CLIMATE CHANGE
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A comparison of assumptions and sector results between the EU Impact Assessment 2040 and the UBA Pathways 2050 scenarios

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Abstract: Projected EU emissions in 2040

This study analyses EU-wide greenhouse gas reduction scenarios for the year 2040. Four scenarios presented by the European Commission, in its Impact Assessment (IA) for the 2040 intermediate climate target, are compared against three scenarios developed in the project titled 'Pathways to an EU in 2050 with net-zero Greenhouse Gas (GHG) emissions'. The analysis is performed both from an overall and a sectoral perspective.

The comparison shows for most sectors the main differences can be attributed to differences in assumptions. There is a clear picture of the necessary transformation for the energy-related sectors – supply, industry, transport and buildings – based on three pillars: reducing energy consumption, improving energy efficiency, and switching from fossil to renewable energy sources. For the less energy-related sectors, the overall transformation strategy is less clear, leading to a larger variability of scenario results for these sectors.

The main differences found between the two sets of scenarios include: higher electricity generation and higher industrial output in the IA 2040 scenarios, differences in degrees of transport electrification and in buildings standards for new buildings, varying assumptions on the role of technical mitigation options in agriculture and implemented waste measures.

Kurzbeschreibung: Projizierte Emissionen der EU 2040

In dieser Studie werden EU-weite Treibhausgasreduktionsszenarien bis zum Jahr 2040 untersucht. Vier von der Europäischen Kommission für die Folgenabschätzung für das 2040 EU Klimazwischenziel vorgelegten Szenarien werden gegen drei im Projekt „Pathways to an EU in 2050 with net-zero GHG emissions" entwickelte Szenarien verglichen. Der Vergleich erfolgt sowohl auf einer übergeordneten als auch auf sektoraler Ebene.

Der Vergleich zeigt, dass für die meisten Sektoren die wesentlichen Unterschiede durch unterschiedliche Annahmen erklärt werden können. Für die energiebezogenen Sektoren (das sind die Sektoren Energie, Industrie, Transport und Gebäude) zeichnet sich ein klares Bild für den notwendigen Wandel ab, in Bezug auf die drei Säulen Reduktion des Energieverbrauchs, Verbesserung der Energieeffizienz und dem Wechsel von fossilen auf erneuerbaren Energiequellen. Für andere Sektoren ist die Transformationsstrategie weniger klar, was zu einer größeren Variabilität der Szenarienergebnisse für diese führt.

Die Hauptunterschiede, die zwischen den beiden Szenariensets gefunden wurden, umfassen: höhere Stromerzeugung und höhere Industrieproduktion in den IA-2040-Szenarien, Unterschiede im Elektrifizierungsgrad des Verkehrs und in Gebäudestandards für neue Gebäude, unterschiedliche Annahmen zur Rolle von technischen Vermeidungsoptionen in der Landwirtschaft und implementiere Abfallmaßnahmen.

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List of abbreviations

Abbreviation	Explanation
BECCS	Bioenergy, carbon capture, and storage
BEV	Battery electric vehicle
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
CCS	Carbon capture and storage
CCU	Carbon capture and use
DACCS	Direct air carbon capture and storage
EU ETS	EU Emissions Trading System
EUBase	EU Pathways Base scenario
EUTarget	EU Pathways Target scenario
EUSupreme	EU Pathways Supreme scenario
FCEV	Fuel cell electric vehicle
F-gases	Fluorinated greenhouse gases
GDP	Gross domestic product
GHG	Greenhouse gas
IA	Impact Assessment
ICEV	Internal combustion engine vehicle
kWh/m^2	Kilowatt-hours per square metre (measuring unit for specific energy consumption)
LNG	Liquefied natural gas
LULUCF	Land use, land-use change and forestry
m^3	Cubic metres (measuring unit for volume)
Mha	Megahectares (measuring unit for area)
Mt	Megatonne (measuring unit for mass)
N_2O	Nitrous oxide (laughing gas)
PHEV	Plug-in hybrid electric vehicle
S1	EU Scenario 1
S2	EU Scenario 2
S3	EU Scenario 3
SRC	Short rotation coppice
t	Tonne (measuring unit for mass)

Abbreviation	Explanation
tm^3	Thousand cubic metres
TWh	Terawatt hours (measuring unit for energy)
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

In 2024, the European Commission presented a Communication (European Commission 2024a) and an Impact Assessment (European Commission 2024b) that sketches pathways to 2050 including suggestions for EU-wide targets for 2040 and recommended reducing the EU's net greenhouse gas (GHG) emissions by 2040 by 90%, relative to 1990. In four scenarios, the Commission sets out different rationales for the development of emissions and removals in the EU beyond 2030. To deliver a reduction of net GHG emissions of 90%, the analysis in the Impact Assessment shows that the level of remaining EU GHG emissions in 2040 should be less than 850 Mt CO_2eq while carbon removals (both natural and technical) need to amount to -400 Mt CO_2.

This report compares the EU scenarios published in the Impact Assessment with three scenarios developed under the UBA project '*Pathways to an EU in 2050 with net-zero GHG emissions*'. It analyses estimates for GHG emissions and removals sector by sector for the different sets of the two 'scenario families'. It also reviews the main assumptions with the aim of identifying reasons for differences in the estimates. The report compares the main assumptions for policies and measures as well as modelling approaches and how these affect the results. From the comparison, conclusions are drawn with a view to what options for a sustainable transformation in the economic sectors of EU might be under-utilised in the scenarios.

As the purpose of the Impact Assessment of the European Commission is to provide the scientific background for defining an EU-wide 2040 climate target, the following scenario comparison focuses on EU results and the target year 2040.

Chapter 2 of the report introduces the scenario definitions of these two studies, compares the study results from an overall perspective and compares relevant macro-economic parameters. Chapter 3 considers each sector and explores the extent to which scenarios of the two studies agree with each other or differ. The chapter that closes this study, chapter 4, summarises the results of this scenario comparison.

2 Study-wide comparison

2.1 Comparison of storylines

The Impact Assessment 2040 (IA 2040) presents four scenarios (referred to hereafter as 'IA 2040 scenarios') and defines their scope and assumptions as follows (European Commission 2024b, part 1, pp. 29-30):

- *"S1: up to 2040, this scenario relies essentially on the Fit-for-55 energy trends, which allow it to deliver a target in 2040 that is the "linear" reduction path of net GHGs between 2030 and 2050. It does not assume specific mitigation of non-CO_2 emissions beyond their default evolution within the current framework, for instance in agriculture, or in the LULUCF sector. Beyond 2040 though, all sectors need to drastically reduce GHG emissions in view of meeting the climate neutrality objective by 2050 and all technologies need to be deployed."*
- *"S2: to reach a reduction of at least 85% by 2040, this scenario combines the energy trends reflected in S1 with a further deployment of carbon capture and e-fuels as well as substantial reductions of GHG emissions in the land sector, including non-CO_2 emissions in the agriculture sector and carbon removals in the LULUCF-sector."*
- *"S3: to reach a reduction of at least 90% by 2040, this scenario builds on S2 and relies on a fully developed carbon management industry by 2040, with carbon capture covering all industrial process emissions and delivering sizable carbon removals, as well as higher production and consumption of e-fuels than in S2 to further decarbonise the energy mix."*
- *"LIFE: In addition to the three core scenarios that are used to compare the 2040 target options, a complementary variant (LIFE) looks at the sensitivity of the analysis to key societal trends related to more sustainable lifestyles, resulting from changes in the consumer preferences, from circular economy measures related to the use of energy and materials, as well as from changes in mobility and the food system."*

The European Commission pursues to reduce net GHG emissions by 90% by 2040.[1] The scenario S1 reaches 78%, scenario S2 88% and scenario S3 92% reduction of net GHG emissions by 2040 compared to 1990. The average of S2 and S3 is very close to the 90% target and therefore the average of the two is included in the analysis.

In the project '*Pathways to an EU in 2050 with net-zero GHG emissions*,' three scenarios are developed and analysed (referred to hereafter as the 'Pathway scenarios'). They consist of one reference and two target scenarios. Both EUTarget and EUSupreme aim at reaching net-zero emissions by 2050 for the EU as a total, intermediate targets for 2030 or 2040 are not predefined. The Pathway scenarios are defined as (Duscha et al. n.d., pp. 40-41):

- "EUBase: *This scenario, serving as the reference scenario for the project, analyses the ambition of existing and negotiated policy packages on the EU and Member State level with regards to the 2030 and 2050 climate targets (as of 2022). Reaching the EU emission reduction targets for 2030 and 2050 is not preconditioned.*"
- "EUTarget*: This target scenario illustrates a pathway to GHG-neutrality by putting a strong focus on technical solutions and on national mitigation strategies. It builds on EUBase but makes assumptions on additional measures to reach the EU emission reduction targets for*

[1] https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2040-climate-target_en

2030 and 2050. These assumptions reflect expert knowledge on possible technological pathways and policy developments."

- "EUSupreme: *This second target scenario is based on the common application of strong sustainability criteria in the context of mitigation technologies and a strong focus on non-technical and behavioural mitigation options. Like the EUTarget scenario the scenario builds on EUBase but makes stronger assumptions on sustainability and circularity and implements behavourial change illustrating a highly sustainable pathway to reach GHG-neutrality in the EU.*"

Both studies modelled scenarios up to 2050. However, the intended purpose of the Impact Assessment of the European Commission is to provide the scientific background for defining an EU-wide 2040 climate target by not only presenting likely GHG emission pathways but also analysing investment and cost effects as well as ecological co-benefits. Following this purpose, the scenario comparison focuses on EU results and the target year 2040.

The LIFE and EUSupreme scenarios both aim at reducing GHG emissions as far as possible and have a strong focus on sustainability in general, including circular economy, efficiency, and sufficiency. Therefore, these two scenarios are compared and analysed in more detail.

2.2 Comparison of general modelling assumptions

The two scenario sets have similar assumptions of gross domestic product (GDP). In the IA 2040 scenarios 'real GDP is projected to be 40% higher in 2040 than in 2015' (Part 2, p. 13). The projected GDP in the Pathways scenarios is only slightly lower, amounting to 38% above 2015 values.

Population development in the Pathways scenarios was taken from the PRIMES reference scenario 2020. It is projected to peak by 2025 and decrease thereafter. In 2040 the population is projected to be 0.7% higher than in 2015. For the Impact Assessment, the 'Eurostat's long-term projections (EUROPOP2019) combined with the short-term update of the projected population for the period 2022-2032' (European Commission 2024b) were used. It reflects the increased population due to refugees from Ukraine. The EU population in the IA 2040 scenarios peaks in 2024 and decreases thereafter.

The IA 2040 uses international prices for oil, natural gas and coal from the REPowerEU Action Plan. The real energy prices do not differ between the IA 2040 scenarios. In contrast, the Pathways scenarios EUBase and EUTarget use energy prices from the UBA project Politikszenarien XI (Mendelevitch et al. 2022) while the prices in the EUSupreme scenario are based on the scenario of net zero emissions by 2050 (NZE) of the World Energy Outlook 2022. EUSupreme is a scenario wherein a global transformation to mitigate the climate crisis leads to lower global fossil fuel demands and thus international energy prices. While the energy prices increase only moderately in EUBase and EUTarget and the energy prices in EUSupreme even decrease, the energy prices in the IA 2040 scenarios increase more strongly.[2]

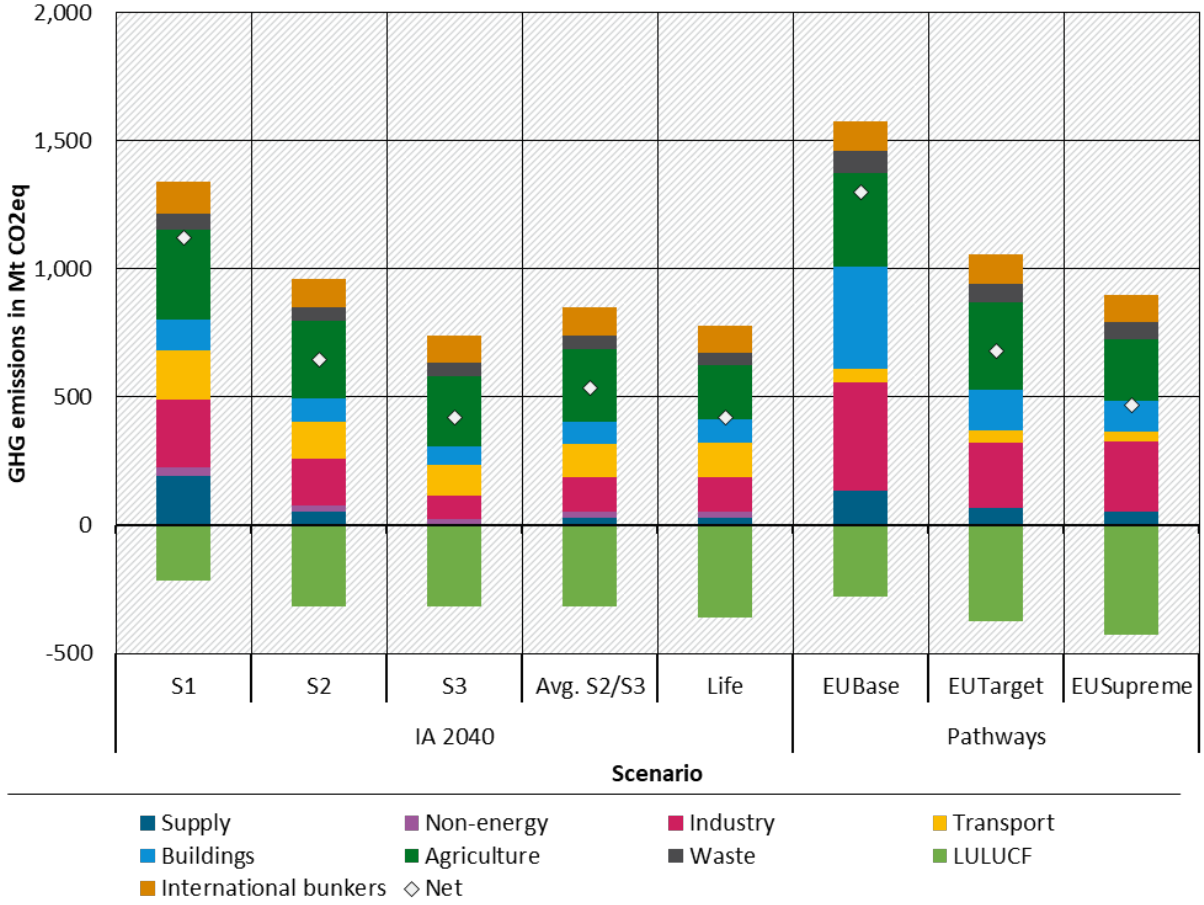
2.3 Comparison of scenario results

Figure 1 presents GHG emission and removals from all relevant sectors achieved in 2040 in the IA 2040 scenarios S1, S2, S3, and the LIFE scenario and compares them against the three Pathways scenarios EUBase, EUTarget, and EUSupreme. The two most ambitious IA 2040

[2] The Impact Assessment provides macro-economic assumptions (GDP, population, energy prices) only as diagrams and not in tabular format. Thus, this comparison could only be made qualitatively.

scenarios are very close to each other: S3 and LIFE (422 resp. 421 Mt CO_2eq). The most ambitious Pathways scenario, EUSupreme, has only slightly higher net emissions (470 Mt CO_2eq). The net emissions of the EUTarget scenario (682 Mt CO_2eq) are slightly higher than for scenario S2 (646 Mt CO_2eq). The net emissions of the IA 2040 scenario S1 (1,122 Mt CO_2eq) are most comparable to the Pathways EUBase scenario (1,300 Mt CO_2eq).

