expectations. Aggregate economic output is primarily supply-driven – it depends on the available endowments of production factors, including labour, capital and natural resources, as well as the level of technology. The model mimics how scarce endowments of production factors are allocated between competing activities and alternative production techniques. Technical progress is exogenous, so it is not accelerated or slowed down by the analysed policies.

283. Apart from economic variables, measured in monetary terms, d-PLACE reports physical volumes of energy and greenhouse gas emissions. Energy forms in final uses include coal, refined oil products, natural gas, electricity, district heating and hydrogen (biomass and biofuels are not modelled explicitly in d-PLACE). Nested CES structures are used to model the possibilities of substituting between energy forms, in particular

62 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. https://www.jgea.org/ojs/index.php/jgea/article/view/77.

63 van der Mensbrugghe D. (2018). The Standard GTAP Model in GAMS, Version 7. Journal of Global Economic Analysis, 3(1), 1–83. https://doi.org/10.21642/JGEA.030101AF.

64 Boratyński J., Pyrka M., Tobiasz I., Witajewski-Baltvilks J., Jeszke R., Gąska J., Rabiega W. (2022). The CGE model d-PLACE. Technical documentation for the model version 2.0. Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw. https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_d-PLACE_v.2_d-place-model_documentation.pdf.

the substitution of fuels for electricity, as well as substitution of energy for capital. The latter is the model representation of energy efficiency improvement, in which energy saving is achieved at the cost of increased investment, albeit the model does not provide disaggregated information on asset types and technologies involved. Greenhouse gas emissions cover CO_2 from fuel combustion and industrial processes, CH_4 and N_2O emissions from agricultural activities, and other non-CO_2 emissions (such as fugitive emissions, emissions from landfills or specific production processes).

284. There are three main extensions of d-PLACE beyond the standard CGE setting. Firstly, the model comprises several explicit abatement options for CO_2 and non-CO_2 emissions. They are specified in terms of assumed (fixed) marginal cost, maximum available potential, and the pace of deployment. These include, among other things, industrial CCS and waste emissions abatement. The same approach is also used to model the substitution of gas and oil for hydrogen. Secondly, the model has a flexible representation of carbon pricing, in which individual emission sources can be assigned to different pricing or cap-and-trade subsystems (country-level, EU-level, etc.). Thirdly and foremost, d-PLACE features comprehensive linkages with specialised models of energy (MEESA), transport (TR^3E) and agriculture (EPICA) sectors. The sectoral models provide a substantially more detailed account of emission abatement opportunities and costs, compared to a typical CGE model. These pieces of information are incorporated into d-PLACE in the process of iterative solutions of the inter-linked models. This process allows for the estimation of carbon price levels that ensure meeting emission reduction targets for the economy as a whole.

Changes to the model

285. D-PLACE undergoes regular revisions, which introduce incremental changes to the modeling framework and scenario assumptions. These changes often relate to the internals of the modeling process, such as improvements in computational efficiency and enhancements in results reporting.

286. While many changes are not listed here, major changes in d-PLACE compared to the previous report[65] are:

- **Disaggregation of agricultural and food products** into ten categories, respectively, from single categories used previously. This change aims to provide a more detailed analysis of the impact of climate policy on the agriculture sector, enabling a more accurate capture of region-specific effects.

[65] Pyrka M., Jeszke R., Boratyński J., Witajewski-Baltvilks J., Antosiewicz M., Tatarewicz I., Rabiega W., Wąs A., Tobiasz I., Lewarski M., Skwierz S., Gorzałczyński A., Lizak S., Zborowska I., Chodor M., Kobus P., Krupin V., Cygler M., Mzyk P., Sekuła M. (2023). VIIEW on EU ETS 2050: Changing the scope of the EU ETS. Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw. https://climatecake.ios.edu.pl/wp-content/uploads/2023/04/LIFE_VIIEW_Changing-the-scope-of-the-EU-Emissions-Trading-System.pdf.

- **Integration with new agricultural model for all EU countries**. The d-PLACE model has been linked to a new agricultural model that covers all European Member States. The connection involves harmonising results, including volumes and prices of agricultural production, as well as agricultural emissions between the models.

