Report

Report no. 6/24

Renewable electricity demand-supply assessment for EU process industries for 2030

ISBN 978-2-87567-186-8

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Renewable electricity demand-supply assessment for EU process industries for 2030

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We thank for their contribution:

- Members of the A.SPIRE association

- Members of the secretariat

ABSTRACT

VITO/EnergyVille was commissioned to do a quantitative assessment of renewable electricity (RES-E) supply and demand projections for process and fuel manufacturing industries for 2030. The Industry Electrification scenario uses green electricity for hydrogen production, with a focus on EU-generated hydrogen, accounting for two-thirds of the total, while assuming constrained growth in nuclear electricity production and the absence of carbon capture and storage.

The EU's 2030 climate targets necessitate robust electrification, projecting a 30% increase in total electricity generation's requirement. More prominently, it necessitates a remarkable 2.3-fold rise in RES-E, which requires an average annual addition of 100 GW of renewable capacity from 2024 to 2030.

The 2023 draft updated NECPs (national energy and climate plans) show increased ambition but still leave a 20% RES-E gap, resulting in a shortage of 250 TWh of renewable electricity at EU level. Belgium, France, Luxembourg, Poland, and Slovakia face gaps exceeding 50% in meeting demand with local RES-E, highlighting the need for increased imports of electricity, renewable fuels or alternative solutions.

Examining total electricity, the EU level shows minimal, or no shortages based on the latest NECPs that incorporate "additional measures". However, at country level, substantial regional gaps exist, ranging from 15% to 35% of expected electricity needs. Notably, increased electricity imports may be necessary, especially for Germany (imports x 6), Poland (imports x 4), Belgium (imports x 2.5), Romania (imports x 1.8), and the Netherlands (imports x 1.7). Strategic measures, including network expansion, innovation, and diversified energy sources, are vital to fortify energy security and achieve sustainability goals.

Combining the assessments of renewable and total electricity, a categorization framework is established for all countries. Key indicators are the RES-E gap and variation in net annual balance. Recommendations include combined focus on import and increased renewables for the Netherlands, Poland, and Romania, import focus for Belgium and Germany, export infrastructure boost for Spain, France, Portugal, and Sweden.

KEYWORDS

Renewable electricity, low-carbon pathways, process industries, EU energy policy, networks

INTERNET

This report is available as an Adobe pdf file on the Concawe website (www.concawe.org).

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1. INTRODUCTION

The European Union (EU) aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU commitment to global climate action under the Paris Agreement. EU scenarios show that energy efficiency measures, direct and indirect electrification (through the production of green molecules like hydrogen and derivates) of demand sectors and processes will play a crucial role in reaching carbon neutrality. Reaching net zero by 2050 will, according to recent scenario work, more than double the electricity demand[1].

Policy context for 2030

For 2030, the EU has legally binding climate targets covering all key sectors of the economy[2]. The Fit for 55 package (FF55) was concluded in October 2023 and its measures are designed to achieve a minimum 55% reduction in net greenhouse gas emissions compared to 1990 levels.

As a component of the REPowerEU strategy, the Commission introduced a sequence of modifications to the renewable energy directive in May 2022. These changes were introduced to reflect recent shifts in the energy landscape. The revised RES Directive[3] entered into force in November 2023 to raise the share of renewable energy in the EU's overall energy consumption to 42.5% by 2030 with an additional 2.5% indicative top up to allow the target of 45% to be achieved. At the global level, the European Commission called for a global pledge at COP28 to triple renewable energy capacity by 2030.

Rapid increase in renewables

Achieving the energy and security goals through electrification hinges on the crucial factor of ensuring fully decarbonized electricity, which necessitates a substantial increase in renewable electricity capacity.

This puts a serious challenge to the power sector, apart from decarbonising current production it needs to speed up its investments in additional, zero carbon capacity. However, when looking at the renewable action plans of the EU member states, one can observe that current ambition is lacking the sense of urgency that is needed to increase investments in additional low-carbon capacity.

[1] SWD(2020) 176 final - Impact assessment, Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people.

[2] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

[3] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

Scope of this study

EnergyVille/VITO was commissioned by Concawe to do a quantitative assessment of renewable electricity supply and demand projections for process industries for 2030. Fuel manufacturing is included as an industry, including the production of transportation fuels. The energy content of the transportation fuels itself, meaning the energy usage within the transportation sector, is not included.

Bottom-up demand projections are compared with supply scenarios and with EU member state renewable electricity projections and ambitions. Within the context of this project, demand projections are selected and built based on following principles:

1) Green electricity is used to produce molecules like hydrogen and derivatives.
2) Most of the hydrogen is produced within the EU (two thirds, based on REPowerEU[4]).
3) Limited or no growth of electricity production from nuclear at EU level
4) No carbon capture and storage (CCS) by 2030 and
5) No additional electricity imports from outside the EU.

The study is re-shaped towards the needs of A.SPIRE, the European Association which is committed to manage and implement the Processes4Planet co-programmed Partnership, in collaboration with the European Commission.

How this report is structured as follows:

- How much energy is used in industries today (chapter 2);
- how strong electricity demand may grow in key industry sectors by 2030 at EU level (chapter 3);
- whether EU Member States move fast enough to get in place the needed investments in additional renewable capacity (chapter 4);
- whether EU Member States draft updated National Plans on total electricity generation are enough for the industry electrification scenario (chapter 5) and
- what could be the possible impact on energy infrastructure in the trilateral region Belgium, the Netherlands and Germany (chapter 6).
- whether EU draft national plans are aligned with industry electrification needs (chapter 7)

[4] The REPowerEU imports around two thirds of the hydrogen, when excluding ammonia imports: 10 Mt out of 16 Mt total hydrogen.

2. CURRENT SITUATION

In this chapter, we discuss the historical energy use of industries within the EU. Presently, the European Union (EU) consumes annually 40,000 PJ (or ca 3800 TWh) of energy and feedstock for final energy purposes. The industrial sector uses 32% of final energy consumption. Over the past three decades, despite efficiency improvements, industrial energy and electricity consumption remains stable. We also discuss in this chapter the current renewable electricity production.

2.1. EU ENERGY USE

At present, the European Union (EU) has a gross inland consumption of approximately 60000 petajoules (PJ) per year. Within this energy consumption, a significant portion of 44000 PJ is available for final consumption. With 14000 PJ. industries account for approximately 32% of the final energy consumption. This corresponds to approximately 3800 terawatt-hours (TWh) out of a total of 12000 TWh. Fuel use amounts to 40000 PJ, out of which 10000 PJ is consumed by the industrial sector. An additional 4000 PJ is used as feedstock, serving as raw material (and not as fuel) in various processes, mostly industrial. Feedstocks are in the EU mainly oil and petroleum products e.g. used for the production of chemicals and natural gas e.g. used to produce fertilisers and hydrogen.

Figure 1 Overall EU gross inland energy consumption in 2021 according to Eurostat[5] in petajoules (PJ) *Left: final energy consumption; Right: transformation and energy losses to be added to the final energy consumption; fuels consumed in power plants and industries involving transformation processes, such as oil refineries, blast furnaces and coke ovens)*

Furthermore, approximately 16000 PJ is allocated to transformation processes and energy losses. Within this category, the industrial sector accounts for 3000 PJ, which corresponds to approximately 800 terawatt-hours (TWh) consumed in industries involving transformational activities, such as refineries.

2.2. ENERGY AND ELECTRICITY USE IN EU PROCESS INDUSTRIES

2.2.1. Energy use by subsector

The industry sector consumes a total of 4600[6] terawatt-hours (TWh) of energy and feedstock. When limiting the feedstocks to only LPG, naphta and natural gas[7], the consumption reduces to 4300 TWh. Presently, the industry consumes approximately

[5] The figures are rounded to the nearest 1000 petajoules (PJ) to simplify the message
[6] The sum of 3800 TWh final energy consumption and around 800 TWh of fuels consumed in transformation processes, mostly within oil refineries, blast furnaces and coke ovens.
[7] By for example excluding bitumen

1000 TWh of electricity, accounting for nearly a quarter of its total energy consumption. In **Figure 2**, the electricity and other energy consumption is visualised by subsector.

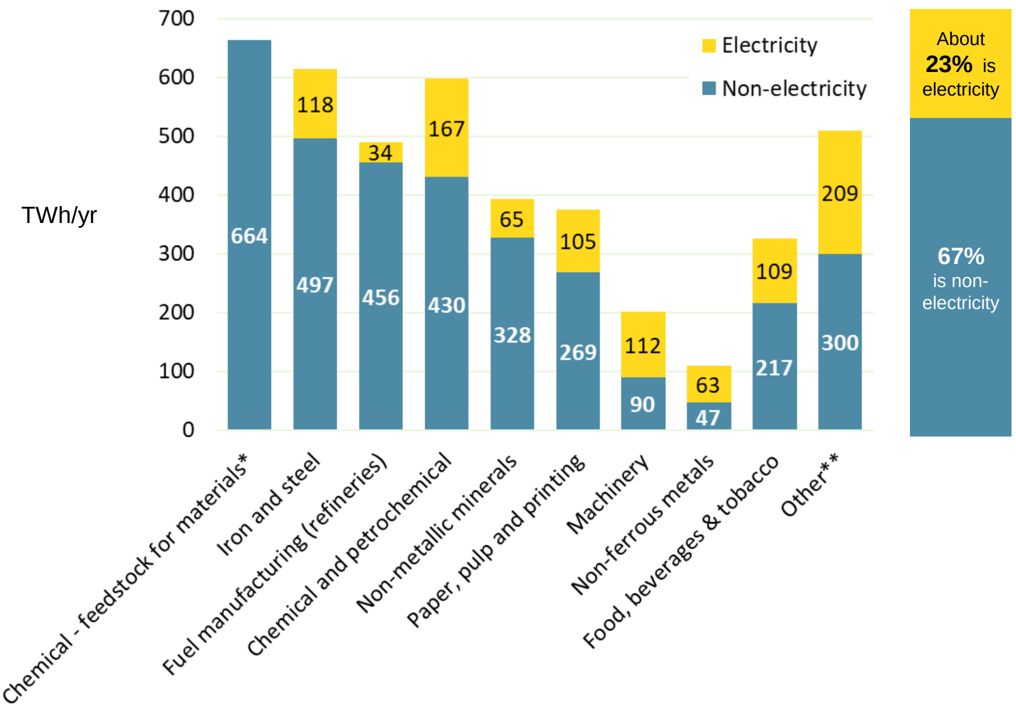


Figure 2 Historical (2018) energy and feedstock demand by subsector[8], according to Eurostat[9]

2.2.2. Historical evolution

Over the past three decades, the energy and electricity use of the EU industry sector has remained relatively stable. Despite advancements in technology and increasing energy efficiency measures, the overall energy consumption and electricity demand have not experienced significant changes between 1990 and the present day.