Figure 1: Net total GHG emissions by sector in 2040



The IA 2040 scenarios include the category of 'Other non-energy sectors' which contain among others fugitive emissions from fuels and emissions of fluorinated greenhouse gases. This category cannot be divided into industry and supply sectors. Estimates for LIFE were gap-filled for supply, industry, and international transport with averages of S2 and S3.

Source: own illustration, Oeko-Institut

3 Sectoral comparison of scenario families

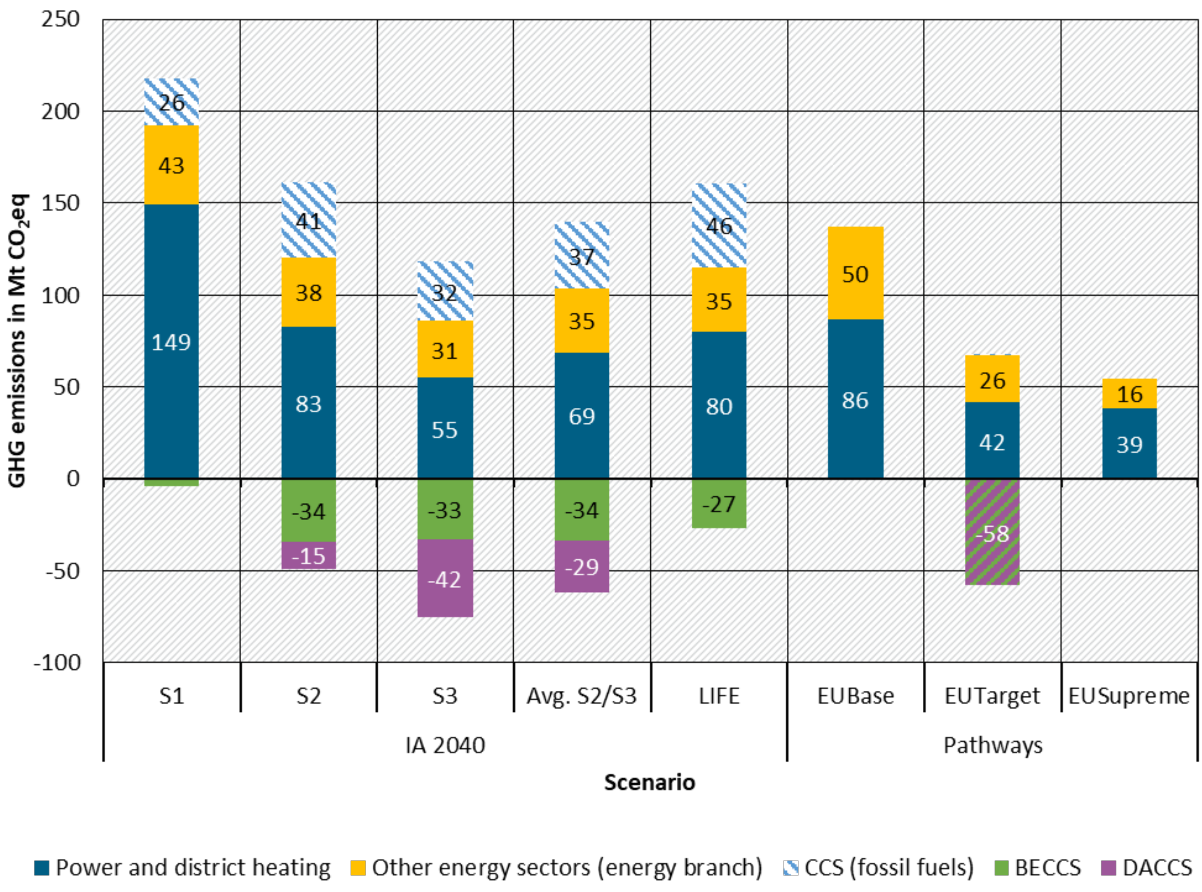
In the following, net GHG emissions and removals from different sources and sinks estimated in the two scenario families are compared: 1) scenarios presented in the European Commission's Impact Assessment (IA 2040 scenarios) and 2) the scenarios in the '*Pathways to an EU in 2050 with net-zero GHG-emissions*' project (Pathway scenarios). The main differences between the scenario families are discussed and reasons for the deviation identified.

3.1 Supply

3.1.1 Overview

Figure 2 shows the emissions from the supply sector across scenarios. Notable gradients in GHG emissions are evident in the Pathways scenarios, from 137 Mt CO_2eq in the EUBase scenario to 65 Mt CO_2eq in EUTarget and 55 Mt CO_2eq in EUSupreme. In contrast, the IA 2040 scenarios show significantly higher emissions, with S1 achieving net emissions of 162 Mt CO_2eq, while S2 and S3 see reductions to 31 Mt CO_2eq and -22 Mt CO_2eq, respectively, resulting in net emissions well below those of the EUSupreme scenario.

Figure 2: Net GHG emissions in the supply sector in 2040



The IA 2040 scenarios include the category 'Other non-energy sectors,' which contains among others fugitive emissions from fuels and emissions of fluorinated greenhouse gases. This category cannot be divided into the industry and supply sectors.

Source: own illustration, Fraunhofer ISI

3.1.2 Comparison of modelling assumptions and results

S1 and EUBase adopt a conservative approach, maintaining existing trends including planned measures, but without additional initiatives. In contrast, S2 and S3 are similar to EUTarget; both integrate advanced technologies and allowing flexibility in achieving climate goals. LIFE corresponds with the EUSupreme scenario, focusing on sufficiency, efficiency, and sustainability criteria for higher emission reductions. A key difference between the scenarios is the use of carbon capture and storage (CCS) technologies. While all IA 2040 scenarios rely on CCS in power generation and S2 and S3 also utilise direct air carbon capture and storage (DACCS), Pathways scenarios only use CCS for electricity and heat generation from waste in EUTarget with a minor amount of only 1 Mt CO_2.

Table 1: Generated GHGs and net GHG emissions in the supply sector in 2040[3]

Category	S1	S2	S3	LIFE	EUBase	EUTarget	EUSupreme
Net emissions power and district heating (incl. CCS and BECCS)	119	8	-10	7	86	41	39
of which CCS (fossil fuels)	26	41	32	46	0	1	0
of which BECCS	4	34	33	27	0	0	0
Generated GHGs from power and district heating (without CCS and BECCS)	**149**	**83**	**55**	**80**	**86**	**42**	**39**
Other energy sectors (energy branch and DACCS)	43	23	-11	35	50	-32	16
of which DACCS	0	15	42	0	0	58	0
Generated GHGs from other energy sectors (without DACCS)	**43**	**38**	**31**	**35**	**50**	**26**	**16**

Source: IA 2040, Fraunhofer ISI

The analysis of net GHG emissions in the supply sector for the year 2040 reveals significant differences between the IA 2040 and Pathways scenarios, particularly when analysing emissions separately with and without the impacts of CCS technologies.

In the category of power and district heating, S1 shows the highest emissions without CCS (149 Mt CO_2eq), compared to 86 Mt CO_2eq in the EUBase scenario. Due to the greater reliance on fossil fuels in S1, emissions remain higher at 119 Mt CO_2eq, even with the utilisation of CCS and bioenergy, carbon capture and storage (BECCS), compared to EUBase. One main reason for this is that fossil electricity remains significantly higher in S1 compared to EUBase. S2, S3 and EUTarget show lower emissions than S1 and EUBase, while emissions in S2 (83 Mt CO_2eq) and S3 (55 Mt CO_2eq) exceed emissions in EUTarget, which amount to 42 Mt CO_2eq. This indicates that significant emission reductions can be achieved even without the use of CCS. The implementation of CCS reduces emissions in S2 and S3 to near or below zero after significant reductions from other measures. LIFE has higher emissions without considering CCS, at 80 Mt CO_2eq, compared to EUSupreme. In LIFE, emissions are also reduced to near zero by means of CCS, while in EUSupreme, emissions are only half as high as in LIFE, even without CCS.

[3] The data is taken from IA 2040 part 3 (annex 8: detailed quantitative analysis of GHG pathways). For ‘Other energy sectors,’ the data differs from the calibrated numbers in part 1 table5.

In the category of 'Other energy sectors,'[3] which covers refinery operations, gas transport and other upstream activities and, importantly, counts any CO_2 removals from direct air capture and storage (DACCS) as negative emissions, all IA-2040 scenarios are at comparable levels (35-43 Mt) and below emissions in EUBase. In contrast, emissions in the Pathways target scenarios are significantly lower, as EUTarget and EUSupreme assume a faster phase-out of fossil fuel supply chains in all sectors. Since neither S1 nor LIFE utilises DACCS, overall emissions in the other energy sectors show the same pattern. In S2 and S3, emissions from other energy sectors are somewhat higher, at 38 Mt CO_2eq (S2) and 31 Mt CO_2eq (S3), compared to the EUTarget scenario, in which the emissions amount to 26 Mt CO_2eq. However, the use of DACCS significantly reduces emissions in S2 and S3, bringing emissions in S2 in line with the EUTarget and even resulting in negative emissions in S3. Overall, the comparison highlights the critical dependence on CCS in the IA 2040 scenarios, while also demonstrating that all Pathways scenarios can achieve significant emission reductions even without CCS.

Table 2: Final electricity demand and electricity generation (TWh)

Category	S1	S2	S3	LIFE	EUBase	EUTarget	EUSupreme
Final electricity consumption	3,255	3,331	3,341	3,233	3,316	3,409	3,370
Electricity generation	4,563	4,899	5,212	4,820	4,059	4,549	4,573
of which renewables	3,692	4,178	4,540	4,096	3,323	3,934	4,006
of which nuclear	494	495	495	495	519	511	458
of which fossil (and reconversion of hydrogen)	377	225	177	228	216	103	109
of which fossil	312	192	152	222	170	52	52
of which reconversion of hydrogen	65	33	25	6	46	51	57

Source: IA 2040, Fraunhofer ISI

Final electricity consumption in the IA 2040 scenarios is projected at 3,255 to 3,341 TWh, which is slightly lower than in the corresponding Pathways scenarios (from 3,316 to 3,409 TWh, see Table 2). However, total electricity generation is expected to be higher in the IA scenarios, rising from 2,905 TWh in 2021 to between 4,563 and 5,212 TWh by 2040, reflecting a growth of 57% to 80%. The main driver of this gap is the much larger amount of electricity that is intentionally produced for energy-carrier conversion: roughly 900–1 100 TWh (≈ 20–25 % of all generation) power electrolysers and e-fuel synthesis in S1–S3, whereas the Pathways scenarios allocate only 250–350 TWh to such uses. Accordingly, the Pathway scenarios have a lower total electricity generation: 4,059 TWh for EUBase, 4,548 TWh for EUTarget and 4,573 TWh for EUSupreme. The higher overall electricity demand in IA 2040 scenarios is covered by higher electricity generation from renewables as well as fossil fuels.

The results of the scenarios differ with a view to the technology mix of electricity generation (and resulting emissions. Renewable electricity generation in the IA 2040 scenarios ranges from 3,692 to 4,540 TWh, while EUBase is lowest at 3,323 TWh. Renewable electricity generation in the EUTarget and EUSupreme scenarios falls within the range of the IA 2040 scenarios (3,934 to 4,006 TWh). The shares of renewable energy (81-87%) are consistent across all IA 2040 and Pathways scenarios. Fossil plants still provide 152–312 TWh in IA 2040 scenarios, 170 TWh in EUBase, but only 52 TWh in the Pathways target scenarios, reflecting their stronger phase-out assumptions. Hydrogen back-conversion contributes an additional 6–65 TWh in IA 2040 scenarios, compared with 46–57 TWh in the Pathways scenarios. Nuclear power generation is held constant at 495 TWh in all IA scenarios but varies among the Pathways scenarios. In EUBase, nuclear power generation is 5% higher and in EUSupreme 7% lower than the IA scenarios. EUSupreme aims at reduced reliance on nuclear energy and does not allow new locations for nuclear power plants.