External drivers of d-PLACE model scenarios

287. The economic trends in the d-PLACE model scenarios are shaped by a number of exogenous drivers. Apart from policy assumptions, such as emission reduction targets, allocation of emission allowances and the scope of carbon pricing, the main external assumptions are:

  - GDP growth by country, based on the EU Reference Scenario 2020[66]. In fact, these GDP growth rates are assumed to drive effective labour and (indirectly) capital endowments, while actual GDP outcomes also depend on the allocation of these endowments across activities, which is affected by climate policies. As a result, GDP growth rates differ slightly between the scenarios due to the different policy assumptions.
  - Fuel prices dynamics (including gas, coal and crude oil), based on projections assigned to the EU Reference Scenario 2020[67]. However, in order to reflect the recent situation on the fuel market, the following adjustments were made to those projections: 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.
  - Autonomous energy efficiency improvement, which refers to the trend of improving energy efficiency driven by technological progress, independent of energy prices. For most sectors, the energy intensity of production/consumption was assumed to decrease by 1% per year due to autonomous efficiency improvements.

- Coal phase-out, which assumes a gradual reduction and eventual elimination of coal-based energy consumption by industries and households by 2030.

[66] 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.
[67] European Commission, op.cit.

Energy system model – MEESA

288. The Model for European Energy System Analysis - MEESA is a model of the energy system of 27 EU Member States, including the United Kingdom, Switzerland and Norway (called EU+), designed for long-term integrated assessment and energy planning in this region68. The main purpose of the proposed software is to gain a clear and comprehensive understanding of the system-wide implications of energy strategies focused on the transition to a competitive low-carbon energy sector in the EU. The MEESA model is designed to formulate and evaluate alternative energy supply strategies consonant with user-defined constraints such as limits on new investments, fuel availability and trade, environmental regulations, market regulations, cross-border energy flows, required levels of emission reductions and required shares of RES in a given period, etc. The model covers the most important dynamics and relationships that reflect the functioning of the power, district heat and green hydrogen sectors.

289. MEESA allows to prepare a long term optimization of future energy mix for connected EU countries based on specific technical, economic and political conditions. The underlying principle of a model, built on the basis of the OSeMOSYS[69], is optimization of an objective function under a set of constraints that define the feasible region containing all possible solutions to the problem. Given a vector of demand for electricity, district heat and green hydrogen, model assures sufficient supply to demand, utilizing the technologies and resources under consideration. Energy demand data, exogenous to the model, is given at the final level of energy chain. The value of the objective function helps to choose the solution considered best according to the given criteria.

Changes to the model

290. Various options for the of implementation e-fuels production technology in the MEESA model were analyzed – in the future development of CAKE Team tools the selected option will be implemented in combination with the TR^{3}E model.

- The code responsible for the exchange of data on agricultural biomass between the MEESA and EPICA models was modified, to take into account the influence of the demand generated by the energy sector on the price of biomass determined by the EPICA model.
- The way negative emissions are modeled in the MEESA model has been modified allowing different prices in EU ETS system and for the negative

[68] Tatarewicz, I.; Lewarski., M.; Skwierz, S. The Model for European Energy System Analysis MEESA. Technical documentation for the model, version 2.0. Available online: https://climatecake.ios.edu.pl/wp-content/uploads/2022/03/CAKE_MEESA_v.2_energy-model_documentation.pdf

[69] 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. 5850-587

emissions system. New approach also allows negative emissions to be reported as a separate result (previously the emission balance was reported).

- The reporting system for MEESA model results and related external tools was rebuilt to facilitate the analysis of results.

Base assumptions in MEESA model

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

- The time horizon was defined for the years 2020-2050, i.e. covering the key period for assessing the impact of energy and climate policies and achieving the Community goals in the field of GHG reduction.

- The 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 for transport (TR^3E) and agriculture (EPICA). At the MEESA model level, additional demand for heat pumps and energy storage is generated.

- The MEESA model internally generates additional hydrogen demand for the energy sector itself. Thanks to the relatively detailed, for the optimization model, 2-hour daily time resolution and several types of days, reflecting different weather conditions and demand profiles, it is possible to assess surpluses of electricity from intermittent energy sources, but also periods of increased demand and the need to use hydrogen as a backup/storage technology.