This indicates that while progress has been made in improving energy efficiency and adopting cleaner technologies, it has been counterbalanced by factors such as industrial growth, changes in production patterns, and increased energy demands from emerging sectors. Between 1995 and 2021 gross added value increased by 48% based on Eurostat National accounts chained linked volumes [EUR] of total industry excl. construction.

[8] (*) Based on non-energy uses of LPG, Naphta and Natural gas. (**) Transport equipment, Mining & quarrying, Wood & wood products, Construction, Textile & leather, Not elsewhere specified (industry)
[9] Following selection of Eurostat data was used for this graph: *Chemical - feedstock for materials*: based on “Non-energy use in industry sector” and only on the fuels Naphta, LPG and natural gas; *Fuel manufacturing (refineries)*: Energy sector + (Transformation out – Transformation in); *Iron and steel:* Energy sector + (Transformation out – Transformation in) + Final energy consumption; *Other sectors:* Final energy consumption

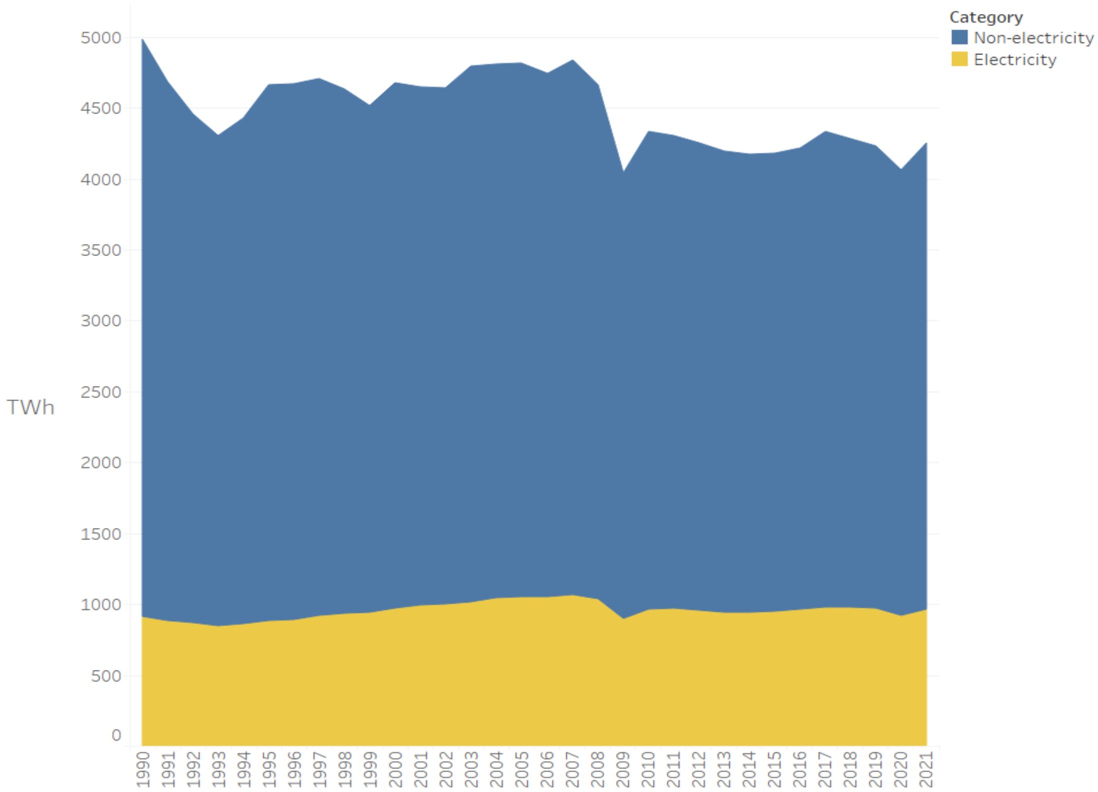


Figure 3 Historical electricity and non-electricity energy and feedstock use in industry sectors [source: Eurostat].

2.3. CURRENT RENEWABLE ELECTRICITY GENERATION

During the year 2021, renewable electricity generation within the EU reached approximately 1000 TWh per year[10]. This comprised around 350 TWh per year from hydro sources and approximately 570 TWh per year from solar and wind energy, with an installed capacity of 350 GW. While it is not feasible to precisely allocate specific electricity sources to individual electricity demands, our estimate indicates that the industry's consumption of renewable electricity amounts to approximately 370 TWh of renewable electricity[11].

In 2022, the European Union (EU) had a hydro capacity of approximately 150 GW, while the installed capacity of solar and wind energy amounted to roughly 400 GW.

[10] Eurostat Shares data
[11] Applying total generation RES share from Eurostat Shares (37.5%) to electricity demand from the industry sector.

3. EU LEVEL ASSESSMENT

In this chapter, we describe the results of our Industry Electrification scenario, zooming into total electricity needs, renewable electricity supply scenarios and performing a demand-supply assessment comparing both.

The key findings reveal a significant surge in total electricity generation by at least 25%, emphasizing a growing demand for energy resources. To meet this escalating need sustainably, renewable electricity must undergo a substantial increase, a factor of 2.3 times the current capacity. However, a notable concern arises when evaluating the future RES-E supply against the demands of the process industry, particularly in scenarios aligning with REPowerEU ambitions. The analysis exposes a shortfall in the RES-E supply, painting a challenging landscape for achieving sustainability goals. In scenarios considering national projections, even with existing measures, the RES-E increase falls short at only 65% of the required rise, resulting in a considerable deficit of 500 TWh. Similarly, when factoring in national plans, the RE increase reaches only 80% of the essential elevation, leaving a shortage of 250 TWh. Addressing this energy deficit necessitates an ambitious average addition of 100 GW per year in renewable capacity from 2023 to 2030, highlighting the urgency for substantial investments in renewable energy infrastructure.

3.1. ELECTRICITY NEEDS

The basis of this assessment is our 'REPowerEU like' scenario, showing a gross electricity generation of 3523 TWh by 2030. Other methodological aspects can be found in Annex 1.

It is important to mention that in the framework of this project, the demand projection is performed following top-down principles. Firstly, the emphasis lies on utilizing green electricity to produce molecules (hydrogen or its derivatives). This approach aligns with the overarching commitment to sustainable energy sources. Secondly, a substantial portion, two-thirds, of the hydrogen production is envisaged to occur within the EU. This strategic distribution, as per the REPowerEU plan, bolsters the region's self-sufficiency in hydrogen generation. Thirdly, the demand projections reflect a situation without growth of electricity production from nuclear sources at the EU level. Fourthly, the project envisions a scenario where Carbon Capture and Storage (CCS) is absent from the energy landscape by 2030, underscoring a commitment to explore alternative, non-carbon-capture strategies. Lastly, the demand projections incorporate a scenario where there are no additional electricity imports from outside the EU, emphasizing the project's dedication to assessing and meeting energy needs autonomously within the European Union.

3.1.1. Industry electricity demand

The industry electricity demand is scrutinized through AIDRES data and own bottom-up assessment that involved data collected through contacts with A.SPIRE members. **Appendix 1** includes information on how AIDRES data was used and includes the assumptions for each subsector. The industry electricity demand reveals a 50% increase by 2030, primarily fuelled by direct electrification and e-fuel production. The results are presented in this section.

This assessment outlines the anticipated surge in electricity demand across various industry sectors, organized by the extent of the projected increase. The overall rise is estimated at approximately 50% compared to historical electricity demands. Fuel manufacturing stands out with the most substantial increase, reaching 82 TWh, driven by the production of hydrogen using green electricity and the generation of e-fuels. Following closely are the chemical and petrochemical sectors, particularly other chemical applications, with an 81 TWh increase. Notably, the chemical-fertilizer segment is expected to witness a significant boost of 73 TWh. The total industry electrification by 2030 is predicted to amount to 468 TWh, marking a substantial transition toward increased reliance on electricity.

	2018		2030	Increase
	[TWh]	[TWh]	[TWh]	[TWh]
Fuel manufacturing	34		115	82
Chemical & petrochemical - other	161		242	81
Chemical - fertilizer	6		79	73
Other	209		260	51
Iron and steel	118		157	39
Nm minerals - other	37		74	37
Paper, pulp and printing	105		143	37
Food, beverages & tobacco	109		142	33
Machinery	112		132	20
Nm minerals - glass	13		16	3
Non-ferrous metals	63		74	11
Nm minerals - cement	14		16	2
Total industry electrification 2030	**982**		**1450**	**468**

Figure 4 Increase of electricity demand by 2030 by subsector

Presented in a graphical format, the depiction includes a future outlook for 2050 represented by grey columns, indicating an additional generation of approximately 2000 terawatt-hours (TWh). This envisioned increase would elevate the total to around 3000 TWh, aligning with projections outlined in the 2018 report by the Institute for European Studies (IES). It's important to note that the primary emphasis of the project remains centered on the year 2030, even though the graphical representation extends the perspective to 2050.