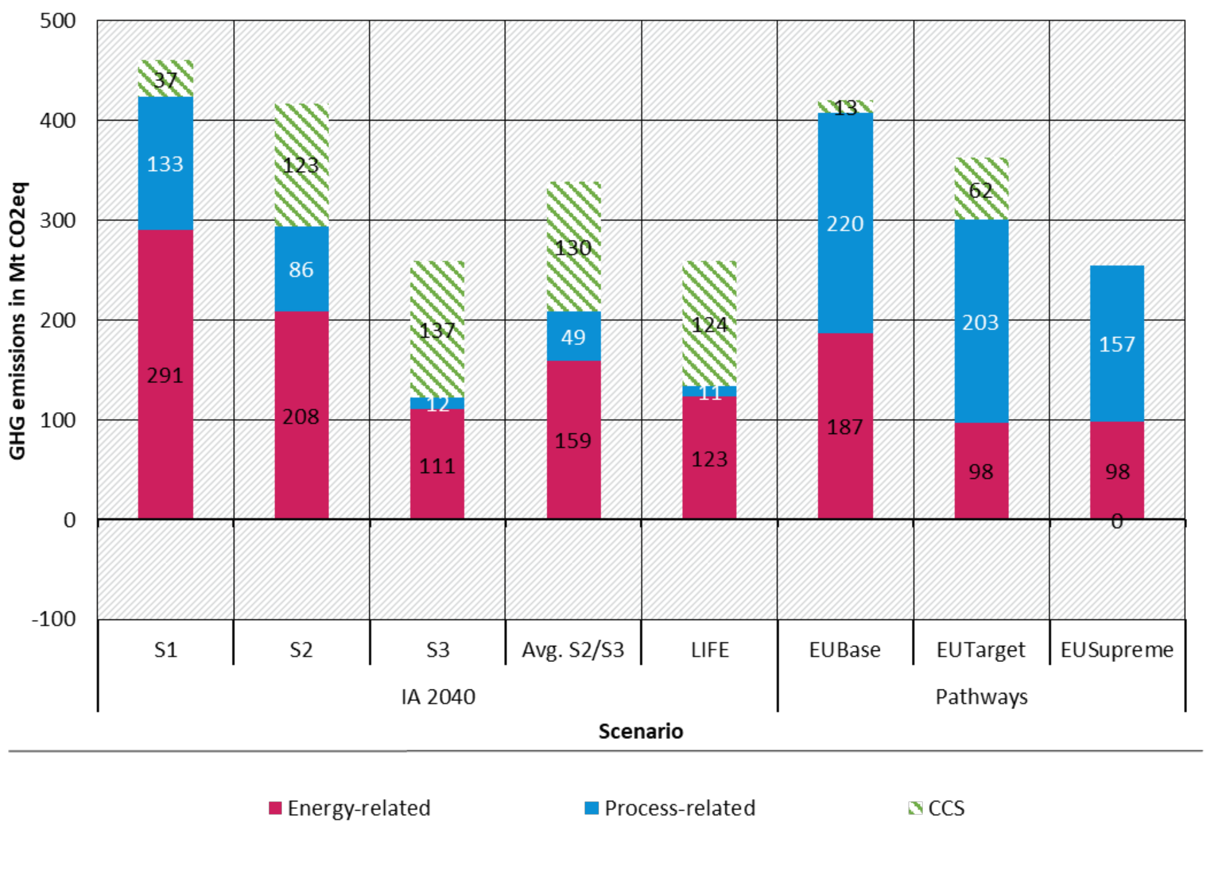
3.1.3 Conclusions

The comparative analysis of net GHG emissions and electricity generation across the IA 2040 and Pathways scenarios reveals significant differences in emissions trajectories and energy strategies. The role of CCS is critical in the IA 2040 scenarios, enabling significant emission reductions, especially in S2 and S3. In contrast, CCS plays no or only a minimal role in the achievement of emission reductions in the supply sector in the Pathways scenarios. In terms of electricity generation, the IA 2040 scenarios project higher total generation driven by increased electricity demands for hydrogen and e-fuel production.

3.2 Industry

3.2.1 Overview

Figure 3: Net GHG emissions in the industry sector in 2040



Source: own illustration, FORECAST, Fraunhofer ISI, Oeko-Institut

Figure 3 shows the projected industrial GHG emissions in the EU 27 by 2040, classified by source (energy-related, process-related, and CCS emissions). The IA 2040 scenarios achieve a substantially more significant reduction in net GHG emissions compared to the Pathways scenarios, primarily due to the extensive use of Carbon capture and use (CCUS). The IA 2040 scenarios place greater emphasis on CCUS, leading to higher captured emissions. Notably, scenarios S3 and LIFE result in negative net emissions in the industrial sector.

A more detailed examination of the sub-sectoral level indicates that the discrepancy between the IA 2040 scenarios (S1-S3 and LIFE) and the Pathways scenarios (EUBase EUTarget and EUGS) is most evident in the non-metallic mineral products sector (Table 3). In this sector, the EUTarget and EUSupreme pathways show considerably higher values than S1, S2, S3 and LIFE, with EUTarget at 132 Mt CO_2eq and EUSupreme at 133 Mt CO_2eq, compared to S1 and S3, which are at 33 and 22 Mt CO_2eq, respectively. Similarly, the chemical industry demonstrates a similar trend whereby EUSupreme still shows much higher GHG emissions than IA 2040 scenarios. Furthermore, the iron and steel sector also exhibit a notable discrepancy, in EUBase and EUTarget, compared to IA 2040 scenarios. However, in the EUSupreme scenario, the GHG emissions for iron and steel align more closely with the IA 2040 scenarios.

Table 3: Total EU 27 industry GHG emissions by 2040 by sub-sector and scenario

Sub-sector /scenario	S1	S2	S3	LIFE	EUBase	EUTarget	EUGS
Iron and steel	16	13	10	11	113	71	18
Chemical industry	13	10	8	9	85	56	56
Non-metallic mineral products	33	26	22	23	148	132	133
Non-ferrous metals	4	3	3	3	9	8	8
Paper and printing	8	6	5	5	9	7	9
Engineering and other metal	17	11	9	11	5	4	5
Food, drink and tobacco	19	14	10	13	7	4	5
Other non-classified	15	10	8	10	11	8	10
Captured emissions	(-)37	(-)123	(-)137	(-)124	(-)13	(-)62	0

Source: own compilation, Fraunhofer ISI, Oeko-Institut

According to Figure 49 in the Impact Assessment, the final energy demand (FED) for the industry excluding refineries ranges from 168 to 176 Mtoe (equivalent to 1,954 to 2,048 TWh) by 2040. This is substantially lower than in the UBA Pathways scenario, in which the FED ranges from 2,686 TWh in the EUSupreme scenario to 2,821 TWh in the EUTarget scenario. Furthermore, there are significant discrepancies in the projected degree of electrification by 2040. The UBA Pathways foresee electrification levels ranging from 57% in the EUTarget scenario to 61% in the EUSupreme scenario, while the IA 2040 scenarios project a lower range of 44% to 49%. In contrast, hydrogen demand remains comparable to the Pathways scenarios, with IA 2040 ranging from 160 TWh in S1 to 216 TWh in S3, and Pathways scenarios ranging from 150 TWh in EUTarget to 200 TWh in EUSupreme.

3.2.2 Comparison of modelling assumptions and results

One of the main drivers of energy demand in the industry sector is the production activities for energy-intensive products in sectors like iron and steel, chemical industry, and non-metallic mineral products. These sectors require high-temperature processes that result in significant energy-related GHG emissions and rely on chemical reactions that result in substantial process-related GHG emissions. The emission intensity of energy-related GHG emissions is strongly influenced by the type of fuel used and the efficiency of the processes. Process-related GHG emissions are mainly determined by the chemical reactions of the processes involved, such as the release of carbon dioxide during calcination in cement production. Consequently, addressing these emissions will require fundamental changes in the production processes, which is often more complex.

The economic framework applied in the IA 2040 differs from that of the UBA Pathways project. A comprehensive comparison is not possible due to the lack of relevant data in the IA 2040 report. However, production activity data, which is driven by economic performance to a certain extent, is available. Table 4 provides a summary of the relative changes in production levels for key domestic production activity for selected products between 2015 and 2050 from both modelling exercises, highlighting the key differences in projected outputs by 2050. In the IA 2040 (S1-S3), the projections generally indicate a stable or increasing production level across all products by 2050, reflecting a strong emphasis on growth. The UBA Pathways scenarios (EUBase-EUTarget) show a similar trend but with more moderate increases. However, there is an exception in the iron and steel sector, for which EUBase projects a reduction in primary production. In contrast, the LIFE scenario and the EUSupreme scenario both include enhanced circular economy and longer-lasting products and thus demonstrate overall reductions in production by 2050 in comparison to (S1-S3) and (EUBase -EUTarget), respectively. The projection of production in EUSupreme shows a more substantial reduction, particularly in sectors such as iron, steel. Table 5 provides a summary of the relative changes in production levels for key domestic production compared to EU Supreme by 2050.

Table 4: Comparison of the projection of domestic production for selected materials changes in 2050 compared to 2015 across different scenarios

Product	S1-S3	EUBase-EUTarget
Iron and steel	0%	-8% (-15% in primary)
Cement	20%	22% (-7% in clinker share)
Petrochemical	25%	0%
Aluminium	35%	1%
Paper and printing	5%	11%

Source: own compilation, Fraunhofer ISI, Oeko-Institut, based on (European Commission 2024b, part 3, table 8)

Table 5: Comparison of projection of domestic production for selected materials changes in EUSupreme and Life versus S1-S3 by 2050

Product	LIFE vs S1-S3	EUSupreme vs S1-S3
Iron and steel	-15% (-25% in primary)	-28% (-45% in primary)
Cement	-25%	-23%
Petrochemical	-15%	-16%
Aluminium	-20	-20%
Paper and printing	-20% (-40% primary)	-7% (-5% primary)

Source: own compilation, Fraunhofer ISI, Oeko-Institut, based on (European Commission 2024b, part 3, table 8)

It is important to note that in the available documentation of the EU IA 2040, there is also no full elaboration of how the projected reductions in material use are to be achieved and what specific measures or policies are driving these changes. Understanding the mechanisms behind these reductions is essential for evaluating the feasibility and effectiveness of the scenarios. Without this detailed information, it becomes difficult to accurately assess how each scenario intends to meet its emission reduction targets and what the broader implications might be for the industrial sectors involved. In addition to the observed differences in production trends, there is a degree of ambiguity regarding the assumptions made about technology diffusion rates in the IA 2040. The details of how rapidly and extensively climate-neutral technologies and fuel-switching strategies are expected to be implemented are not fully elaborated. This makes it challenging to compare the assumptions underlying the IA 2040 scenarios with those of the UBA Pathways.

3.2.3 Conclusions

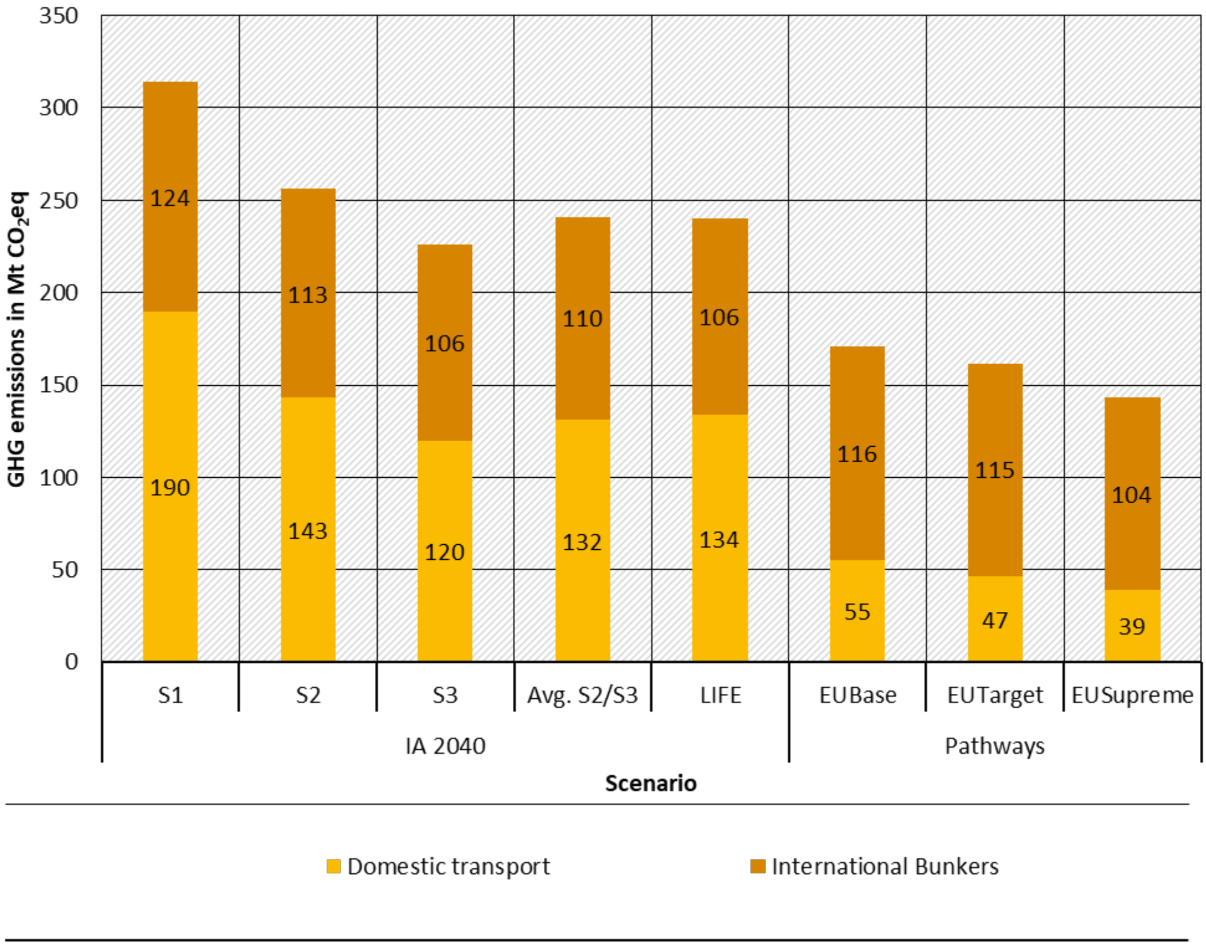
In conclusion, the comparison of the IA 2040 and UBA Pathways reveals significant discrepancies in narratives, assumptions, and projected outcomes. As the EUBase scenario is not a target scenario, it does not align with any of the IA 2040 scenarios. However, the EUTarget scenario can be compared to S2 or S3 in terms of production activity assuming higher production activities and more ambitious emission reduction efforts. These scenarios share a common focus on the rapid diffusion of novel technologies while maintaining or increasing significant industrial output. The LIFE scenario is comparable to the EUSupreme in its ambitious approach to deep decarbonisation through lifestyle adjustments and reductions in material demand. However, the EUSupreme scenario stands out for its higher ambition level but does not achieve the net GHG emission reduction achieved in the IA 2040 scenarios. This is because CCUS is not permitted in the EUSupreme scenario, which leaves residual emissions unaddressed within the industrial sector. As a result, these emissions would need to be fully compensated in other sectors to meet overarching climate targets. The lower final energy demand and GHG emissions in IA 2040, despite substantial industrial activity, raise critical questions about the assumptions driving these projections and the feasibility of the transformation paths in IA 2040. This involves in particular the mechanisms behind projected reductions in material use and diffusion rates of climate-neutral technologies and fuel switching strategies.