- National targets for each EU country in terms of coal phase-out, approaches to nuclear power (including units planned and under construction) and other significant investments that are of interest to a given country[70,71].

- Cross-border exchange capacity under the ENTSO-E – both in terms of historical data[72] and their planned development[73]. The MEESA model takes into account 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

[70] 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)
[71] World Nuclear Association (https://www.world-nuclear.org/information-library/country-profiles.aspx access: 31.12.2021)
[72] Transparency Platform (https://transparency.entsoe.eu access: 30.11.2020)
[73] Ten Year Network Development Plan 2020, ENTSO-E, Brussels 2020.

reserve at a level specified for each country, with import capacities not included in the power reserve balance.

- Maximum potentials of RES generation capacity common to the analytical scenarios (onshore wind farms, solar power plants, biomass, biogas, geothermal power plants)[74,75,76]. On the other hand, concerning offshore wind farms, the power potentials forecast by Wind Europe[77] and the World Bank[78,79] were used (due to 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[80]), hydrogen production with possible use in the energy sector. The model assumes that the electricity used to produce hydrogen comes from renewable energy sources (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.
- With regard to carbon capture and storage technology, the MEESA model assumes that this technology will be available both in units powered by fossil fuels as well in biomass units. The annual potential for CO_2 capture and storage in the EU is based on EC estimates[81]. These two elements - biomass availability and CO_2 storage potential - have a very significant impact on net emissions from the power sector and strongly influence the estimation of marginal emissions costs in the EU ETS.
- The adopted method of accounting allows for the full reflection of GHG emissions from the entire cycle of biomass generation, processing and transport, as well as revenues from market trading of negative emissions. Emission data for each part of emission chain were based on information contained in Annex VI of RED III[82]. The biomass emission range in the RED III is between 3 and 54 g CO_{2eq}/MJ. In the

[74] Ten Year Network Development Plan 2018, ENTSO-E, Brussels 2018.
[75] Ten Year Network Development Plan 2020, op.cit.
[76] 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.
[77] Our energy, our future. How offshore wind will help Europe go carbon-neutral, Wind Europe, 2019.
[78] Offshore Wind Technical Potential in Romania, The World Bank, 2020.
[79] Offshore Wind Technical Potential in Bulgaria, The World Bank, 2020.
[80] 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.
[81] 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.
[82] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652

analysis it has been assumed that only 80% of absorbed emissions can be considered as avoided one, i.e. the indirect emissions of the entire biomass life cycle will be in the range of 22 g CO_2 eq./MJ (EU). Taking into account both indirect emissions related to biomass processing with efficiency of CO_2 carbon capture unit, overall amount of assumed negative emissions is about 70% of direct CO_2 emission of biomass power plant without CCS (per fuel input – this share calculated per energy output would be even smaller due to energy consumption by CCS unit).

- 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[83]. 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.
- CO_2 emission allowance prices 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 perspective of the MEESA model, changes in allowance prices cause changes in the energy mix and affect the emission reductions achieved. From the perspective of the d-PLACE model, changes in the emission reductions achieved in the energy sector affect the allowance prices in the EU ETS system.
- Energy demand is the output variable of the d-PLACE model. The three main mechanisms included in the model that determine energy demand are (i) autonomous improvement of energy efficiency; (ii) substitution of energy by other factors of production, mainly capital, resulting from changes in relative energy prices; (iii) substitution between different energy carriers, in particular the

[83] 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.

substitution of electricity for fossil fuels in industry and transport (electrification), resulting from changes in the costs of using different carriers.

- The technical and economic assumptions in the MEESA model were mainly based on the final assumptions adopted at the end of 2020, which are the basis for the development of the new EU Reference Scenario 2020[84]. Potential data gaps were additionally supplemented with information from studies prepared by recognised research centres dealing with energy modeling and investment processes, such as the International Energy Agency, the Joint Research Centre, Tractebel, Ecofys or Frontier Economics.