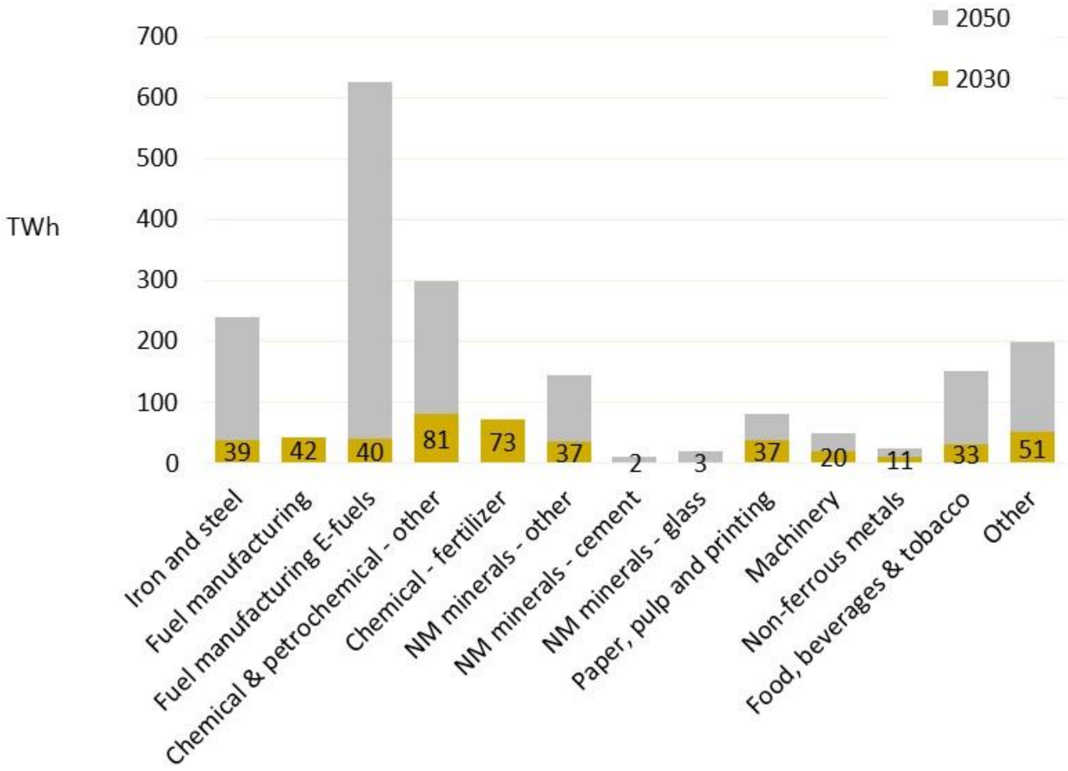


Figure 5 Graphical representation of the increase of electricity demand by 2030 and 2050 by subsector

Figure 6 illustrates the anticipated surge in electricity consumption across various sectors, with distinct emphasis on green colours denoting hydrogen or molecular processes. Half of the increase in electricity demand is allocated to the production of hydrogen and derived fuels or chemicals. This is visually represented, with green colours signifying processes related to hydrogen or molecular transformations. Two effects are observed in this context. Firstly, for energy use and synfuels, a comparable amount of electricity is needed compared to REPowerEU. Secondly, a higher proportion of electricity is dedicated to the production of e-fuels (107 TWh). This is driven by the assumption to reach a 29% reduction in CO2 emissions in the chemicals sector. Direct electrification in other industries is expected to spike from 87 to 212 TWh, signifying a prominent shift towards increased electricity usage. Additionally, hydrogen-related processes in various industries, such as fertilizers and others, contribute to this rise.

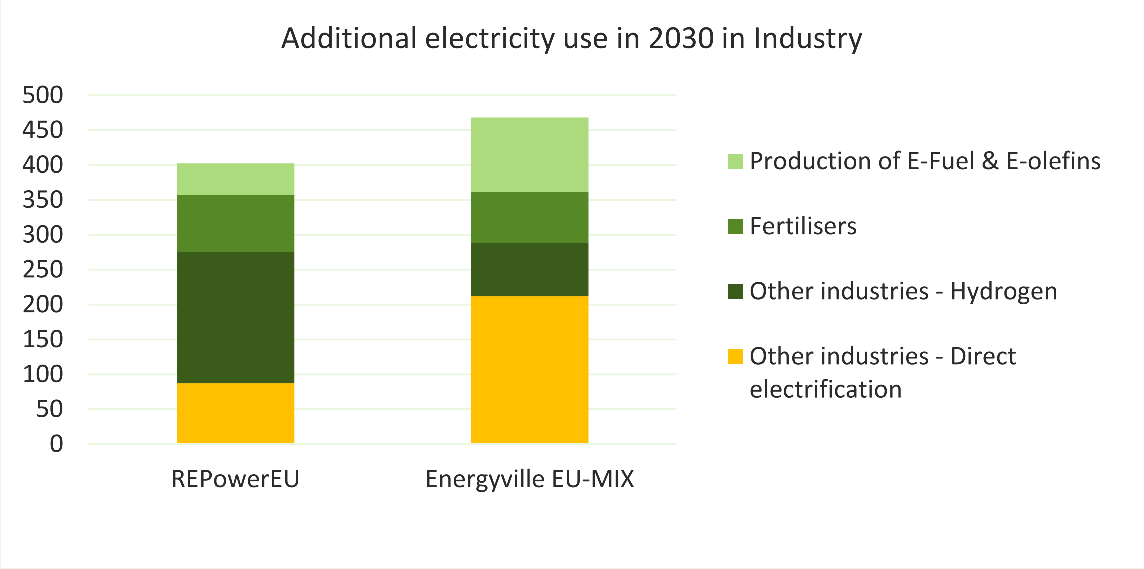


Figure 6 Increase of electricity by 2030 by usage

In conclusion, the estimated increase of electricity for industries amounts to around 50% of the historical electricity demand. Within this increase, around 50% is used to produce hydrogen and derived fuels or chemicals. The other half is used for direct electrification of industrial processes.

3.1.2. Non-industry electricity demand

For non-industry sectors, we follow the 'REPowerEU like' scenario with a gross electricity generation (3523 TWh) in line with REPowerEU (3450 TWh[12]). Without considering the industry sectors, the electricity from renewable sources from this scenario adds up to 2031 TWh and consists of 4 elements: the 2020 renewable electricity (1036 TWh), the replacement of non-renewable power generation (606 TWh), the electricity expansion in the transport and buildings sectors (294 TWh) and the hydrogen use in non-industry sectors (95 TWh).

[12] Source: Non paper on complementary economic modelling undertaken by DG ENER analysing the impacts of overall renewable energy target of 45% to 56% in the context of discussions in the European Parliament on the revision of the Renewable Energy Directive, June 2022. https://energy.ec.europa.eu/system/files/2022-06/2022_06_20%20RED%20non-paper%20additional%20modelling.pdf

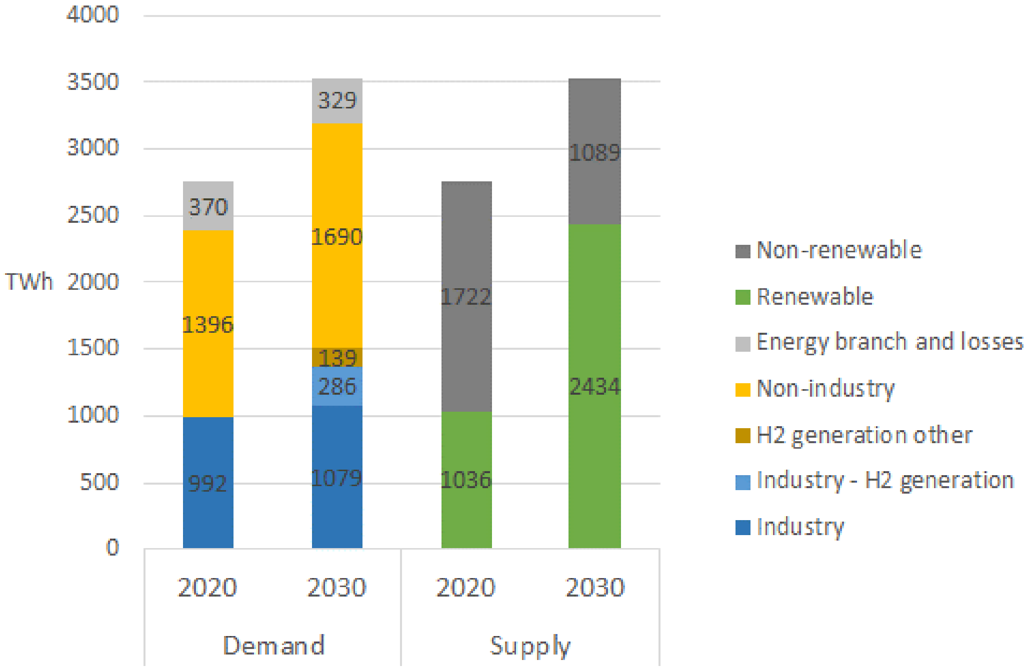


Figure 7 Graphical representation of the increase of electricity demand by 2020 and 2030 by subsector

3.1.3. Total renewable electricity needs

The demand for renewable electricity is 2499 TWh, as the sum of the non-industry part (2031 TWh) and the additional electricity demand from the outlook for industries (468 TWh). Approximately 40% of the new renewable electricity production is earmarked for replacing fossil-based electricity sources, contributing to a cleaner energy mix. Additionally, around 30% of the newly generated renewable electricity is allocated for advancing electrification, including the production of hydrogen, of the industry sectors.

Table 1 Projection of total electricity in the Industry Electrification scenario (TWh)

	INDUSTRY ELECTRIFICATION 2030
2020 RENEWABLE (EUROSTAT)	1036
Replacement of non-RES electricity gen.	606
Buildings and transport	294
Hydrogen other	95
Industry	468
TOTAL	**2499**

3.2. RENEWABLE ELECTRICITY SUPPLY ASSESSMENT

As we navigate through the EU's renewable energy targets for 2030, the chapter unfolds the ambitious plans to surpass 60% renewable electricity, underlining specific targets for industries and comprehensive supply assessments.

The projection of a 2.3-fold increase in total RES-E further emphasizes the challenges and gaps in meeting the rising demand.

3.2.1. EU RES target for 2030

In December 2020, EU leaders have endorsed a new climate target and to achieve a net domestic reduction of greenhouse gas emissions by at least 55% by 2030, relative to the levels recorded in 1990. The Fit for 55 package was concluded in October 2023 and its measures are designed to achieve a minimum 55% reduction in net greenhouse gas emissions compared to 1990 levels.

The revised RES Directive entered into force in November 2023 to raise the share of renewable energy in the EU's overall energy consumption to 42.5% by 2030 with an additional 2.5% indicative top up to allow the target of 45% to be achieved. Each member state will contribute to this common target.