3.3 Transport

3.3.1 Overview

Figure 4 presents net GHG emissions in the transport sector for the two sets of scenarios. GHG emissions from international bunkers are at the same level, ranging from 106 to 124 Mt CO_2eq in the IA 2040 scenarios and from 104 to 116 Mt CO_2eq in the Pathways scenarios. GHG emissions from domestic transport, however, differ substantially between the two scenario sets: IA 2040 scenarios result in emissions of 120-190 Mt CO_2eq. whereas the Pathways scenarios result in 39-55 Mt CO_2eq. Table **6** disaggregates the direct CO_2 emissions by transport mode, showing that the largest differences between the two scenario sets are in road transport. In 2040, cars and trucks account for about half of CO_2 emissions in the IA 2040 scenarios (S1, S2, S3, and LIFE), but only a fifth (EUSupreme, EUTarget) to a quarter (EUBase) of CO_2 emissions in the Pathways scenarios.

Figure 4: Net GHG emissions in the transport sector in 2040



Source: own illustration, Oeko-Institut

Table 6 Direct CO_2 emissions from EU27 transport sector in 2040 by mode (Mt CO_2)

Transport mode	S1	S2	S3	Avg.S2/S3	LIFE	EUBase	EUTarget	EUSupreme
Road	165.1	122.5	100.9	111.7	115.0	43.6	34.4	28.0
- Passenger cars*	95.6	71.9	60.4	66.1	69.1	12.5	12.2	16.0
- Trucks*	57.5	41.8	33.4	37.6	37.5	31.1	22.2	12.0
- Other*	12.0	8.8	7.2	8.0	8.4	-	-	-
Rail	**1.6**	**1.2**	**1.0**	**1.1**	**1.1**	**0.6**	**0.4**	**0.5**
Navigation	**51.1**	**40.0**	**31.4**	**35.7**	**31.4**	**52.9**	**66.6**	**63.7**
- Domestic	9.9	7.3	6.3	6.8	7.1	5.8	7.2	8.2
- International	41.2	32.7	25.1	28.9	24.3	47.2	59.4	55.6
Aviation	**92.2**	**88.8**	**85.7**	**87.3**	**78.1**	**73.3**	**60.3**	**50.7**
- Domestic	9.0	8.5	8.1	8.3	7.2	5.2	4.6	2.5
- International	83.2	80.3	77.6	78.9	70.9	68.5	55.7	48.2
Total transport	**310.0**	**252.4**	**219.0**	**235.7**	**225.6**	**170.9**	**161.8**	**143.0**

*) The 'trucks' category aggregates light commercial vehicles (<3.5t) and heavy goods vehicles (>3.5t). Pathways include buses in trucks and two-wheelers in cars. IA 2040 groups buses and two-wheelers together as "other road transport".
Source: IA 2040 (Fig. 76), Fraunhofer ISI

3.3.2 Comparison of modelling assumptions and results

While the IA 2040 used the PRIMES-TREMOVE model to simulate the equilibrium of the transport market, covering all modes with a single model, the Pathways project used separate models to derive the energy demand from cars (including two-wheelers), trucks (including buses and light commercial vehicles), rail transport, navigation, and aviation. In the following, the main drivers of energy demand and emission intensity such as the transport activity development, the diffusion of alternative drivetrains, and the share of sustainable fuels are compared for each mode. If no individual scenario is specified, the comparison of Pathways and IA 2040 includes all scenarios within the two scenario sets (EUBase/EUTarget/EUSupreme compared with S1-S3/Life).

In the IA 2040 scenarios, no carbon-containing e-fuels are imported. In the Pathways scenarios. it was assumed that imported e-fuels are carbon-neutral (produced with CO_2 from direct air capture).

3.3.2.1 Road transport

For passenger cars, the IA 2040 scenarios model a technology mix of battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), internal combustion engine vehicles (ICEVs) and fuel cell electric vehicles (FCEVs). They result in a car stock consisting of 57-58% BEVs, 11% PHEVs and 5% FCEVs. ICEVs still make up about a quarter of the stock in 2040. The Pathways scenarios, however, generally assume that only BEVs will prevail on the passenger car market. They model a country-specific diffusion curve of plug-in electric cars (BEVs and PHEVs as transitional technology) based on a logistic regression of the market development in Norway. They show an almost complete electrification by 2040, with the result that ICEVs make up less than 3% of the car fleet.

For trucks, the Pathways project used the agent-based simulation ALADIN, which derives market shares of drive technologies in Germany based on individual total cost of ownership. The diffusion of alternative drives in Germany is transferred to other EU27 countries based on the territorialised road freight transport performance. For the Pathways scenarios, ALADIN considered 6 drive options: diesel, BEVs, PHEVs and FCEVs as well as two types of catenary trucks (battery electric and diesel hybrid, only for heavy-duty vehicles >12 tonnes). IA 2040 additionally considered liquified natural gas (LNG) trucks in the heavy-duty segment, but did not consider catenary trucks.

For light duty trucks (<3.5 tonnes, also known as vans or light commercial vehicles), the agent-based simulation for the Pathways scenarios results in an almost fully electrified fleet by 2040 (97% BEVs, <3% diesel, <1% FCEVs, <1% PHEVs), whereas in the IA 2040 scenarios, the 2040 stock is more diverse, consisting of BEVs (39-40%), diesel trucks (38%), FCEVs (5%), and PHEVs.

For heavy duty vehicles (>3.5 tonnes), the technology mix is more diverse in both studies. In the IA 2040 scenarios, diesel trucks make up half of the stock; only a quarter is battery electric. The remaining stock consists of FCEVs (12-14%), liquefied natural gas (LNG) trucks (5-6%), and different types of diesel hybrids (5%). In all Pathways scenarios, over 80% of the vehicles of 3.5 tonnes or more are fully electric (including 14-15% catenary), the remaining stock is divided in ICEVs, FCEVs, and diesel hybrid catenary trucks. As in the passenger car segment, the difference in the emission gap between the two studies can be explained by the different degree of electrification in 2040. Possible reasons for this are the consideration of different technologies (catenary trucks are considered only in the Pathways scenarios), the different geographical coverage of the agent-based models used (Germany or EU).

3.3.2.2 Other transport modes

For rail transport, aviation, and navigation, the Pathways scenarios are built on assumptions for transport activity, efficiency improvements, and fuel mix. The IA 2040 scenarios were modelled using the PRIMES-TREMOVE model. This model calculates transport activities endogenously in its transport demand allocation module before determining the mix of vehicle technologies in its technology choice and equipment operation module.

Rail transport plays a minor role in terms of total emissions as it is already largely electrified, and its energy demand is comparatively low. Up to 2040, both scenario sets expect a substantial growth of both passenger rail transport (average annual growth of 1.8-2.2% in Pathways, 2.6-3.0% in IA 2040) and freight rail transport (average annual growth of 1.9-2.0% in Pathways, 3.1-3.2% in IA 2040), especially in the sufficiency scenarios, EUSupreme and Life, which model an additional modal shift to rail. This makes rail transport the fastest-growing mode in all scenarios, with growth in the IA 2040 scenarios even more pronounced than in the Pathways scenarios. This, combined with a less advanced degree of electrification, leads to higher emissions in the IA 2040 scenarios, compared to the Pathways scenarios.

In the aviation sector, the results from agent-based modelling in IA 2040 are fundamentally similar to the assumptions made in the Pathways scenarios. A large share of the jet fuel used in domestic and international aviation is still fossil, while the direct use of electricity and hydrogen make up less than 2% (IA 2040 scenarios) and less than 3% (Pathways scenarios) of the total energy demand. Both domestic and international air transport activity is expected to grow steadily in the main scenarios (0.5% a year in Pathways' EUBase/EUTarget, 1.8-2.0% a year in IA 2040 S1-S3) and to be comparatively lower in the sufficiency scenarios, due to a reduced growth (Life) or even an absolute decline (EUSupreme). The generally lower emissions in the Pathways scenarios can be explained by the smaller transport activity growth and the higher share of sustainable aviation fuel (43-55%, compared to 34-37% in IA 2040).

In domestic navigation, fossil fuels make up about the half of energy consumption in both the Pathways and IA 2040 scenarios. However, transport activity growth differs substantially. While the Pathways scenarios only consider growth in freight transport activity in the EUSupreme scenario to account for a modal shift from road to inland waterways, the IA 2040 scenarios expect growth in activity across all scenarios.

International navigation is the only transport mode for which IA 2040 scenarios generally show lower emissions than the Pathways scenarios. This is due to the high share of biogenic and synthetic fuels (>70% combined) and the incipient diffusion of electric and hydrogen-powered ships in all IA 2040 scenarios. The Pathways scenarios do not expect alternative drives in international navigation and assume that fossil fuels still make up about half of the 2040 fuel mix (non-fossil fuels reach shares of over 70% only from mid-2040s onwards).

3.3.3 Conclusions

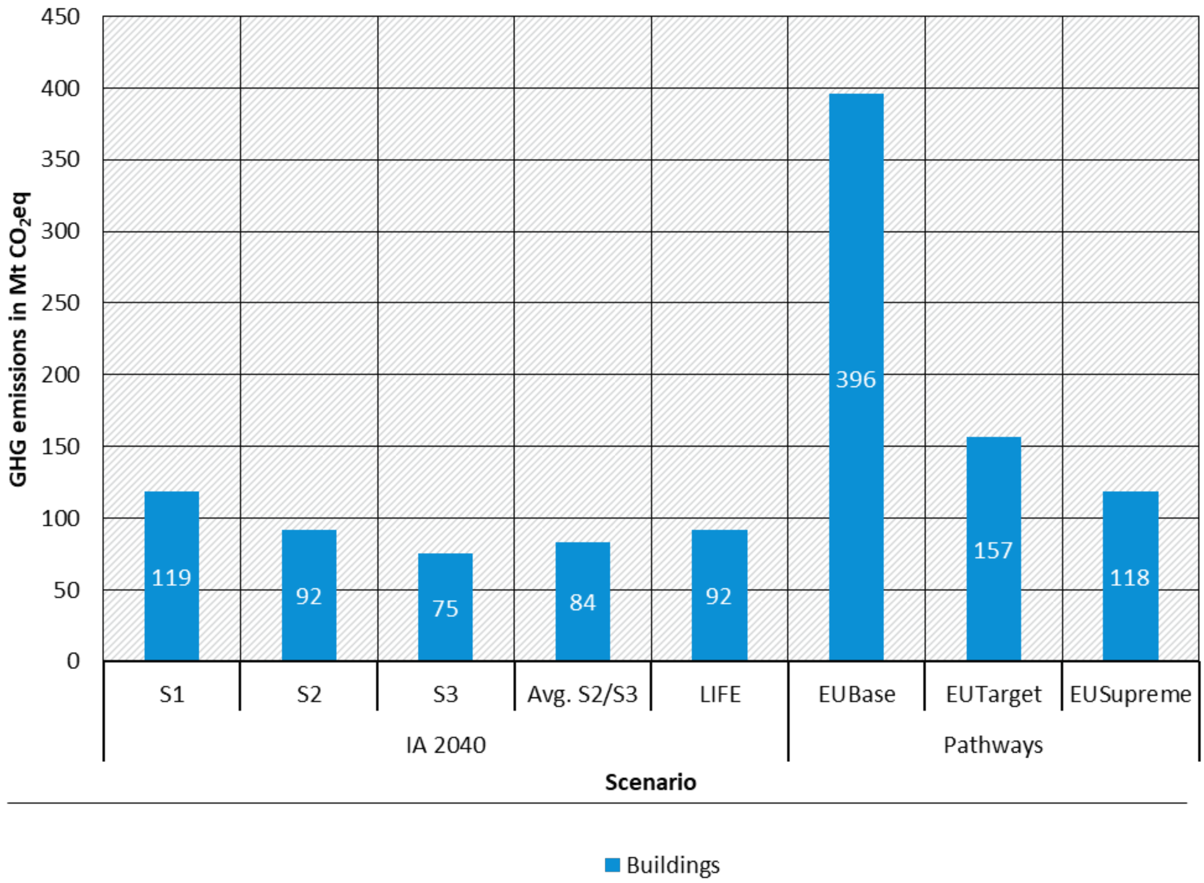
The Pathways scenarios provide a clear strategy for achieving net-zero transport: electrification on land, and the use of synthetic and biogenic fuels on water and in the air. Hydrogen is used only in niche applications for heavy-duty trucks, short-haul aircraft, and inland waterway vessels. In contrast, the IA scenarios model a mix of technologies and fuels in all segments. Compared to the Pathways scenarios, they are less ambitious with respect to the electrification of road and rail transport and generally more optimistic with respect to the use of hydrogen and biofuels in transport. The total demand for synthetic fuels is comparable to that of the Pathways scenarios, but is spread across all transport modes; however, the Pathways scenarios use them specifically in the hard-to-abate transport modes of aviation and navigation. The electrification of the vehicle stock plays a key role in reducing road transport emissions by improving both energy efficiency and emission intensity. It further facilitates the targeted use of limited biomass and e-fuels in hard-to-abate sectors such as maritime and air transport. In the Pathways scenarios, the electrification of both passenger and freight road transport is almost complete, whereas the IA 2040 scenarios still expect a substantial share of ICEVs in all modes. The different ambition level in terms of electrification leads to large differences in emissions between the two sets of scenarios. Therefore, it is not meaningful to compare the individual scenarios in detail. From a storyline perspective, however, the LIFE and EUSupreme scenarios are similar as they both model a reduction in transport activity in road transport and aviation and a modal shift to rail and domestic navigation.