Transport sector model – TR³E

292. The TR³E model for transport sector used in the simulations is a partial equilibrium class model. Accordingly, it means that market equilibrium and market clearing is achieved with exogenous assumptions concerning prices and quantities in other markets. In TR³E model we assume fuels and vehicles prices, income levels of households (firms) as given. Also, the assumptions regarding the demand for transport activities are adopted in response to economic growth resulting from the scenarios in d-Place model. In the model we highlighted two submodels for passenger and freight activities. These models cover 4 main transport modes: road, rail, aviation and water transport. Due to characteristics of engine types and technology options, up to 37 means of transport have been distinguished.

Logic of the TR³E transport model

293. The demand for transport activities (both demand allocation and the technology choices modules) translates into the demand for new means of transport and its structure is anticipated in the fleet module. Both modules are solved simultaneously and are linked by information exchange. The transport demand module provides for decisions on the allocation of transport activities to various modes such as cars, buses, trains. In the technology selection module, the number of new vehicles according to the technology that must be used to meet consumer demand, is determined. The presented modules are dynamic in time, with annual resolution, applying a time horizon up to 2050.

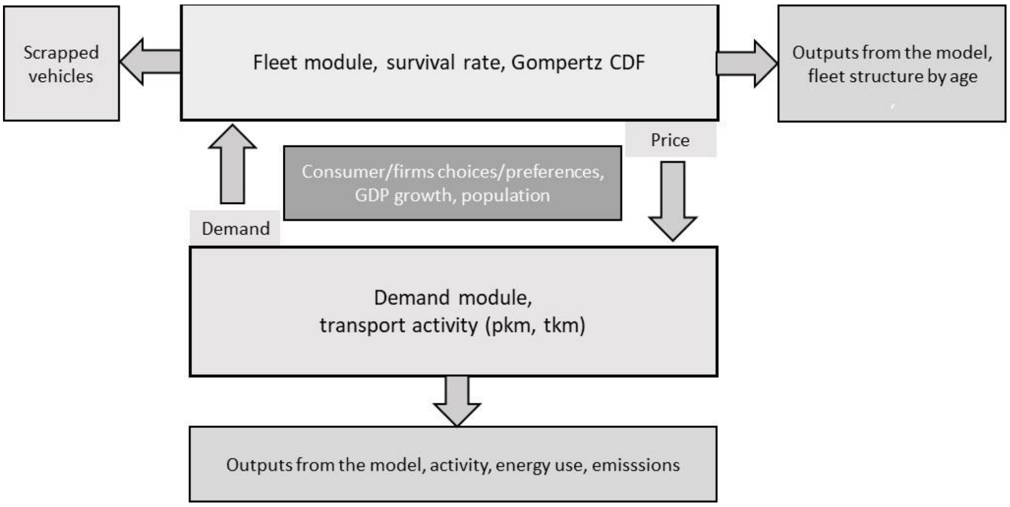
294. The model simulation results contain activity levels (passenger-kilometre travelled or tonne-kilometre transported) for different modes. Then, following the calculated coefficients of energy intensity of transport work and trends in its improvement, energy

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

consumption are counted. The quantity of used petroleum fuels is used to determine the level of CO_2 emissions, while hydrogen and electricity are treated as zero emission fuels.

295. An additional module of the TR³E is the anticipating of fleet structure. Prices (costs of transporting people and goods) adjust in the dynamic process until supply equals demand. It allows us to study the efficiency and comparative statistics.

Graph 6. Logic of the TR³E transport model



Source: CAKE/KOBiZE

Demand module

296. The transport demand module simulates decision regarding allocation (structure) of transport activity to various modes (types) for both individuals (households) and businesses. The technology choice module determines the vehicle technologies (transport means) that will be used in order to satisfy transport demand. These flows (decision process) depend on consumer preference and relation of prices transport services. The choices are made by households and businesses separately. In TR³E the choice of transport mean using a nested way approach. The nested constant elasticity of substitution (CES) function was applied during designing model structure. The nested CES utility function captures the preferences of households and firms. Using CES function determines the constant percentage change in the relation of factors (e.g. private cars and public transport) in quantity adequate to a percentage change in prices. The decision tree for passenger transport was designed using the nested CES utility (production) technology. The choice of vehicle technology (e. g. diesel vs electric) was applied using the standard multinomial discrete choice model.