3.2.1.1. Increasing the share of renewable electricity sources to more than 60%

The share of electricity produced by renewable energy sources (predominantly solar and wind) is expected to grow from 37% in 2020 to more than 60% by 2030[13].

For wind offshore, EU nations have collectively set ambitious, long-term targets for offshore renewable electricity deployment up to 2050 across the five sea basins. With interim goals for 2030 and 2040, the combined vision aims for approximately 111 GW of offshore renewable capacity[14] by the decade's end—nearly double the 60 GW target in the 2020 EU Offshore Renewable Energy Strategy. This trajectory expands further to around 317 GW by mid-century, aligning precisely with the Strategy's ultimate objective.

3.2.1.2. Doubling total RES share

Doubling the share of total RES would require around 80% more energy from renewable sources in 2030 compared to 2021. Rising the RES-share from approximately 22% in 2021 to 45% by 2030 is a notable increase of 23 percentage points (pp) that can be broken down into two distinct components:

1. A 4 pp increase stemming from reduced energy consumption, primarily driven by the electrification of transportation and resulting in a 17% decrease in overall energy consumption.

2. A significant 19 pp increase achieved through greater utilization of renewable electricity and renewable fuels, corresponding to approximately 6,700[15] petajoules (PJ) or 1,850 TWh. When using the definition from RED II, the

[13] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/electricity-market-design_en

[14] https://energy.ec.europa.eu/news/member-states-agree-new-ambition-expanding-offshore-renewable-energy-2023-01-19_en

[15] The 19% increase is calculated relative to a total estimated denominator of 35000 PJ, which represents 83% of the gross final energy consumption amounting to 42,400 PJ.

increase amounts to around 2000 TWh which is 80% of the 2021 consumption of energy from renewable sources.

3.2.1.3. More than doubling renewable electricity by 2030

Of the absolute increase in RES, roughly two-thirds comprises renewable electricity or Renewable Fuels of Non-Biological Origin (RFNBO), necessitating a minimum of 1,400 TWh per year of renewable electricity[16].

By 2030, it is possible to see a 30% growth in overall electricity production, with the proportion of renewable electricity increasing by 80% (from 37.5% in 2022 to 69% in 2030). When we consider both these factors together, we expect the total electricity generated from renewable sources to more than double, increasing by a factor of 2.3.

Table 2 Projected increase of total energy from renewable sources and electricity from renewable sources

	Share	Absolute value
RES (total energy from renewable sources)	x 2.0	x 1.8
RES-E (electricity from renewable sources)	x 1.8	x 2.3

3.2.1.4. Specific targets for industries

The provisional agreement provides that industry would increase their use of renewable energy annually by 1.6%. They agreed that 42% of the hydrogen used in industry should come from renewable fuels of non-biological origin (RFNBOs) by 2030 and 60% by 2035.

The agreement introduces the possibility for member states to discount the contribution of RFNBOs in industry use by 20% under two conditions: 1) if the member states' national contribution to the binding overall EU target meets their expected contribution or 2) the share of hydrogen from fossil fuels consumed in the member state is not more 23% in 2030 and 20% in 2035.

3.2.2. Supply projections

In delineating the supply projections for renewable energy, three distinct categories come into focus. Firstly, national projections from 2023, as mandated by Governance Regulation Art.18, provide insights into Member States' estimations, with a subset offering specific information on renewable electricity (RES-E). Secondly, national plans, representing the strategic blueprints devised by individual countries, play a pivotal role in shaping the trajectory of renewable energy adoption. Lastly, market projections, often derived from comprehensive analyses and forecasts, contribute valuable perspectives on the potential evolution of renewable energy markets. By examining these three categories, a comprehensive understanding of the dynamics influencing renewable energy supply emerges, incorporating both governmental planning and market-driven factors.

[16] One-third of the RES increase is attributed to biofuels, bioenergy for heating, derived heat, ambient heat, or renewable cooling.

Outlooks for PV and wind as a comparison basis

The JRC CETO report[17] mentions: "The global cumulative PV installed capacity exceeded 1000 GW in March 2022, out of which 170 GW in the EU. According to projections, the EU capacity will increase to 328 GW in 2025, between 500 GW and 1 TW in 2030 and between 7 TW and 8.8 TW in 2050, whereas the projected global installed capacity will increase between 22 TW and 60 TW."

Indeed, different outlooks show a total PV capacity above 500 GW and a wind capacity above 350 GW.

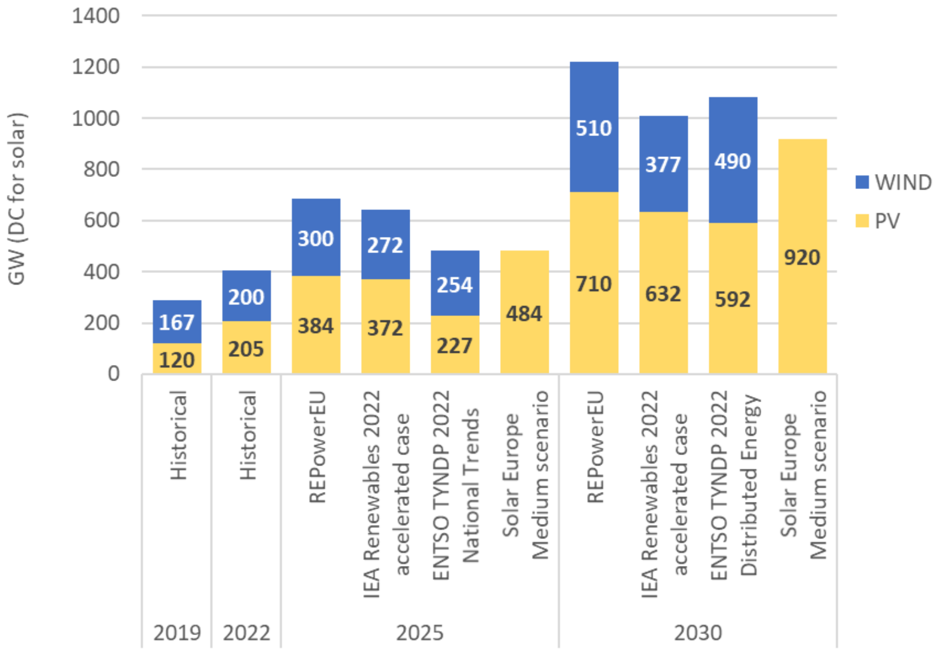


Figure 8 Various projections of the wind and solar capacities up to 2030

[17] Chatzipanagi, A., Jaeger-Waldau, A., Cleret de Langavant, C., Letout, S., Latunussa, C., Mountraki, A., Georgakaki, A., Ince, E., Kuokkanen, A. and Shtjefni, D., Clean Energy Technology Observatory: Photovoltaics in the European Union – 2022 Status Report on Technology Development, Trends, Value Chains and Markets, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/812610, JRC130720.

3.3. DEMAND – SUPPLY ASSESMENT

3.3.1. Renewable electricity vs supply

The depiction of renewable electricity supply is characterized by three distinctive blocks highlighted in orange: national projections, national plans, and various outlooks[18]. National projections for 2023, as governed by Regulation Art.18, involve Member States providing insights into their renewable electricity (RES-E) estimations.

Figure 9 Renewable electricity demand vs supply for 2030 (Left: demand, First brown bar: national projections, middle block: national projections, right: other outlooks)

The yellow bars underscore the significance of investments in solar and wind energy. Recent trends reveal a robust growth in solar/wind capacity at an impressive rate of approximately 50 GW per year. A notable proposal from RePowerEU envisions the installation of around 1100 GW of solar/wind capacity by 2030, demanding an average yearly addition of 100 GW to meet these ambitious targets. This insight underscores the pivotal role of solar and wind investments in shaping the future landscape of renewable electricity supply. The installed capacity of solar and wind energy amounted to roughly 400 GW. This solar/wind capacity has been expanding at a rate of approximately 50 GW per year. If the growth observed in recent years

[18] ENTSO-E Ten-Year Network Development Plan (TYNDP) National Trends scenario and the Distributed Energy scenario are two different scenarios used to model the future development of the European power system. The National Trends scenario is a centralised scenario that assumes a continuation of current trends and policies. The Distributed Energy scenario assumes a more rapid and radical transformation towards a decentralised and flexible energy system based on distributed energy resources and local energy communities.

would remain, it is projected that an additional 400 GW of solar/wind capacity will be added by 2030.

3.3.2. Additional renewable electricity demand vs supply

In scenarios considering national projections, even with existing measures, the RES-E increase falls short at only 65% of the required rise, resulting in a considerable deficit of 500 TWh. Similarly, when factoring in national plans, the RE increase reaches only 80% of the essential elevation, leaving a shortage of 250 TWh.

Figure 10 Additional renewable electricity demand vs supply for 2030 (Left: demand, First brown bar: national projections, middle block: national projections, right: other outlooks)

4. MEMBER STATE ASSESSMENT OF RENEWABLE ELECTRICITY

The focus of this chapter is a quantitative assessment of the Industry Electrification 2030 scenario by Member State. We project the electricity needs for an intense electrification of the industry sector and compare it against member states' projections and outlooks from Ember and the ENTSOs.

4.1. ELECTRICITY NEEDS

This section presents the renewable electricity demand by 2030 using the methods and approaches as described in **Appendix 5 and 6**. Three scenarios are presented: '*Industry Electrification 2030*' by EnergyVille (**section 4.1.1**), '*Technology Driven*' by Ember (**section 4.1.2.1**) and '*Distributed Energy*' by ENSTOs (**section 4.1.2.2**). All these scenarios are designed to meet at least 55 % emission reduction in 2030.

The '*Industry Electrification 2030*' scenario was designed to meet the needs of the local industry in a context where the use of coal and natural gas is significantly reduced. This implies that regions with more industrial activity will generate a higher need for renewable electricity by 2030. The other two scenarios arise from cost-effective approaches proposed by two different studies, offering a different viewpoint. Regions with more favourable conditions (potential for renewable electricity, costs or interconnections) will see increased renewable electricity generation by 2030 in these scenarios.