3.4 Buildings

3.4.1 Overview

With the exception of S1, all four IA 2040 scenarios reach GHG emission levels in the buildings sector of 92 Mt CO_2eq or less (S1: 119 Mt CO_2eq). For the UBA Pathways scenarios, only EUSupreme comes close to a similar GHG reduction value, reaching 118 Mt CO_2eq in 2040. With 157 Mt CO_2eq, the EUTarget is far ahead of EUBase, which is expected to reach close to 400 Mt CO_2eq by 2040.

Figure 5: Net GHG emissions in the buildings sector in 2040



Source: own illustration, Oeko-Institut

3.4.2 Comparison of modelling assumptions and results

The models used in the Pathways scenarios and the IA 2040 scenarios differ substantially. While the IA 2040 scenarios for the buildings sector were modelled with the integrated PRIMES energy model, the Pathways scenarios are based on a simple stock-exchange modelling approach.

Renovation rates differ slightly between the two sets of scenarios. The IA 2040 scenarios show a steep increase in renovation rates in residential buildings from 1% in 2020 to more than 2% in 2030 before falling again slightly to 1.5-2% thereafter (the changes are less pronounced for non-residential buildings). The Pathways scenarios also see a steep increase towards 2030, reaching renovation rates of more than 2%. However, in contrast to the IA 2040 scenarios, the rates stay on average at around 2.5% thereafter (in EUSupreme, they are slightly higher; in EUTarget, they are slightly lower). In accordance with the IA 2040 scenarios, the renovation rates for non-residential buildings remain at slightly lower levels compared to the residential buildings.

There are some marked differences in building standards for new buildings. New buildings in the IA 2040 scenarios start at around 40 kWh/m^2 of useful energy for space heating in 2020 reducing to 27 kWh/m^2 by 2040. EUSupreme, in contrast, starts at 60 kWh/m^2 of final energy demand in 2020 and linearly decreases to 15 kWh/m^2 by 2040, showing a much steeper decline in energy standards compared to the IA 2040 scenarios.

In terms of final energy consumption, only EUSupreme reaches levels similar to the IA 2040 scenarios in 2040: EUSupreme has a total of 2,713 TWh of final energy (excluding ambient heat made available via heat pumps to enable comparison with the IA scenarios), while the average of the combined S2/S3 scenarios amounts to 2,726 TWh in 2040. EUTarget only manages 3,038 TWh in 2040.

The energy carrier distributions differ in various ways between the EUSupreme and the IA 2040 scenarios. Electricity and biomass usage are substantially higher in the IA 2040 scenarios compared to EUSupreme, whereas district heating and solar thermal are much reduced. Uptake of heat pumps is more pronounced in the IA 2040 scenarios, even though EUSupreme is also very ambitious with the roll-out of heat pumps. Heating oil usage is higher in the EUSupreme scenario compared to any of the IA 2040 scenarios. By 2050, however, heating oil usage is completely eliminated in the EUSupreme scenario. Natural gas usage is fairly similar, with the S1 scenario showing the highest usage in 2040 with close to 400 TWh compared to both the other IA 2040 scenarios and EUSupreme (all with less than 300 TWh).

The increase in floor area in residential buildings is higher in the IA 2040 scenarios (+21% with respect to 2015) compared to the Pathways scenarios (+17% in EUBase, +10% in EUTarget and +8% in EUSupreme). For non-residential buildings, the floor area does not increase much in either set of the considered scenarios. While the LIFE scenario assumes more sustainable lifestyles and a move towards a more circular and shared economy, this does not have an impact on the floor area in residential buildings. Sufficiency measures in LIFE focus on room temperature reductions in winter. In contrast, in the Pathways scenarios EUTarget and EUSupreme sufficiency focuses on a combination of less new buildings being built and better use of existing buildings leading to a reduced increase in floor area.

3.4.3 Conclusions

The only scenario from the Pathways suite of scenarios that achieves outcomes similar to those of the IA 2040 scenarios is the EUSupreme scenario. In terms of final energy consumption in 2040, EUSupreme achieves levels very similar to the S2/S3 scenarios while with a view to GHG emissions, EUSupreme only achieves levels similar to S1 and lags behind the more ambitious S2/S3 scenarios.

The level of ambition is already high for the EUSupreme scenario, but in terms of GHG emission reductions S2, S3 and LIFE achieve even higher reductions by 2040. Given that the final energy consumptions do not vary significantly, this extra GHG emissions reduction in the more ambitious IA 2040 scenarios stems from an even higher roll-out of heat pumps combined with lower levels of fossil heating oil usage. Regarding the growth in floor area, EUSupreme and EUTarget are more ambitious than any of the IA scenarios, allowing EUSupreme and EUTarget to reach the reported final energy consumption and GHG emission values in 2040.

In terms of modelling, there are clear differences between the models used. The Pathways scenarios have been modelled with a comparatively simple stock model approach with price signals from CO_2-prices parameterised outside the actual modelling environment. The IA 2040 scenarios were modelled with the PRIMES energy model, which includes an integrated optimisation to price signals.

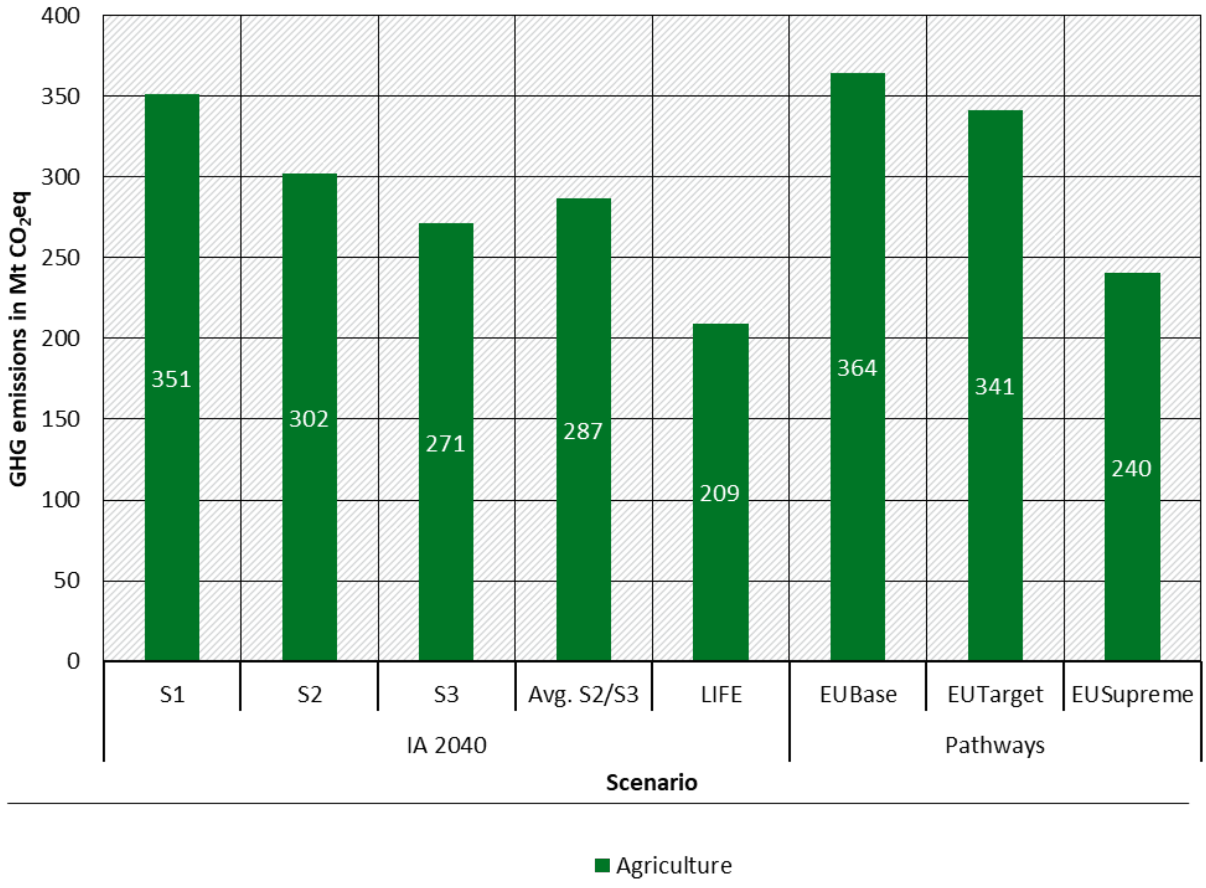
3.5 Agriculture

3.5.1 Overview

Figure 6 shows the emissions from the agricultural sector across various scenarios in the EU's IA, compared to those in the UBA Pathways project. GHG emissions from the EU's IA show partly a stronger reduction by 2040, ranging from -5% to -44% compared to 2022, whereas the EU Pathways scenarios achieve reductions between -2% and -35%. In terms of the storyline and the emission reduction pathways of the scenarios, the scenario S2 of the IA can be compared to the EUTarget Scenario and the LIFE to the EUSupreme. In the LIFE scenario, emissions can be reduced to 209 Mt CO_2eq, while in the EUSupreme scenario, emissions are reduced to 240 Mt CO_2eq. The S2 scenario sees emissions reduced to 302 Mt CO_2eq, whereas in the EUTarget scenario, agricultural emissions are 342 Mt CO_2eq. Thus, compared to the IA scenarios, emissions in the Pathways scenarios are approximately 40 Mt CO_2eq higher.

In S1, emissions follow current trends up to 2040 and the main emission reductions occur between 2040 and 2050. S2 represents a linear pathway to 2050, while S3 and the LIFE scenario achieve major emission reductions by 2040 and the emission reduction curve flattens out after 2040. The UBA pathways scenarios also follow a linear pathway up to 2050 like S2. Therefore, even though the EUSupreme scenario shows lower emissions in 2050 compared to the LIFE scenario, the emissions in 2040 are still higher due to the linear reduction pathway of the LIFE scenario compared to the emission pathway of the LIFE scenario.

Figure 6: Net GHG emissions in the agriculture sector in 2040



Source: own illustration, Oeko-Institut

3.5.2 Comparison of modelling assumptions and results

3.5.2.1 Technical mitigation measures

The EU IA employs a broad range of technical mitigation measures to reduce emissions from the agricultural sector. These measures include anaerobic digestion, feed additives, breeding for ruminant efficiency, variable rate technology, precision farming, and nitrification inhibitors.

The mitigation potential against the baseline varies for each technology over time and additionally depends on factors such as farm size and combination of technologies. However, some mitigation options are assumed to have significant potential. For example, the emission reduction from applying nitrification inhibitors in mineral and organic fertilizers ranges from 19% to 54% compared to baseline levels. Feed additives show a mitigation potential of up to 15%, while breeding becomes relevant with a mitigation potential of up to 35%. Using variable rate technology can reduce N_2O emissions by between 16% and 41%.[4]

The UBA Pathways scenarios also consider technical mitigation options such as anaerobic digestion, feed additives, nitrification inhibitors, and increased nitrogen efficiency. However, due to conservative assumptions about the mitigation potential of these measures, the overall potential of technical measures is lower. For instance, an emission reduction of 34% is assumed for nitrification inhibitors and 15% for feed additives, while breeding effects and application of

[4] https://climate.ec.europa.eu/document/download/e1ae0c6c-aa6a-4757-9c27-6f8bdc83bcb8_en?filename=policy_strategy_targets_2040ct_technology_assumptions.zip

variable rate technologies are not reflected in the scenarios. In the EUSupreme scenario, feed additives and nitrification inhibitors are not considered due to uncertainties regarding environmental impact, animal welfare, and long-term mitigation effects (IPCC 2022).

3.5.2.2 Development of animal numbers and dietary changes

A significant driver of emission reduction is the development of animal numbers in combination with a reduction in demand for animal products on the consumption side. While emissions from poultry and pigs can be addressed through technical measures like anaerobic digestion and nitrification inhibitors in slurry, CH_4 emissions from ruminants are particularly relevant. Scenarios vary regarding animal numbers (see Table 7). Scenarios S1-S3 project a very slight decrease in animal numbers by 2040, with cattle numbers decreasing by only 6% compared to 2020, while the pig population remains almost stable, and sheep and goat numbers increase. The EUTarget scenario presents a moderate reduction in animal numbers, whereas the LIFE and EUSupreme scenarios show a more substantial reduction. In the EUSupreme scenario, livestock numbers nearly halves compared to the base year 2020 by 2040. This is due to the assumption that the Planetary Health Diet is implemented on the consumption side up to 2050. In the LIFE scenario, there is an almost -30% reduction in animal numbers by 2040 and in line with a changing demand for animal products.

Table 7: Development of animal numbers in 2040 in comparison to 2020

Animal numbers	S1, S2, S3	LIFE	EUBase/EUTarget	EUSupreme
Total cattle	93.9%	68.0%	87.0%	51.1%
of which dairy cows	91.9%	82.8%	86.1%	51.7%
of which other cattle	95.8%	59.3%	87.8%	50.6%
Pigs	98.6%	72.0%	84.0%	38.1%
Poultry	89.5%	69.7%	108.0%	72.0%
Sheep and goats	107.9	87.1%	106.0%	66.7%

Source: IA 2040, Oeko-Institut

3.5.3 Conclusions

Despite the analogies in the storylines of the scenarios of the IA and UBA Pathways, there are differences in the assumptions and the ambition level which explain the differences of about 30 to 40 Mt CO_2eq between the results of the IA scenarios and the UBA pathways scenarios. In all IA scenarios, animal numbers remain higher than in the EU Pathways scenarios, exceeding EUBase/EUTarget values for all categories except sheep and goats. In the LIFE scenario, livestock numbers also remain higher than in the EUSupreme. Even with lower livestock numbers, emissions remain higher in the UBA Pathways scenarios compared to the IA scenarios. Due to the implementation of additional mitigation technologies, their adoption rate and ambitious assumptions about the mitigation potential of various technical options, emission reductions through technical measures are significantly higher in the IA scenarios. Even if animal numbers are not reduced as drastically as in the Pathway scenarios, total agricultural emissions in these scenarios therefore reach a lower emission level.