Costs module

297. In TR^3E model the choice between the means of transport are based on demand functions which includes response to level of transport costs. For each type of transport means the cost per mile was calculated. This cost per mile consists of three factors:

- cost of energy carrier per km travelled (petroleum, diesel, electricity, hydrogen, etc.),
- values of the repair and the insurance (maintenance) per vehicle,
- purchase price of new vehicle (containing subsidies and changes resulting from technological progress and technology popularization).

298. In practice, we can easily disaggregate the cost per mile according to the policy scenario (i.e. reduced cost of purchasing a new vehicle thanks to government subsidies). The cost per mile may depend on the respective transportation policy, for instance, we may extend the cost per mile with the additional cost of emissions added to the fuel cost.

Survival/scrappage rate – fleet module

299. In TR^3E model the fleet of the vehicles was modelled using survival rate based on probability density. For this purpose, cumulative distribution function (CDF) of the Gompertz distribution was used:

$$F(x:\eta, b) = 1 - \exp(-\eta(e^{bx} - 1))$$

300. This function is a type of mathematical model - generalised logistic function. The Gompertz survival function corresponds to exponential mortality rate increases with time. The parameters in this distribution are:

b – denotes the scale parameter;

η – indicates the shape parameter (corresponding to scrappage rate).

301. All the parameters of the CDF (Gompertz's) function were selected such that they properly reflect the vehicle structure by age of fleet. For passenger cars age of fleet was designed up to 30 year and for buses to 20 year old. The average age of the vehicles was calculated using IDEES dataset and corresponds to the average age of the vehicle from the theoretical distribution. In the fleet module, new cars replace the scrapped ones and come into use to meet the demand for additional transport services (activities). In FIT55_trans scenario η parameter was increased by 25%.

Data source

302. The main source of data to feed the TR^{3}E model is historical data from the JRC European Energy Sector (IDEES) Integrated Database. This dataset includes: transport activity, number of vehicles, energy consumption per km, emissions intensity of energy. The level of stocks was updated from national statistics - Local Data Bank for current stock of vehicles. The prices of new vehicles for the baseline year were taken from the PRIMES-TREMOVE model. The fossil fuels prices (petroleum products) are adopted on the basis of data from World Energy Outlook[85] meanwhile the prices of electricity and hydrogen are calculated in energy model MEESA.