4.1.1. Industry Electrification 2030

As described in **Appendix 5**, the first method presents a top-down distribution of the residual 448 TWh to bridge the gap between the FF55 EU total and the 2449 TWh of EU total renewable electricity as concluded from WP1-3. The distribution is based on the total hydrogen and e-fuel demand by MS in 2030 using REPowerEU data obtained from the ENTSOs TYNDP 2022 study[19]. This first scenario provides a local industry perspective by trying to fulfil local industry demand with local renewable electricity generation. This scenario is developed in this research and will be referred to as the '*Industry Electrification Scenario*' throughout the rest of this report.

The resulting increase in renewable electricity demand compared to 2021 Eurostat data is shown in **Figure 11**. Most MSs show an increase in renewable electricity demand ranging between a factor 1 and 4. The countries exceeding a factor 4 are: Lithuania (7.8), Poland (4.4), the Netherlands (4.5) and Luxembourg (4.8). In the EU level assessment, an average growth factor of 2.3 was calculated. This value can be retrieved from this illustration as well by taking the weighted average of each MS growth factor with its current renewable electricity generation from Eurostat.

[19] ENTSOG and ENTSO-E, "TYNDP 2022 Scenario Report: Download," September 28, 2021, https://2022.entsos-tyndp-scenarios.eu/download/.

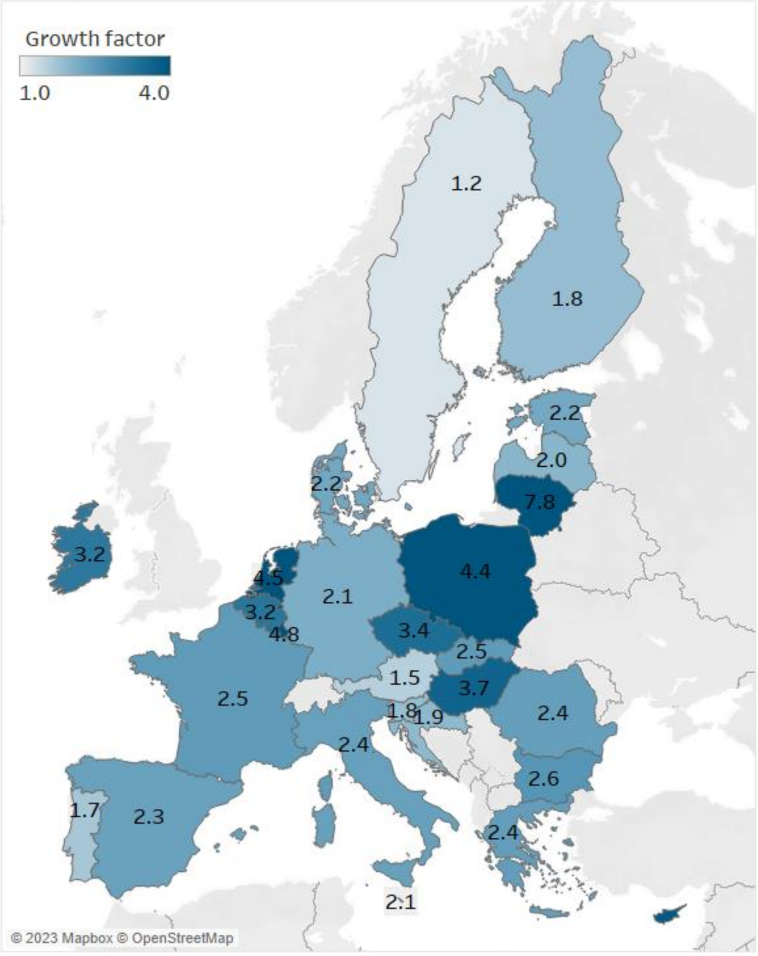


Figure 11 Renewable electricity demand growth factor by 2030 according to 'Industry Electrification 2030' compared to 2021 Eurostat values

4.1.2. Electricity demand in alternative electrification outlooks

4.1.2.1. Technology Driven Scenario - Ember

The first alternative electrification outlook is selected from a study executed by Ember (New Generation: Building a clean European electricity system by 2035[20]). The Ember study explores the modelling results of three European decarbonisation pathways for the power sector based on cost optimization with the aim of almost completely decarbonising Europe's power sector by 2035. The method behind the results is the Artelys Crystal Super Grid power system modelling platform. These results provide us with open, detailed, country by country and hour by hour power system modelling data and can be used as a benchmark for the required renewable electricity supply by country.

The selected scenario for this research is the Technology Driven Scenario which minimises cost while remaining within a carbon budget compatible with the Paris Agreement climate goals and consistent with a net-zero 2050. The scenario allows for investment in new nuclear capacity and power generation equipped with carbon

[20] "New Generation | Clean Power Europe 2035," Ember, June 21, 2022, https://ember-climate.org/insights/research/new-generation/.

capture and storage **(CCS)** technology. The total EU renewable electricity generation by 2030 in the Technology Driven Scenario equals 2485 TWh, which is aligned with the 2499 TWh total used in the Industry Electrification 2030 Scenario as presented in the first method. Furthermore, interconnection expansion is cost optimised and upper bounded by the ENTSOs TYNDP 2022[21] candidate project list.

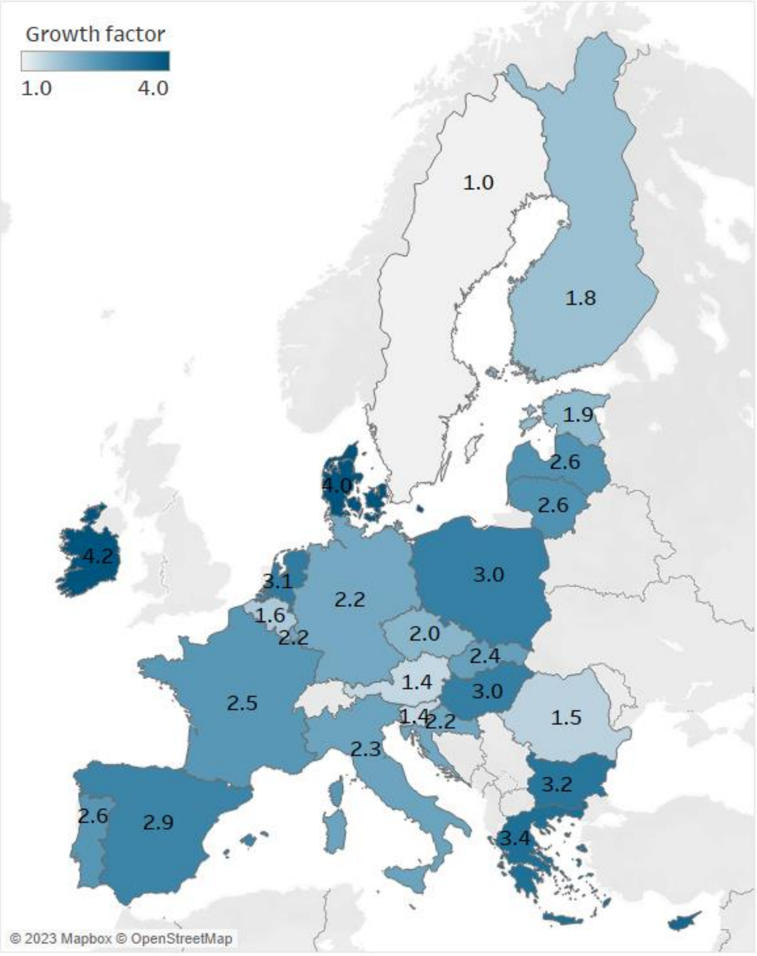


Figure 12 Renewable electricity demand increase by 2030 according to Ember Technology Driven Scenario compared to 2021 Eurostat values

Figure 12 presents the growth factor of renewable electricity generation according to the Ember scenario between 2030 and 2021 Eurostat values by MS. The largest growth factor can now be observed for Ireland and equals 4.2. Note that all scenarios approximate a 2500 TWh renwable electricity demand by 2030. The growth factors present a smaller distribution compared to the Industry Electrification Scenario, indicating a more evenly spread-out renewable electricity increase over the different MSs with less extremes. The Ember scenario has a lower level of electrification in the industry sectors leading to lower difference between countries. Also, the industry demand representation is less detailed which may also be the reason for some electrification options not to be identified.

[21] ENTSO-E, "TYNDP 2022 Scenario Report."

4.1.2.2. Distributed Energy Scenario - ENTSOs

The other alternative scenario is the ENTSO TYNDP 2022 Distributed Energy Scenario. The Ten-Year Network Development Plans (TYNDP) result from a close collaboration between ENTSOG and ENTSO-E to develop scenarios which provide a comprehensive assessment of European energy infrastructure requirements from a whole energy system perspective.[22]

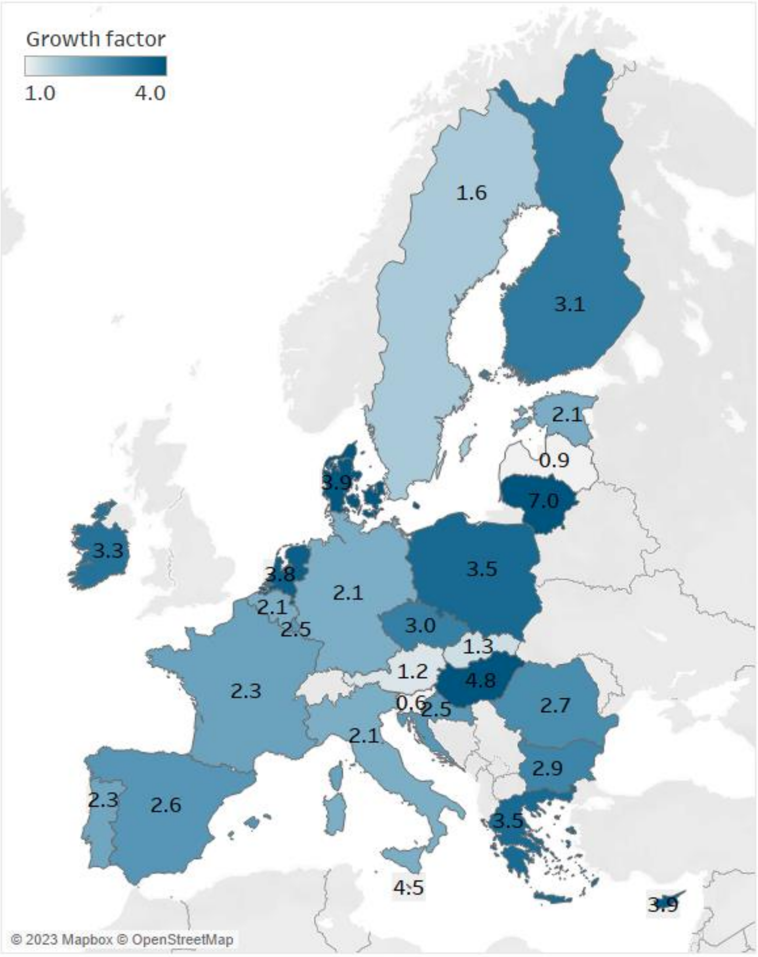


Figure 13 Renewable electricity demand increase by 2030 according to ENTSOs Distributed Energy Scenario compared to 2021 Eurostat values Note: multipliers or "growth factors" higher than 4 are all coloured in the same dark blue