Besides this explanation there are differences in methodology, such as varying submission years and emission factors, which might explain some of the discrepancies. However, it is not possible to determine the exact impact of these differences on absolute GHG emissions.

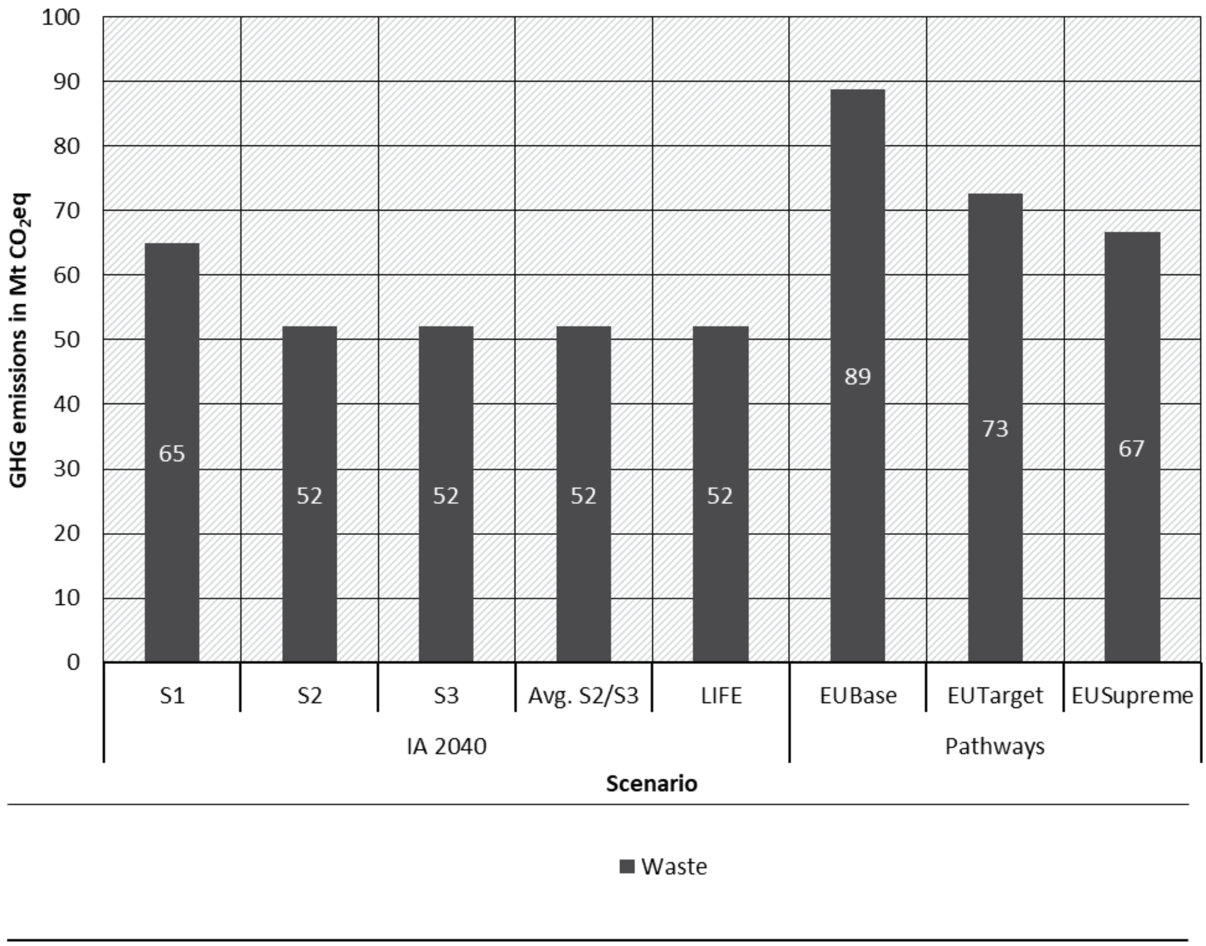
Overall, the differences in scenario results can largely be attributed to the varying assumptions made. However, it remains very unclear whether the ambitious assumptions about the technical mitigation in the IA scenarios (e.g. up to -35% for breeding or -35% for the implementation of variable rate technology) can be achieved in practice.

3.6 Waste

3.6.1 Overview

The IA 2040 scenario S1 leads to 65 Mt CO_2eq in 2040 while the scenarios S2, S3 and LIFE lead to 52 Mt CO_2eq. These levels are below all the results for the Pathways scenarios: While in EUBase, GHG emissions from the waste sector are at 89 Mt CO_2eq, they fall to 73 Mt CO_2eq in the EUTarget scenario and reach 67 Mt CO_2eq in EUSupreme. Figure 7 shows the emissions in the waste sector for 2040 for the different scenarios.

Figure 7: Net GHG emissions in the waste sector in 2040



Source: own illustration, Oeko-Institut

3.6.2 Comparison of modelling assumptions and results

For the IA 2040 scenario S1 and for the Pathways scenario EUBase, the current EU directives and policies on landfills, waste management and wastewater treatment are implemented in the models used for the respective reports.

The S2, S3 and LIFE scenarios implement additional measures such as source separation and anaerobic digestion technology with biogas recovery for waste treatment and 2-stage treatment for wastewater. For EUTarget, mandatory pre-treatment and increased gas collection is mandated for landfills, food waste levels are reduced and optimised wastewater treatment is implemented in countries with previously high emission factors. Measures are intensified in the EUSupreme scenario with, for example, a ban on untreated organic waste on landfills and higher levels of ambition overall.

The models used in the two assessments take a very different approach in the development of the projections:

- The GAINS model (JRC 2024) used in the IA considers mitigation potentials and costs for reduction air pollution and emissions. It focuses on cost-effective strategies for emission reduction.
- Waste_Mod, which is applied in the Pathways project, uses the emissions from the GHG inventory category CRF 5 to calculate the emission trajectories for the different sub-categories based on assumptions for their development. Emissions for landfills are based on the multi-phase waste model developed by the IPCC.

Both models use information from GHG inventories as a basis: GAINS is calibrated with statistics to reflect 2020 as a historical year with additional calibration to match emissions data from the 2023 GHG inventory (UNFCCC 2023). Modelling in the Pathways project uses 2022 GHG inventory data (UNFCCC 2022). This leads to differences in base year data as improvements of data quality as well as methodology have resulted in, for example, significant changes in inventory data for Germany. Table 8 shows that the sum of waste sector emissions for 2019 is 15% lower in the 2023 inventory submission than in the 2022 edition, with varying differences for the respective sub-sectors.

Table 8: Difference of waste sector GHG inventory data for 2019 in the 2023 submission compared to the 2022 submission

5. Waste	5.A Solid waste disposal	5.B Biological treatment of waste	5.C Incineration and open burning of waste	5.D Wastewater treatment and discharge	5.E Other
-15%	-18%	-23%	-8%	-4%	-5%

Source: UNFCCC (2023), UNFCCC (2022)

Additionally, it should be noted that data availability and quality for the waste sector is quite poor, although the situation has improved in recent years. This can additionally lead to differences in modelling results as gap filling assumptions have to be made. Since no information is available on such assumptions made in GAINS, it is not possible to compare the assumptions made for both models.

3.6.3 Conclusions

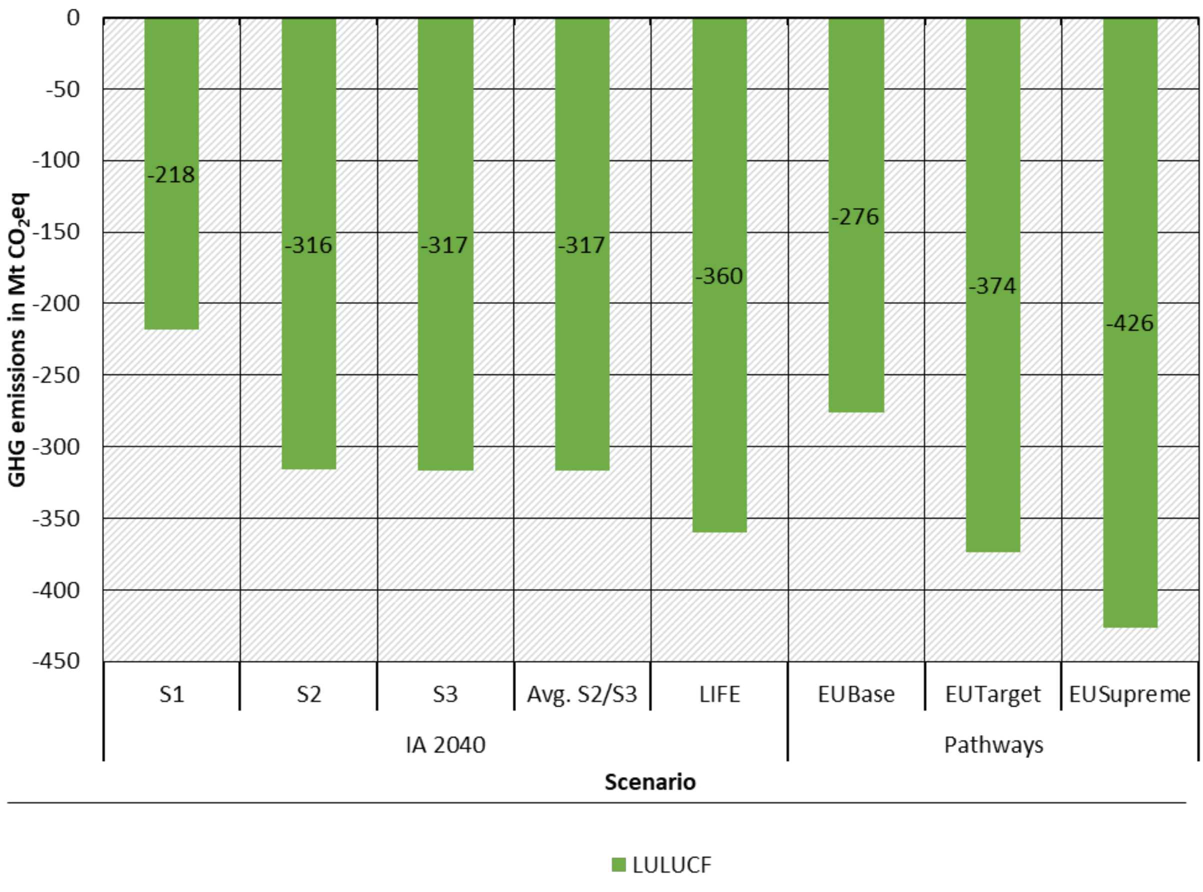
The EUBase scenario is most similar to S1 in terms of underlying assumptions and ambition level, while assumptions for the EUTarget scenario resemble those for S2 and S3. EUSupreme has a higher level of ambition for the waste sector as the IA. However, due to different modelling approaches and different historical data used in both projects, the results are not comparable.

3.7 Land Use, Land-Use Change and Forestry (LULUCF)

3.7.1 Overview

Figure 8 presents net GHG removals from the LULUCF sector achieved in 2040 in the IA scenarios S1, S2, S3, and the LIFE scenario and compare them against the three Pathways scenarios EUBase, EUTarget, and EUSupreme. The expected net sink ranges from a decrease from current levels (-236 Mt CO_2e in 2022, see EEA (2024)) to -218 Mt CO_2eq in S1 to a value that is almost double as low in EUSupreme (-426 Mt CO_2eq). Scenarios S2 and S3 are almost identical (-316 and -317 Mt CO_2eq, respectively). LIFE and EUTarget estimate a similar level for the net sink (-360 and -374 Mt CO_2eq, respectively).

Figure 8: Net GHG emissions in the LULUCF sector in 2040



Source: own illustration, Oeko-Institut

3.7.2 Comparison of modelling, assumptions and results

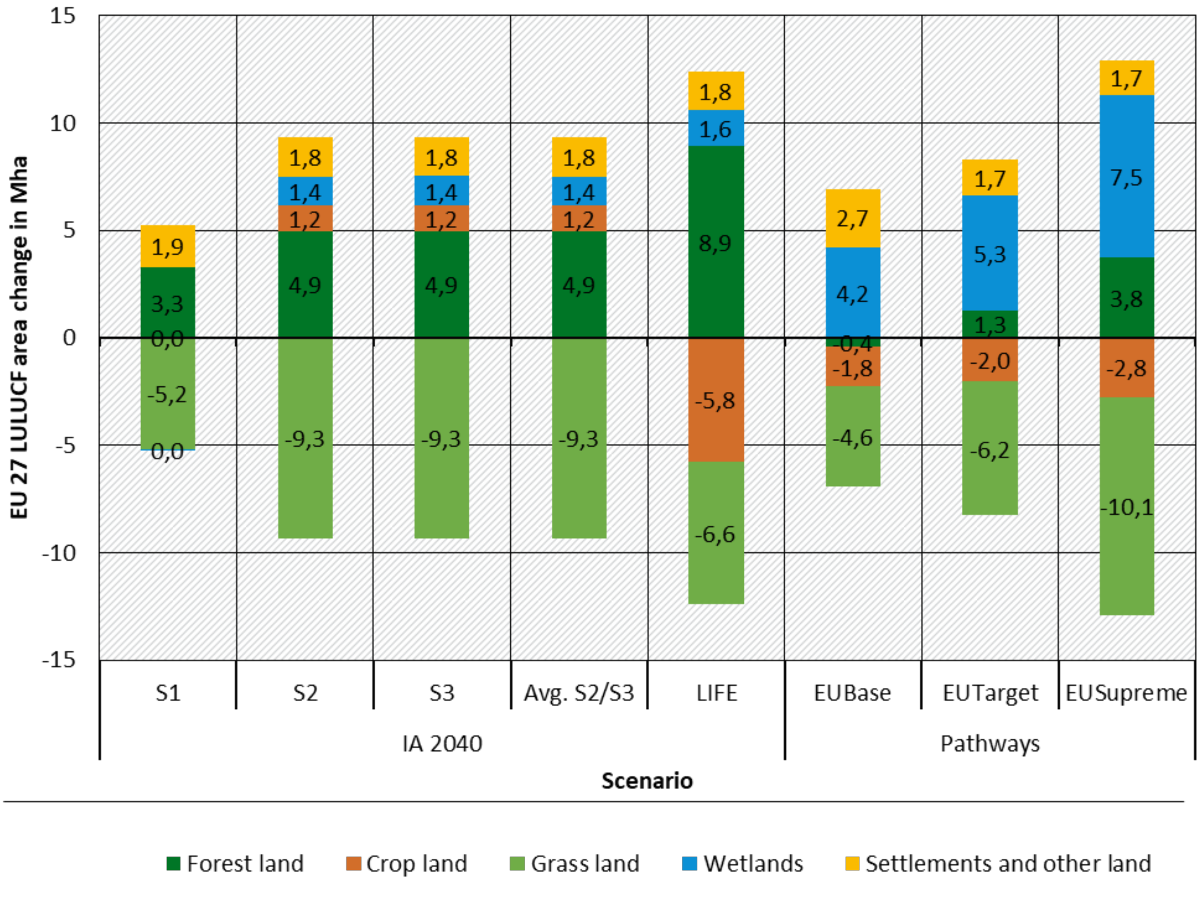
Both the S2 and S3 scenarios assume an increase in bioenergy until 2040 and a decline thereafter. The LIFE scenario instead assumes more sustainable lifestyles and a move towards a more circular and shared economy. These differences have implications for the LULUCF sector.