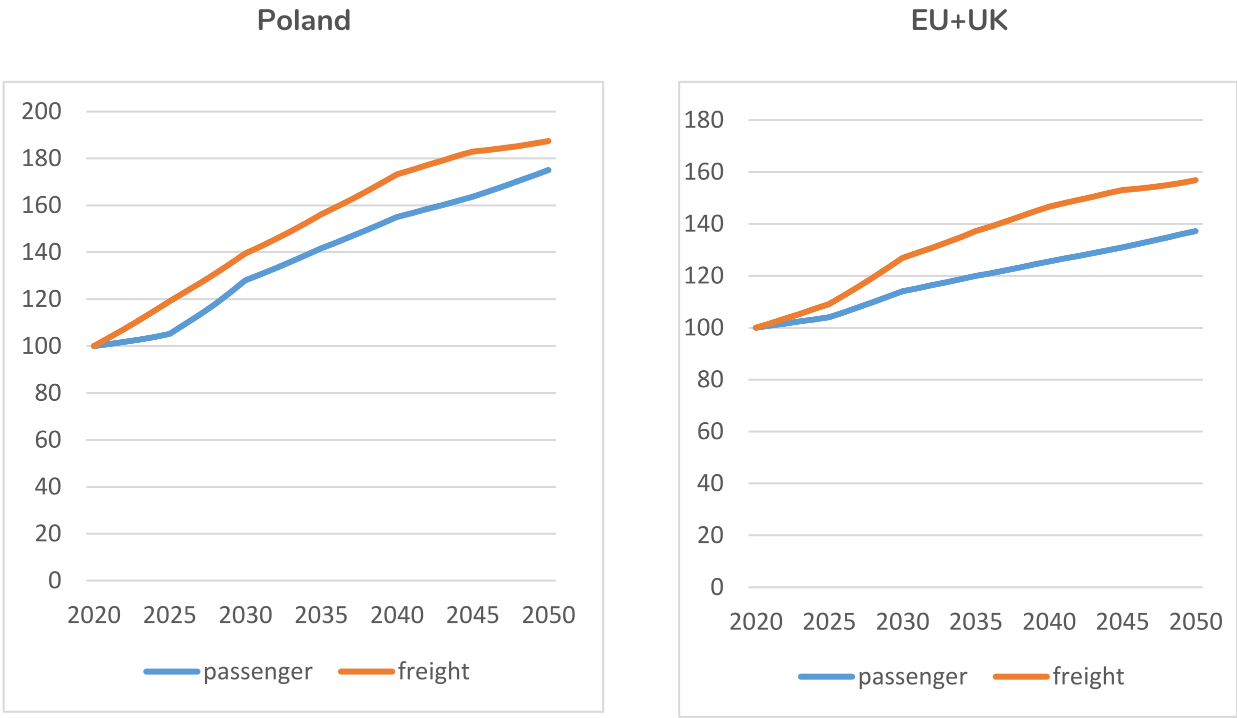
Fit55 scenario

303. In TR^{3}E model Fit55 scenario was prepared to better understand the impact of the implementation of current policies and measures on the sector activity as well as on the CO_2 emissions levels. Fit55 scenario serves as a reference point to which comparison of analytical (policy) scenarios is made.

304. We set different assumptions on the development of the economy and specific indicators as CO_2 emissions intensity, the prices of different types of vehicles and costs of fuels. We adopt the same activity growth projections for all scenarios. Therefore, in the case of Poland growth in passenger activity between the years 2020 and 2050 is set to 1.9% (y/y), and 1.2% (y/y) for EU27+UK, while the average growth in freight activity is set to 2.1% (y/y) for Poland and 1.5% (y/y) for EU27+UK.

[85] https://www.iea.org

Figure 53. Assumptions on passenger and freight activity in Poland and EU27+UK in the years 2020 – 2050 [2020=100]



Source: CAKE/KOBiZE

Latest changes to the model

- Update of basic input parameters related to the size of the zero-emission fleet of transport and passenger vehicles.
- Verification of key structural parameters such as elasticities of substitution and analyzing their role in the output of simulation by means of sensitivity analysis.
- Verification of new emission standards for heavy duty vehicles and modifications in the TR^{3}E model in order to account for these new emission standards.
- Conceptual work on the use of synthetic fuels (e-fuels) in road and air transport. Work on the integration on TR^{3}E model with d-PLACE through the mutual exchange of data on the size of investment in the transport sector.

Extended description of the TR^{3}E model can be found in Rabiega et al. (2022).

Agriculture sector model – EPICA

305. EPICA: “Evaluation of Policy Impacts – Climate and Agriculture”[86] is a model aimed at estimation and support of analyses of climate policy inflicted changes in agricultural production with estimation of its influence upon climate change through greenhouse gas emissions for 27 EU Member States, additionally including the United Kingdom. The model was built to consider wide range of policy instruments, but the essential ones are: direct (as in the current ETS scheme) and indirect (additional charges on selected inputs, such as fertilisers) emission charges, emission quota at sector level and wide range of operational subsidies in line with the ones currently implemented within the Common Agricultural Policy. The model also is able to estimate impact of climate change upon agricultural sector, however it requires the introduction of exogenous parameters (e.g., yield change due to climate change).

306. Key feature enabling the EPICA model to stand out among other modeling approaches is the implemented assumption of farm income driving the farm behaviour in their choice of production. The choices include the structure of production (referred to as farm activities) and production intensity with its relevant processes and practices. The fundamental EPICA model assumption states that the farmers strive to maximise their income by adjusting production structure to the present (expected) market and political situation.

307. The EPICA model simultaneously employs several approaches to modeling and combines a CGE d- Place model and MEESA model to reach supply-demand balance regarding agricultural products. Demand for agricultural products is determined in an iterative process between EPICA model and the macroeconomic model (d-PLACE) and energy sector model (MEESA).