Like the Technology Driven Scenario by Ember, this new scenario adopts the 1.5°C target of the Paris Agreement and the net zero 2050 in its modelling constraints. Additionally, the EU Climate Law ambition of minimum 55% GHG emission reductions by 2030 is included in the top-down approach as well. The scenario is driven by a willingness of the society to achieve energy autonomy and focuses on decentralised technologies. It minimises imports from outside the EU, the use of nuclear power and deployment of CCS technologies. The Distributed Energy Scenario by ENTSOs presents a renewable electricity generation of 2559 TWh by

[22] "TYNDP 2022 Scenario Report – Introduction and Executive Summary," accessed August 18, 2023, https://2022.entsos-tyndp-scenarios.eu/.

2030, aligned with the Industry Electrification 2030 Scenario from the first method in this research (2499 TWh) and the Technology Driven Scenario by Ember (2485 TWh).

Figure 13 illustrates the growth factor of renewable electricity according to the Distributed Energy Scenario by ENTSOs between 2030 and 2021 Eurostat values. This figure shows a similar but smaller distribution of growth factors compared to the Industry Electrification Scenario by EnergyVille, but larger compared to the Technology Driven Scenario by Ember. Consequently, the Distributed Energy Scenario presents itself as an in-between distribution between the Industry Electrification Scenario which shows higher values for central MSs and lower ones for the surrounding MSs while the Technology Driven scenario presents a more even distribution over all MSs. The countries exceeding a growth factor of 4 are now Lithuania (7.0) and Hungary (4.8).

4.2. RENEWABLE ELECTRICITY SUPPLY ASSESSMENT

On the supply side, two different perspectives are presented: the national projections based on existing measures and the latest national plans. The first is largely based on the National projections of greenhouse gas emissions (Art. 18 of the Governance Regulation) and the second is largely based on the draft updates[23] of the National Energy and Climate Plans (NECPs) that were due by June 2023 (article 14 of the same regulation). Both sources provide data on the renewable electricity supply by 2030 on a MS level.

[23] European Commission site,

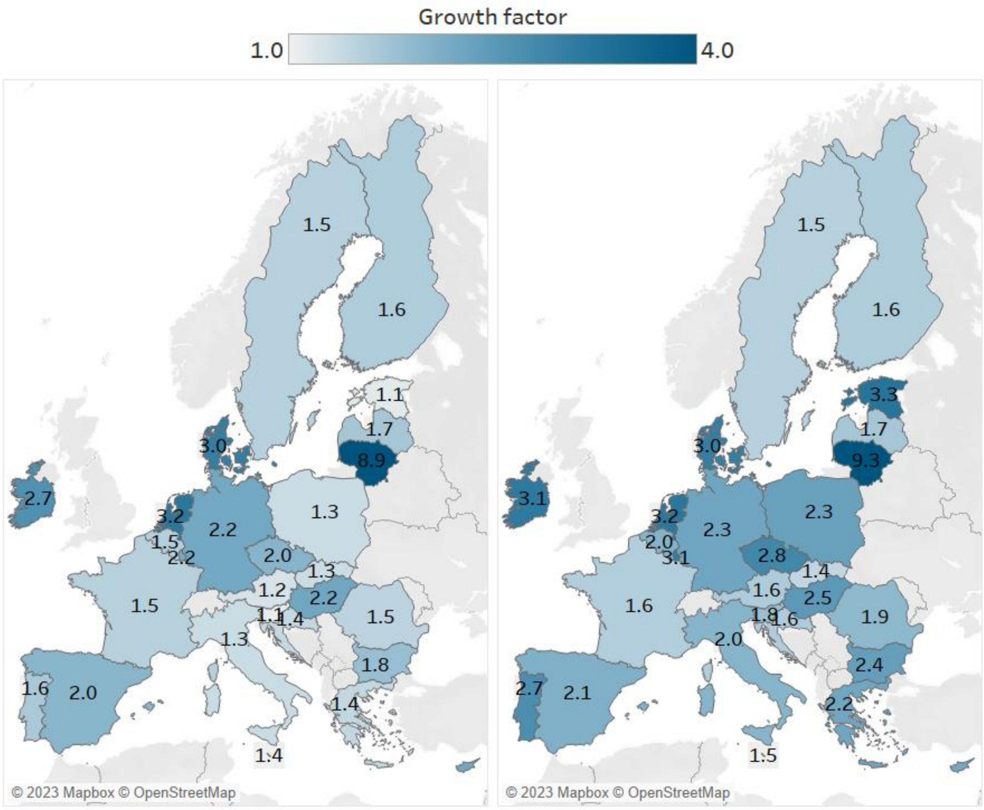


Figure 14 Renewable electricity supply increase by 2030 according to Existing Measures (left) and Latest National Plans (right) compared to 2021 Eurostat values. Note 1: missing data for Austria, Estonia, Ireland, Italy, Malta and Slovakia. Note 2: multipliers or "growth factors" higher than 4 are all coloured in the same dark blue.

4.2.1. Projections based on existing measures

The Governance Regulation (art 18) requires Member States to report national projections of anthropogenic GHG emissions. The GHG projections are reported every two years for two scenarios: 'with existing measures' (WEM) and 'with additional measures' (WAM).

Most Member States provide data on the renewable electricity projections in terms of absolute generation. For countries that don't provide this (non-obligatory) data, we took data from the Stated Policy scenario from Ember's New Generation report[24].

A total of 1978 TWh of renewable electricity is achieved by 2030 on an EU level. This is a factor 1.8 higher than the 2021 value from Eurostat. The WEM scenario reflects existing measures and policies, providing an outlook on the GHG emissions if no additional measures are taken. For the existing measures supply assessment, this WEM scenario is selected and the data is presented in **Appendix 7**.

[24] "New Generation | Clean Power Europe 2035."

Compared to the scenarios presented in the demand side assessment in **section 0**, The growth factors are smaller. This is a first indication of the gap between the demand scenarios and the existing measures.

4.2.2. Latest national plans

The national energy and climate plans (NECPs) outline the MS strategy to tackle the transition towards a sustainable, secure and affordable energy system for the period up to 2030. Draft updates of the National Energy and Climate Plans (NECPs) were due by June 2023 (article 14 of the same regulation) and data is available for most countries. For the other countries, we use Ember's 'Target Tracker' based on the latest policies that go beyond the original, 2019 based, NECP data on a MS level.[25]

Figure 14 also shows the growth factors for the renewable electricity supply in 2030 as defined by the latest national plans compared to 2021 Eurostat values. The latest national plans are more ambitious than the existing measures, shown by the larger growth factors. Compared to the demand side assessment however, most member state growth factors remain smaller, indicating that a gap is present for almost all MSs. For Cyprus, Denmark, Finland, Sweden, Latvia and the Netherlands, the plans and the existing measures are identical. A more detailed gap analysis is performed in **section 4.3**.

4.3. RENEWABLE ELECTRICITY DEMAND – SUPPLY ASSESSMENT

In this section, the renewable electricity supply and demand by 2030 are compared against each other on a member state level. **Section 4.3.1** presents the assessment for the Industry Electrification Scenario for both the existing measures and the latest national plans. **Section 4.3.2** discusses the supply and demand assessment for the two alternative outlooks: the Technology Driven Scenario and the Distributed Energy Scenario. **Appendix 7** provides additional context on the demand – supply analysis for the FF55 legislation.

4.3.1. Satisfying industry needs to a high degree of electrification

In this section we estimate the magnitude of the supply and demand gap in the Industry Electrification Scenario. In this scenario, renewable electricity gaps are large in countries that have a higher industrial activity, which mostly relates to switching the use of fossil fuel to electricity and hydrogen and starting to use electricity to produce a certain amount of e-fuel.

4.3.1.1. Gap to projections based on existing measures

The gap with the existing measures is of interest to show that new and additional policy measures must be taken to fulfil the industrial renewable electricity demand by 2030. In other words, the existing measures gap indicated the magnitude of the 'problem' each MS is facing currently.

By comparing the Industry Electrification Scenario from the demand assessment with the existing measures supply assessment, the following map illustrates the magnitude of the gaps by MS. Belgium (110%) as well as Luxembourg (121%), Poland (224%) and Lithuania (239%) exceed a gap size of 100%, colouring dark red on the map. These countries will therefore need to more than double their existing measures if they want to meet the 2030 industrial renewable electricity demand,

[25] "EU Power Sector 2030 Targets Tracker," Ember, accessed August 18, 2023, https://ember-climate.org/data/data-tools/european-renewables-target-tracker/.

following the Industry Electrification Scenario. Denmark (-26%), Germany (-5%), Lithuania (-13%) and Sweden (-20%) however, have a negative gap and are coloured green. Its existing measures are already more than enough to meet the 2030 industrial renewable electricity demand according to the Industry Electrification Scenario. These countries do not need to sharpen their existing measures to cover the future demand.