Compared to the EU IA 2040 results, the EUBase scenario assumes an increase of forest area through new forest plantations by 1% of current forest area, i.e. 1.6 Mha by 2050 compared to 2020 (see Figure 9 below). This is about 50% of the additional increase in forest area expected in the S1 scenario and 30% of the increase in S2 and S3. The EUTarget scenario, which assumes a 5% increase in forest area through new forest plantations by 2050 compared to 2020, is very close to S2 and S3. In the EUSupreme scenario, forest area can be increased by 10 Mha by 2050, which is very close to the estimates in the LIFE scenario.

While the IA expects that total cropland remains unchanged in S1, it increases by 1.2 Mha in S2 and S3. This is because around 80% of the required area for lignocellulosic crops comes from cropland currently used for first generation biofuels (7.5 Mha) or other croplands (1.9 Mha). Additional coppice and short-rotation plantation systems are established in the Pathways scenarios. By 2050, only 0.3 Mha of coppice area are established in 2050 in the EUBase scenario, whereas 6.9 Mha of coppice area are established in the EUTarget scenario, and 13.6 Mha in the EUSupreme scenario.

The additional sink capacities in S2 and S3 by 2040 are the result of sink enhancement through improved forest management, the establishment of new forests, and emission reductions through rewetting. These activities also influence changes in net emissions and removals in the Pathway scenarios. These expansions, including the increase in forest area, occur entirely on grassland and other natural land, i.e. land categories that do not affect crop production directly. Cropland for enhancing natural sink capacities only becomes available in the LIFE scenario used for carbon farming and increasing biodiversity through set-aside and fallow land. These anticipated land use changes are based on the assumption of reduced demand for feed due to lower meat and milk production.

Figure 9: Projected changes in land use between 2020 and 2040 in different scenarios

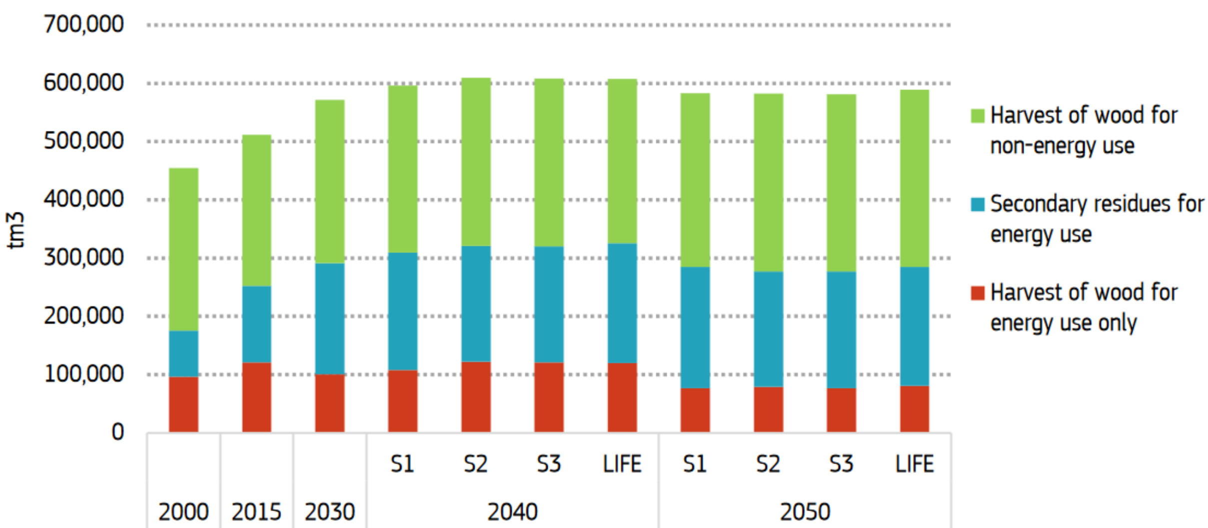


Source: own illustration, Oeko-Institut

In all scenarios, the net sink in the EU is dominated by the forest sink. Its strength depends on the relationship between forest increment and forest mortality and harvest levels. According to the IA, the wood harvest increased significantly after 2000, primarily due to an increased energy demand. The increase is expected to continue up to 2040, from 450 million m^3 in 2015 to around 600 million m^3 in 2040, an increase by 30%. However, differences between scenarios remain surprisingly small (see Figure 10 below). This is similar to the EUBase scenario that shows that carbon stocks in existing forests can potentially be increased. It assumes the forest sink can be maintained compared to 2020 by stabilising the harvest rate at about 84% of increment. In 2050, this amounts to 614 million m^3 (511 million m^3 of roundwood and 103 million m^3 of wood fuel (wood directly harvested for energy use)).

In the EUTarget and EUSupreme scenarios, wood supply is lower at 573 million m^3. This corresponds to 67% of the annual increment and results in higher carbon stocks in EU forests than in the EUBase scenario. It is assumed that the harvet reductions mainly relate to wood that is harvested for energy purposes. This is partly compensated by wood from newly established short rotation coppice (SRC).

Figure 10: Observed wood harvest in the EU in the past and projected demand in different scenarios



Note: 1 tm^3 =1000 m^3

Source: European Commission (2024b, part 3, figure 89)

Climate change feedbacks on natural emissions and removals are not explicitly considered in either the IA scenarios or the UBA Pathways scenarios. However, the authors of the IA carried out a modelling experiment simulating uncertainties associated with different assumptions on climate change drivers and a series of possible extreme events in 2035 for LULUCF net removals. As a consequence of these effects, net removals in 2035 could be dropping to -160 or even increase +30 Mt CO_2 at the time of the disturbance. After the event, the net sink recovers relatively quickly within a decade. However, such perturbations could result in a variability of the net sink to range between -130 to -330 Mt CO_2 in 2050.

3.7.3 Conclusions

In terms of the ambition level, the scenarios LIFE and EUTarget seem to be most comparable when examining the level of net removals. The EUSupreme scenario goes beyond the level of 400 Mt CO_2 in 2040, which is not reached by any of the scenarios of the IA.

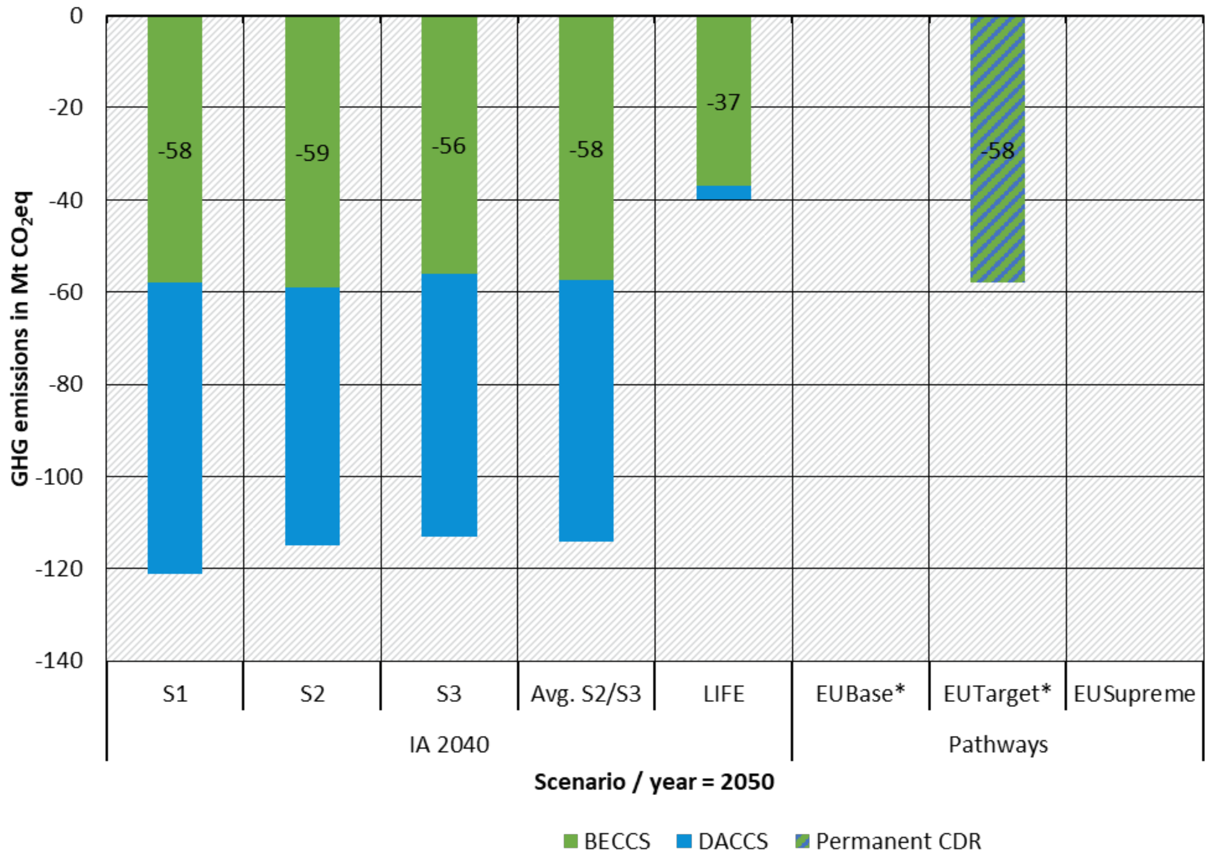
The similarity between assumptions in the LIFE and the EUSupreme scenarios is large with a view to the area expected to be used for afforestation. A major difference is that the S1, S2 and S3 scenarios of the IA assume that the area expansion of forests can be accomplished on grassland and other natural land without affecting crop production. In these scenarios, the cropland area even increases compared to 2020. In contrast, the UBA Pathways scenarios assume that considerable amounts of cropland need to be converted for sink enhancement already in both the EUBase and EUTarget scenarios. The total conversion of cropland is highest in the EUSupreme scenario and similar to the LIFE scenario (about 3 and 5 Mha by 2040, respectively).

There seem to be methodological differences regarding the forest growth dynamics. While the models of the IA assume that the forest sink can be increased by improved forest management that even increases wood production, the UBA Pathway scenarios assume that the forest sink can only be increased if the harvest level decreases. While this may appear to be a contradiction between the two scenario families, it can be explained by different considerations regarding measures to improve forest management (e.g. the IA's consideration of optimising forest rotation). However, it is questionable whether the IA's measures will have the assumed effects in the short and medium term. In contrast, changes in harvest levels have immediate effects of accumulated carbon stocks in forests.

3.8 Technical sinks: DACCS/BECCS

The IA 2040 specifically emphasises carbon management including CCS, CCU and technical carbon dioxide removals (CDRs). In the following, we concentrate on the role of technical CDRs; the role of CCS in combination with fossil or geogenic CO_2 emissions is covered in the sector-specific chapters of this report. In the context of technical CDR, the IA 2040 focuses on BECCS and Direct air carbon capture and storage (DACCS).

Figure 11: Technical carbon dioxide removals in 2050



A comparison with 2050 is presented because no CDR pathway has been modelled; thus, in the Pathway scenarios, no information is available on the amount of CDR in 2040.
* BECCS and DACCS are not explicitly modelled. The scenario may contain the capture and storage of biogenic emissions from the cement and lime industry, but the overall emissions of the cement and lime sector are still positive. Carbon removals may result from DACCCS, BioCCS or other permanent carbon removals.
Source: own illustration, Oeko-Institut

The role of technical CDRs differs significantly between the two studies. In the IA 2040, a specific focus is put on the role of technical CDR, identifying sources for capture, options for use of CO_2 and potential for geological storage. Despite differences in overall ambition, the three IA 2040 scenarios have remarkably similar BECCS and DACCS quantities. In the LIFE scenario, the CDR quantities are significantly reduced compared to the main scenarios. In contrast, the UBA Pathways scenarios assume a rather limited role for technical CDRs. They are only included in the target scenarios when the target cannot be met with mitigation measures and natural sinks alone. In the IA 2040, BECCS and DACCS are treated as ‘novel technologies to reduce CO_2 emissions’ like electrolytic hydrogen and e-fuel. In contrast, in the Pathways scenarios technical CDR sinks are not included as a measure that competes with mitigation measures or natural sinks.

The Pathways scenario EUBase includes CCS in the industry sector only and limits the use to projects to be realised by 2030. By definition, the ambition of climate policy after 2030 is not strong enough in that scenario to incentivise the application of CCS in the energy or in the industry sector or for DACCS or BECCS projects. The following applies to CCS in industry: no specific assumptions are made about the amount of biogenic emissions captured by the modelled projects. In total, the capture of cement emissions is significantly lower than the emissions in that sector. Therefore, we interpret CCS as allowing for a reduction of emissions in the cement industry only. It is not interpreted as a method to achieve significant amounts of carbon dioxide removals in this scenario despite the fact that in a mixed waste gas flow, captured CO_2 would include geogenic as well as biogenic carbon.