308. Produced commodities are divided into primary crop and animal outputs, which go along the relevant GHG emissions. GHG emissions as one of the key estimation targets in the EPICA model are evaluated based on each farm activity output, for crop production as CO_2 eq./ha and for animal production as CO_2 eq./LU.

Emissions from crop production cover such sources as:

- soil management (N_2O),
- histosols (N_2O), and
- urea and liming (CO_2).

[86] Wąs, A., Witajewski-Baltvilks, J., Krupin, V., Kobus, P. (2022). The EPICA Model, ver. 2.0, The Institute of Environmental Protection – National Research Institute/ National Centre for Emissions Management, Warsaw 2022. https://climatecake.ios.edu.pl/wp-content/uploads/2020/12/CAKE_EPICA_model_documentation_.pdf

Emissions from animal production cover:

- enteric fermentation (CH_4), and
- manure management (CH_4, N_2O).

309. The main result of the farm module is an optimal structure of the production activities, which provides the highest farm income in conditions described in the scenario. It means that the most basic solution of the model includes:

- number of hectares of crop activities for each of the crops;
- number of livestock units for each considered animal activity, both distinguished according to applied technologies;
- farm income achieved at optimal structure of farm activities;
- level of GHG mitigation measures as rewetting of histosols and biogas production as well as GHG removals as cropland afforestation.

310. Main Model assumptions:

- The time horizon was defined for the years 2020-2050, i.e. covering the key period for assessing the impact of the Common Agricultural Policy and climate policy and achieving the Community goals in the field of GHG reduction.
- For the afforestation of croplands the maximum afforestation area have been assumed in the model. The maximum area of afforestation is up to 1% of agricultural cropland per year and up to 25% of base year cropland area. The implemented restrictions serve the purpose of demonstrating the limited availability of nursery material of adequate quality and the labour-intensive nature of forest establishment. It was also assumed that afforestation is irreversible process thus the forest could not be converted to the cropland.
- It was also assumed that only part of histosols would be suitable for rewetting up to 75% of existing drained histosols area.
- Due to organisational constraints the biogas could be produced only at farms with herds of appropriate size. Thus only 80% of the manure could be converted to the biogas.
- The Common Agricultural Policy was implemented in the shape existing in 2020.
- Prices of the inputs for agricultural production was indexed in line with the d-Place results for assumed scenarios

Prices of CO_2 emission 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.

311. Main developments of the EPICA model:

- Expansion of the model of Polish agriculture onto EU level.
- Defining and calibrating models for each EU member country and each region along with the D-Place delimitation.
- Developing the database of agricultural activities parameters for each of EU countries including intensity level, costs of production, yields and prices.
- Elaborating costs of GHG mitigation measures for EU countries like: afforestation and peatland rewetting.
- Supplementation of data on the areas of organic soils within cropland and grassland land types.
- Supplementation of data on forest losses due to fires.
- Supplementing of data on afforestation of cropland and peatland flooding for each EU Member States.
- Verification of applied coefficients regarding chosen emission sink methods (afforestation of agricultural land, peatland flooding, biogas production).
- Detecting data inconsistencies and verification of the results of individual model iterations.
- Testing the alignment of the extended agricultural EPICA model with the d-PLACE model, improving compatibility and convergence between the models.
- The current version of the EPICA model, used for preparing this report include afforestation of arable land as a agricultural related GHG removal measure. While peatland recovery and agricultural biogas production represent GHG mitigation measures, which could be used to decrease the level of unnecessary GHG emissions from the agricultural sector.

LIFE VIIEW 2050

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

Co-funded by the European Union

LIFE VIIEW 2050

Centre for Climate and Energy Analyses

National Centre for Emissions Management
Institute of Environmental Protection
National Research Institute

Funded by
NATIONAL FUND FOR ENVIRONMENTAL PROTECTION AND WATER MANAGEMENT

Project entitled „The impact assessment of the EU Emission Trading System with the long-term vision for a climate neutral economy by 2050 (LIFE VIIEW 2050 – LIFE19 GIC/PL/001205)" is co-funded by the Life Programme of the European Union and the National Fund for Environmental Protection and Water Management.