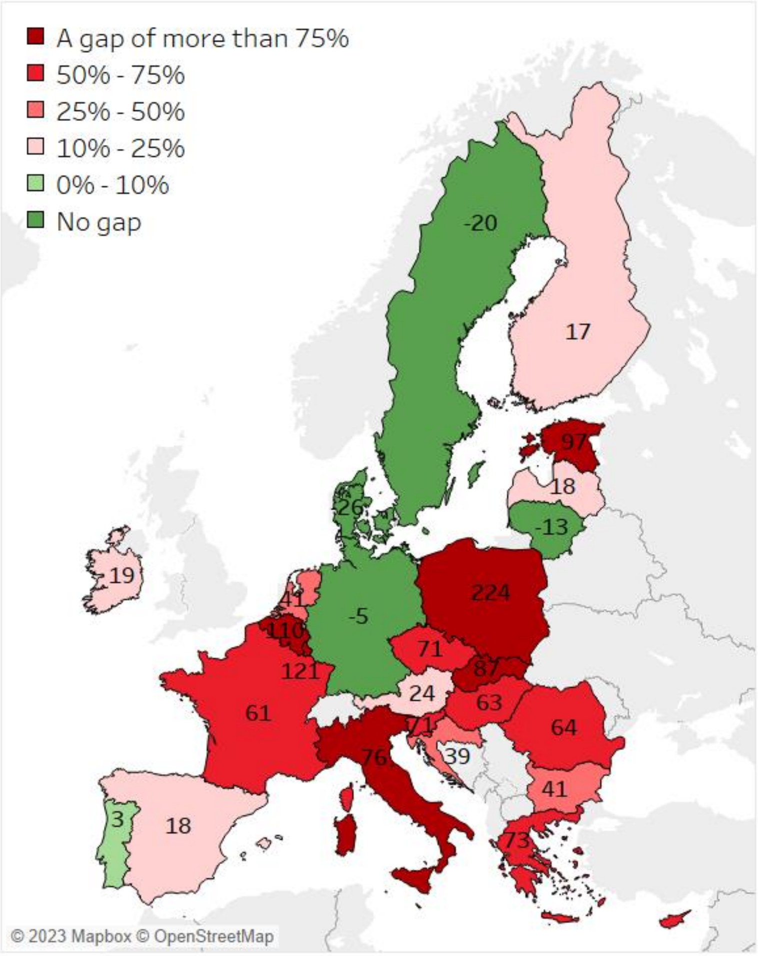


Figure 15 Renewable electricity gap by 2030 to fulfil 2030 demand following the Industry Electrification Scenario using the Existing Measures supply assessment. Gap expressed as percentage of required increase (or decrease) of existing measures to reach the demand

4.3.1.2. Gap to latest national plans

The gap with the Latest National Plans indicates that the plans from MS are also not sufficient to cover the 2030 industrial renewable electricity demand. The latest national plans gap shows that although plans to increase renewable electricity generation by 2030 are present, most MS require an increase in ambitions to be able to fulfil the 2030 demand. The gap analysis is performed by comparing the Industry Electrification Scenario on the demand side with the latest national plans supply side assessment. Doing so, the gaps per MS are presented in **Figure 16**.

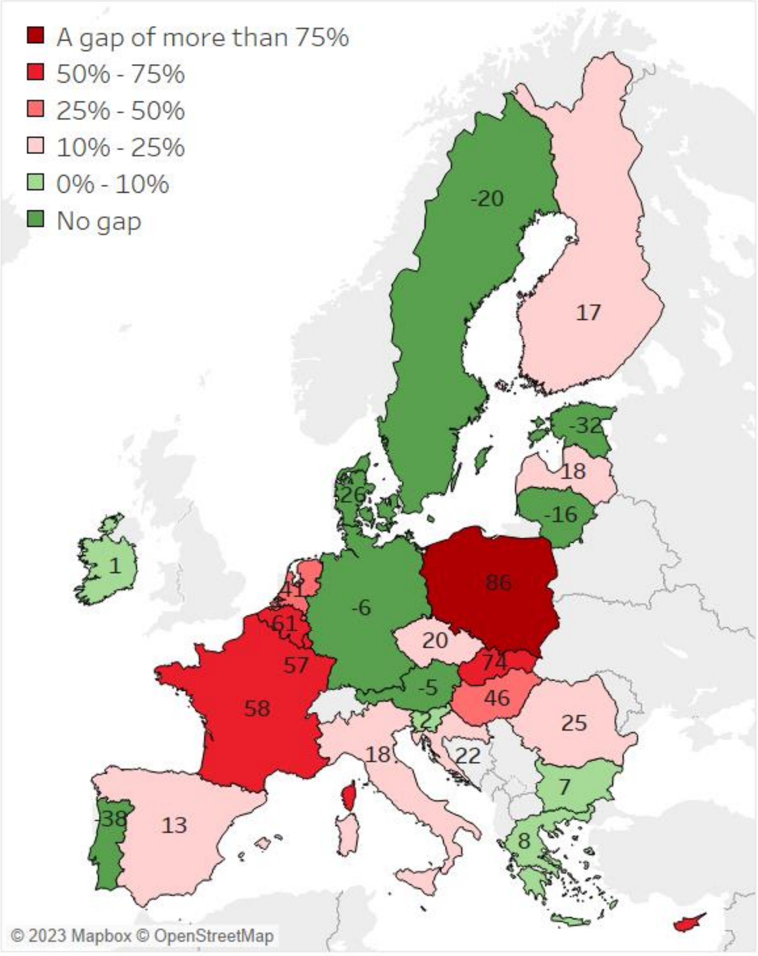


Figure 16 Renewable electricity gap by 2030 to fulfil 2030 demand following the Industry Electrification Scenario using the latest national plans supply assessment. Gap expressed as percentage of required increase (or decrease) of latest national plans to reach the demand

Only Luxembourg (57%), Belgium (61%), Slovakia (74%) and Poland (86%) exceed a gap size of 50%. Belgium decreases its gap size from 110% to 61%, indicating that ambitions to close the gap are present but not sufficient to close the gap. Aside from Denmark (-26%), Germany (-6%), Lithuania (-16%) and Sweden (-20%), that already coloured green for the existing measures gap, Portugal (-38%), Austria (-5%) and Estonia (-32%) have a negative gap as well. Portugal's latest national plans enable the country to go from a relatively small gap (3%) with the existing measures to an excess (-38%) of renewable electricity for industry in 2030.

4.3.2. Alternative electrification outlooks

To provide multiple perspectives on the demand supply assessment, the analysis is extended by the use of the alternative electrification scenarios on the demand side, as described in **section 4.1.2**. By repeating the gap analysis as performed for the Industry Electrification Scenario for both the Technology Driven Scenario and the Distributed Energy Scenario, we can compose six maps. **Table 3** provides an overview of the six gap analyses discussed in this research. **Figure 17** shows the gap analyses results.

Table 3 Gap analyses overview

GAP ANALYSES		2030 ELECTRICITY GENERATION ACCORDING TO MODELLING RESULTS		
		Industry Electrification (EnergyVille)	Technology Driven (Ember)	Distributed Energy (ENTSOs)
2030 ELECTRICITY GENERATION ACCORDING TO POLICIES	Existing Measures	MAP 1	MAP 2	MAP 3
	Latest National Plans	MAP 4	MAP 5	MAP 6

4.3.2.1. Technology Driven Scenario - Ember

The Technology Driven Scenario presents a different gap distribution compared to the Industry Electrification Scenario by providing an economical perspective to the electricity system. The potential renewable resources in a country play a higher role and also, the Ember scenario has a lower level of electrification in the industry sectors.

In general, more centrally located MSs such as Belgium, the Netherlands and Poland have a smaller gap, while the surrounding countries such as Greece or Spain have a larger gap. As was mentioned in **section 4.1.2.1**, the Ember scenario approximates the same total EU renewable electricity demand in 2030 (+/- 2500 TWh) as the other two demand scenarios, while the distribution over the different MSs differs due to the different models that are used for the different studies. The Ember study was modelled with less detail on a subsector level, resulting in a possibly less accurate modelling of certain subsectors which are more likely to electrify by 2030 such as the iron and steel sector in Belgium. This could indicate an underestimation of the 2030 renewable electricity demand by the Technology Driven Scenario.

The Ember results indicate a negative gap size for Belgium compared to the latest national plans, which means that Belgium is planning more than the cost-optimal level of renewable electricity generation. This indicates that Belgium could be better off importing its renewable electricity (or decreasing its export) to satisfy the local industry, instead of strengthening its national plans and producing it locally.

For countries which are coloured red, the opposite applies. These countries should strengthen their national plans and focus on export (or decreased import) to achieve an economically optimal gap distribution.