The Pathways scenario EUSupreme does not require any technical removals to reach the 2050 target. The implementation of additional measures compared to the EUTarget scenario is sufficient to reach negative emissions by 2050 without technical removals. This differs significantly from the EU IA scenarios; even the LIFE scenario includes technical CCS-based sinks (mainly BECCS), although of a significantly lower order of magnitude compared to the other target scenarios.

The Pathways scenario EUTarget is hence the only scenario with a stronger role for technical CDRs in this scenario family. The scenario applies technical CDRs (such as BECCS or DACCS) in addition to LULUCF by 2050 to cover the remaining emissions. This results in 27 Mt of technical CDRs by 2050 to reach net-zero. However, no CDR pathway has been modelled; thus, no information is available for the amount of CDR in 2040.[5] For the EU IA, the average S2/S3 scenario reaches a total of 62 Mt CO_2 removals by 2040 for technical CDRs. This means already in 2040 the amount of technical CDRs in the IA scenarios is more than twice as high as technical CDR demand in the EUTarget scenario in 2050. By 2050, negative emissions from technical options roughly double in the EU IA scenarios, i.e. levels are four times higher in 2050 in the EU IA scenarios compared to the Pathways scenario EUTarget.

In summary, the comparability of the results of the EU IA and the Pathways scenarios is very limited due to the significantly different approach of including technical sinks in the different studies. The order of magnitude required by 2050 in the EUTarget scenario is roughly one fourth of the IA 2040 scenarios except for LIFE. Values for 2040 are not available for the Pathways scenarios and are therefore not comparable as the uptake of technical CDRs was not modelled in the project. For the IA LIFE scenario, technical CDR is significantly lower compared to the other IA scenarios. However, while the Pathways scenario EUSupreme reaches net-zero and even negative emission levels by 2050 without applying technical CDR, the IA LIFE scenario requires about 40 Mt of technical CDR by 2050.

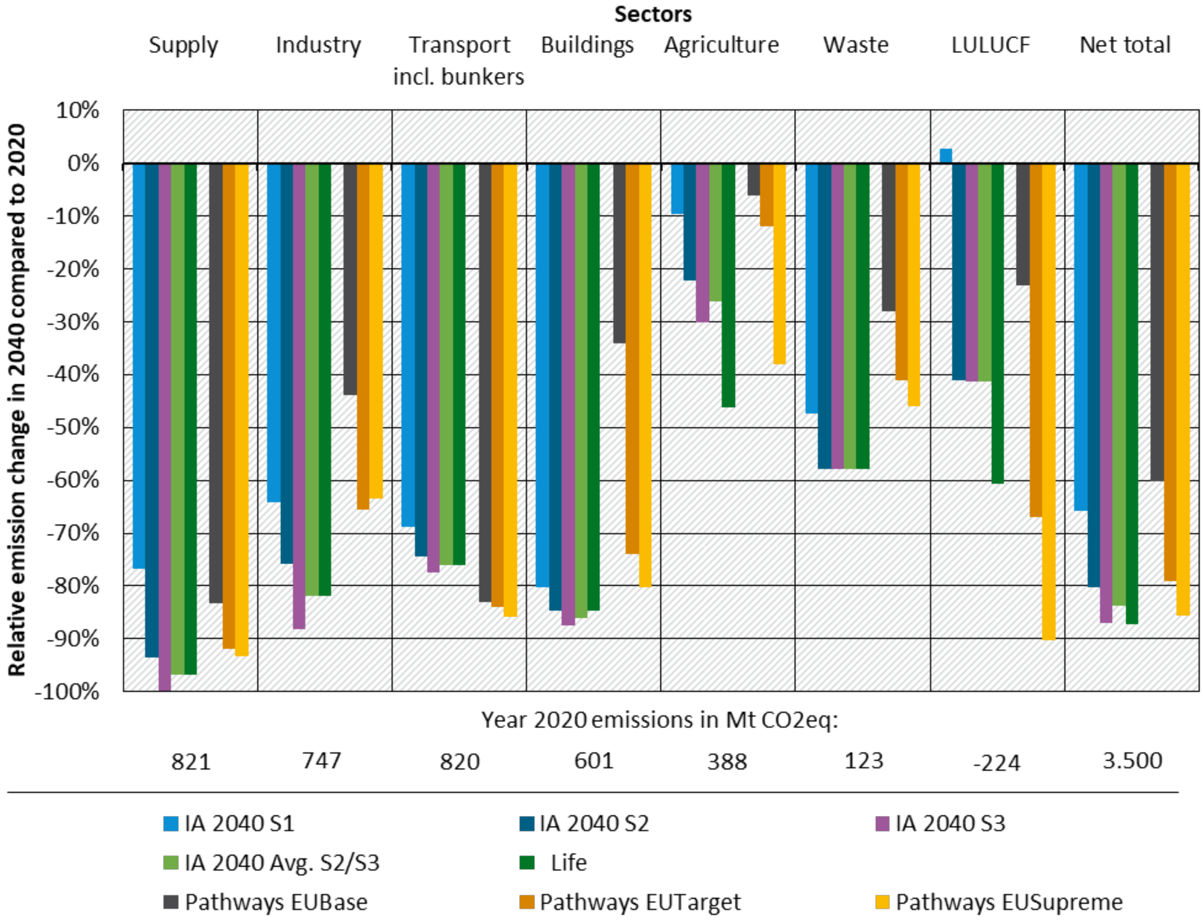
[5] Figure 11 shows values for 2050 for both scenario families as values for 2040 for the Pathways scenarios are not available.

4 Overview of development of GHG emission reductions in sectors

4.1 Summary of analysis

The comparisons of scenario families across sectors revealed variability is higher in some sectors than in others. How projected changes in net GHG emission levels develop in different sectors can be observed from Figure 12. It compares changes in net emissions or removals relative to the 2020 emission level for each sector. The year 2020 is the base year of Pathways scenario and was hence used as reference for comparison of relative emission changes.

Figure 12: Relative net emission changes in 2040 compared to 2020 (UBA pathways base year)



To make LULUCF comparable, it is shown with the opposite sign. A -100 % change of the LULUCF sink would thus mean an increase of the LULUCF sink by a factor of 2.

Source: own illustration, Oeko-Institut

Figure 12 shows that most sectors expect considerable emission reductions exceeding 80% in at least some scenarios in 2040. This applies to the supply, industry, transport, and buildings sectors. These are the largest sectors in terms of the total amount of GHG emissions in 2020. Moreover, for the supply and transport sectors, there is remarkably small variability between the scenarios. In fact, inter-sector variability is high in both the IA 2040 and the Pathways scenarios.

There are larger differences between the scenarios with a view to the agriculture and waste sectors. Hypothetically, for these sectors, there are many different options for emission reductions, which have a rather wide range of potential impacts on GHG emissions when they are implemented. In terms of absolute emissions, they are comparatively small in 2020. However, their relative share increases over time with successful emission reductions in other sectors.

Regarding the LULUCF sector, it should be noted that the comparison shows the relative difference to the observed sink in 2020. A relative change of zero implies a constant sink level; 100% would indicate a doubling of the sink. Therefore, the sector shows largest discrepancies between scenarios. Compared to 2020, the net sink decreases, resulting in a positive value.

The very small differences between the scenarios with regard to greenhouse gas emissions from bunkers suggest that a relatively small set of measures is assumed, and that the impact of these measures on greenhouse gas emissions is more homogeneous.

4.2 Differences in the main assumptions and methodology between IA 2040 and Pathways scenarios

The comparison of the GHG emissions and removals estimated in the IA 2040 and UBA Pathways scenarios per sector revealed considerable differences in assumptions.

In the **supply** sector, differences in GHG emissions between the two sets of scenarios can be attributed to total electricity generation. The latter is approx. 15 % higher in the IA 2040 S3 projection compared to the Pathways scenario EUSupreme and 12 % higher when comparing S1 and EUBase. There are also differences in the allocation of electricity to hydrogen and e-fuel production. This is about 25 % higher in the S3 IA 2040 scenario compared to the Pathways projection for EUSupreme. The most important difference is the use of CCS, which is not considered in the pathways for this sector, despite significantly reducing emissions in the IA after 2030.

GHG emission paths in the **industry** sector differ due to assumptions regarding projected outputs of steel, iron and other industrial products. The IA 2040 assumes higher production levels for iron and steel in the LIFE scenario compared to EUSupreme. For cement production, the EUSupreme scenario shows a similar reduction. It could be expected that these differences lead to similar GHG emission reductions overall. However, the IA 2040 scenarios yield considerably higher reductions (around 80%) compared to the Pathway scenarios. In the latter, the reductions amount to 60% compared to the base year 2020 (see Figure 12 above). Thus, this is an example in which the main assumptions cannot readily explain the differences. This raises critical questions about the mechanisms behind the projected reductions in material use, the diffusion rates of climate-neutral technologies, and the switching of fuels in the IA 2040 scenarios.

The degree of electrification is considered in the main assumptions made for the **transport** sector. This explains part of the difference in the emission levels between scenario sets. The degree of electrification also affects the demand for synthetic fuels. This is found to be comparable between the scenario sets. There are differences with a view to the allocation: while the demand for such fuels is spread across all transport modes in the IA 2040, the Pathways scenarios use them specifically in the hard-to-abate transport modes of aviation and navigation. Another key assumption is the degree of electrification in domestic transport. In the Pathways scenarios, this is assumed to be close to 100 %, while internal combustion engine vehicles still play a role for all domestic transport modes in the IA 2040 scenarios.

One of the major steering wheels of change in GHG emissions in the **buildings** sector is the renovation rates. As discussed in the sector analysis above, these differ only slightly between the two sets of scenarios. Instead, larger differences have been found regarding assumed building standards for new buildings. The energy demand of new buildings in the IA 2040 decreases from a moderate level (40 kWh/m^2) by about 33%. EUSupreme starts from a higher level (60 kWh/m^2) and assumes an even higher reduction of 75%, increasing the relative ambition level compared to IA 2040. Still, the IA 2040 scenarios present higher relative emission reductions compared to the Pathways scenarios due to a higher heat pump roll-out combined with lower levels of fossil heating oil usage (see Figure 12 above).

Like the IA 2040 scenarios, the Pathways scenarios also consider technical mitigation options for the **agriculture** sector such as anaerobic digestion, feed additives, nitrification inhibitors, and increased nitrogen efficiency. Assumptions about the mitigation potential of these measures are rather conservative, leading to an overall lower impact of technical measures. In the EUSupreme scenario, feed additives and nitrification inhibitors are not considered at all, what partly explains why this scenario reduces GHG emissions to a smaller extent compared to the LIFE scenario. Another important driver of emission reduction is the demand for animal products. Especially the LIFE and EUSupreme scenarios show a substantial reduction though differences can be observed. In the EUSupreme scenario, livestock numbers are reduced by almost 50% while the LIFE scenario assumes only a 30% reduction.

The measures assumed in the projections to reduce emissions in the **waste** sector were found to differ significantly. Although both approaches are based on information from GHG inventories, there are differences in the concrete measures. The IA 2040 scenarios implement additional measures such as source separation and anaerobic digestion. In contrast, the Pathways scenarios assume that the waste levels are reduced (e.g. by increasing recycling and consumer awareness) and optimised wastewater treatment is implemented in countries with previously high emission factors.

An important assumption that has an impact on GHG emissions and removals in the **LULUCF** sector is the amount of biomass production, biomass use and where the biomass is generated (on agricultural or forest areas). Assumptions on the change in forest area are similar for the EUSupreme and LIFE scenario, with both assuming considerable increases. A major difference is that the IA scenarios assume that the area expansion of forests can be accomplished on grassland and other natural land without affecting crop production. The UBA Pathways scenarios assume that considerable amounts of cropland are converted to forests or SRC plantations, which lead to an increase in the carbon sink in both the EUBase and EUTarget scenarios. There are also differences with a view to the area expansion of short rotation plantations that are almost double the area of the LIFE scenario under the EUSupreme scenario. This additional production capacity reduces pressure on the forest and brings about a higher forest carbon sink in the EUSupreme scenario.

4.3 Overall conclusions

From the comparison of the two sets of scenarios, a number of conclusions can be drawn:

- The comparison revealed that for most sectors, differences between the IA 2040 and the Pathways scenarios can largely be attributed to the differences in the assumptions made. One example is the afforestation area assumed in the LULUCF sector. Other examples are differences in assumptions regarding projected outputs of steel, iron, and other industrial products in the industry sector or the degree of electrification in the transport sector.
- There are remaining discrepancies between the different sets of scenarios. For example, the lower final energy demand and GHG emissions in IA 2040, despite substantial industrial

activity, raise critical questions about the assumptions driving projections in the industry sector and the feasibility of the IA 2040 transformation paths.

- One difference between the scenarios relates in the industrial sector. CCS in industry is not permitted in the EUSupreme scenario until 2050. Until the energy transition in industry is successfully completed in 2050, residual emissions will be released into the atmosphere. As a result, these emissions have to be fully compensated in other sectors to meet overarching climate targets.
- For the more energy-related sectors (supply, industry, transport and buildings) in both scenario families, the necessary transformation is clear and consists of three pillars: reducing energy consumption, improving energy efficiency and switching from fossil fuels to renewable energy sources. The overall transformation strategy for the less energy-related sectors (agriculture, LULUCF and waste) is less clear. This results in greater variability in the scenario results for these sectors.

Overall, it is challenging to compare the individual scenarios in the two studies. However, it can be observed that the LIFE scenario seems to be most comparable to the EUSupreme scenario in terms of its ambition level. Comparing these two more ambitious scenarios reveals that emission reductions are achieved to a large degree through lifestyle adjustments and reductions in material demand. However, the kinds of lifestyle changes implemented in the models differ significantly. For example, the LIFE scenario translates sufficiency measures into room temperature reductions in winter. In contrast, in the Pathways scenario EUSupreme, the sufficiency measures focus on a combination of fewer new buildings being built and better use of existing buildings, leading to a reduced increase in floor area. This demonstrates that similar results of emission reductions can be achieved through different combinations of measures. This could also mean opportunities for deeper emission reductions by combining the different measures of the two studies. Future studies could explore the room of underutilised mitigation opportunities for such combined measures more consistently.

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