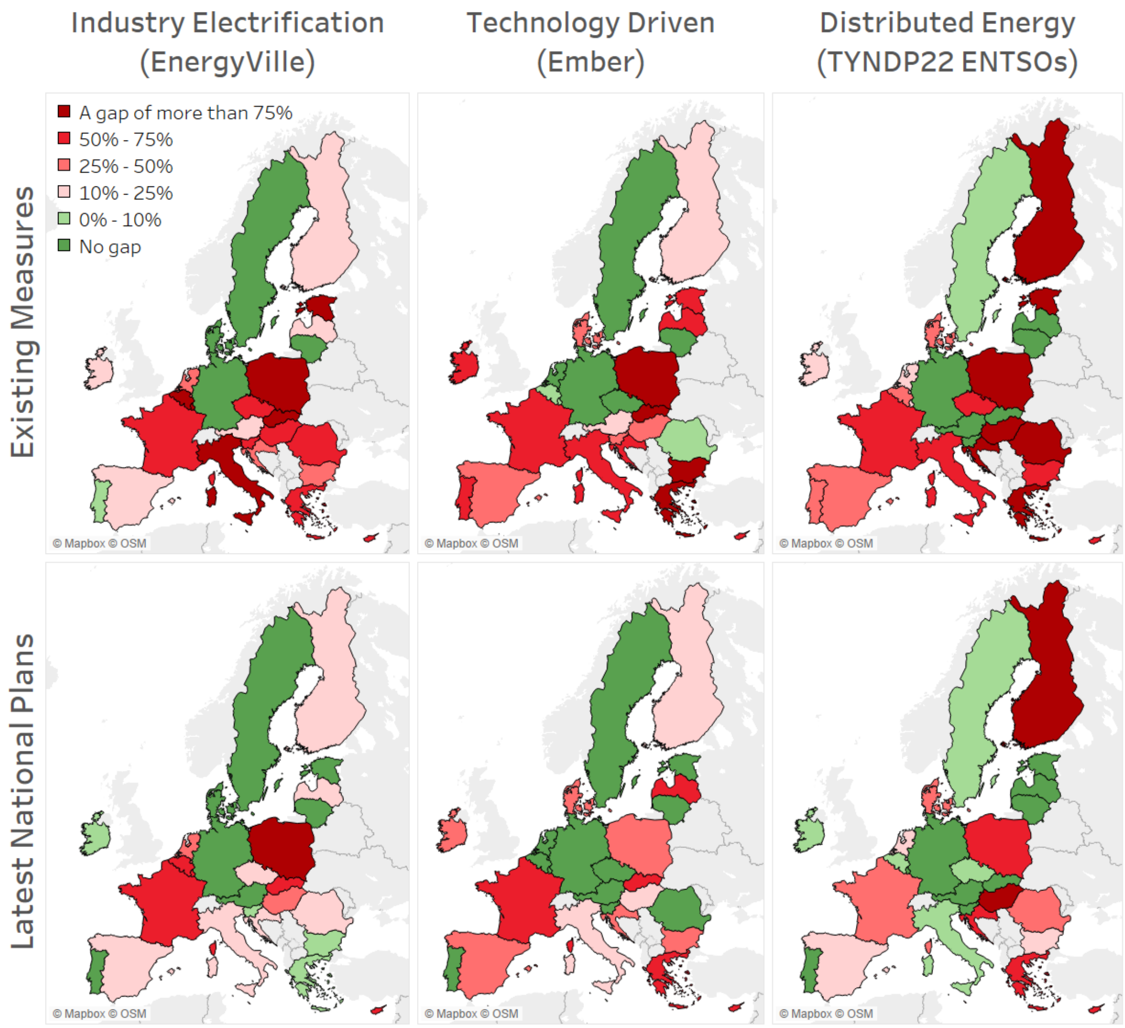


Figure 17 Gap analyses for existing measures (top) and latest national plans (bottom) on the supply side compared to the Industry Electrification Scenario (left), Technology Driven Scenario (middle) and Distributed Energy Scenario (right)

4.3.2.2. Distributed Energy Scenario - ENTSOs

The Distributed Energy Scenario is driven by a willingness of the society to achieve energy autonomy and focuses on decentralised technologies, while optimising costs, like the Ember scenario perspective. ENTSOs implements more detailed subsector level modelling and assumes a greater electrification in industry by 2030, changing the gap distribution.

This scenario presents a smaller gap for Belgium and the Netherlands, while the gap size increases in other countries such as Sweden and Finland. Compared to the Technology Driven Scenario however, Belgium's gap remains positive for both the existing measures (38 %) and the latest national plans (6%). This means that according to the ENTOSs modelling exercise, Belgium should strengthen its national plans to be more aligned with an EU economically optimised 2030 renewable electricity generation. The gap size in the Distributed Energy Scenario is smaller than the gap size in the Industry Electrification Scenario which means that Belgium should partially rely on imports of renewable electricity to satisfy its industry needs in 2030 when assuming the electricity generation from the ENTSOs scenario.

The amount of renewable electricity from the Distributed Energy Scenario is used in the next chapter to assess the level of ambition from each country.

4.3.3. The renewable electricity gap based on the TYNDP Distributed Energy

The renewable electricity gap is below 10% (or negative) for around half of the countries (14 out of 27). A larger gap is noticed for countries that we consider 'movers' for future updates of their RES-E ambition. These 13 countries get a darker colour in the categorisation in the Results section (4.4.3). For some countries, like Denmark, this may mean that they would increase their ambition above 100%.

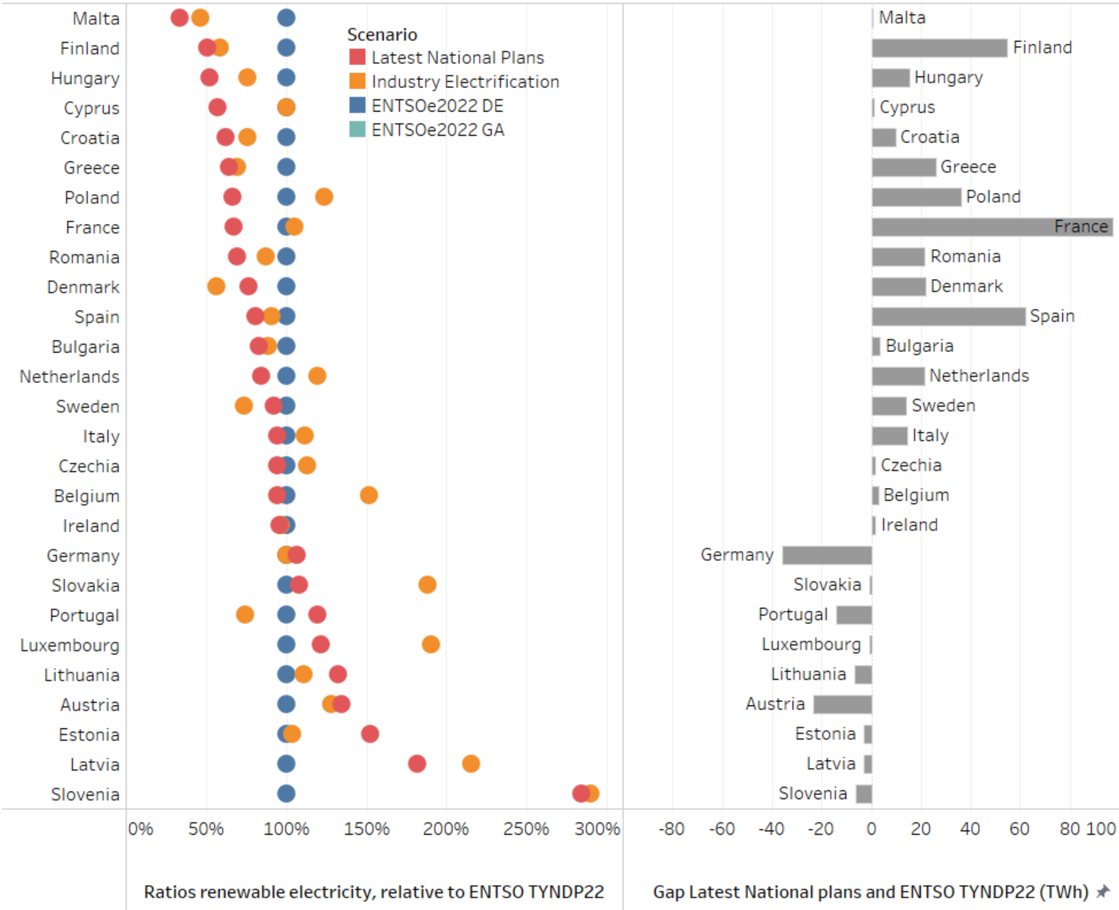


Figure 18 Relative gap Latest National Plans and Industry Electrification against the ENTSOs2022 Distribute Energy scenario (left, ranked by Latest National Plans) and the absolute gap (right)

5. MEMBER STATE ASSESMENT OF TOTAL ELECTRICITY

The aim of this chapter is to expand the member state assessment to a total electricity perspective. Firstly, the new dataset for the total electricity gap is provided and compared to historical values in **section 5.1**. Secondly, an overview for the different countries is provided in **section 5.2** which categorizes each MS according to the change in its total electricity net annual balance and its share of renewable electricity.

This chapter generates insights especially for countries that may face problems from a rapid industry electrification. There are two components to analyse how the industry electrification can be realised: the ambition of countries to generate enough energy and the ambition to import or export energy to where the demand will increase significantly.

5.1. THE TOTAL ELECTRICITY GAP - COMPARING THE INDUSTRY ELECTRIFICATION SCENARIO WITH HISTORICAL DATA

Net annual total electricity balance

In the previous assessments of this study, the Industry Electrification Scenario provided data on electricity *supply* per MS and comparing this to the draft updated Latest National Plans provided insights in the lack of installed renewable electricity generating capacity per MS. From this chapter onwards, the renewable electricity view is broadened to a total electricity perspective. To this end, the dataset of the Industry Electrification scenario and the Latest National Plans (**Table 4**) are adapted in two ways:

1) The ***total electricity supply*** is calculated by accounting for the RES-E share per country in the ***Latest National Plans*** to convert the amount of renewable electricity to total electricity.

2) The Industry Electrification ***total electricity demand*** is calculated analogously to the initial dataset on renewable electricity generation per country, but now starts from the FF55 ***total electricity demand*** per country before adding the additional component based on hydrogen and e-fuel consumption per MS.

Table 4 Total electricity gap for the Industry Electrification demand compared to the draft updates NECPs (Latest National Plans)

MEMBER STATE	CONSUMPTION INDUSTRTY ELECTRIFICATION SCENARIO [TWH]	PRODUCTION LATEST NATIONAL PLANS [TWH]	IMPORT [TWH]	EXPORT [TWH]
AT	91	91*	0	0
BE	146	93*	53	0
BG	43	51*	0	8
HR	26	22	4	0
CY	7	6*	1	0
CZ	85	83*	1	0
DK	55	72	0	17

EE	11	9	2	0
FI	115	102	13	0
FR	517	652*[26]	0	135
DE	729	666	63	0
EL	72	59*	13	0
HU	68	55	13	0
IE	50	47*	2	0
IT	391	350	41	0
LV	10	8	2	0
LT	25	26	0	1
LU	9	3	6	0
MT	4	3*	1	0
NL	193	156	37	0
PL	257	200*	56	0
PT	59	95	0	36
RO	96	78*	18	0
SK	41	36*	5	0
SI	20	19	1	0
ES	323	350	0	27
SE	149	224	0	75
EU	3591	3557	34	0

*Note: for these countries, total electricity comes from the Technology driven Scenario (Ember), because this data is not available in the 2023 updated draft NECPs or arrived too late for this project in the case of France.

Comparison to historical data

A crucial aspect is the impact on the annual electricity balance. The Industry Electrification scenario will drive countries into increased imports of non-fossil energy. In **Figure 19**, a comparison is presented between historical and projected flows. The two bottom maps can be used to compare historical 'highs' with required flows according to the new dataset of the Industry Electrification scenario.

Very large changes are observed for Germany (imports x 6), Poland (imports x 4), Belgium (imports x 2.5), the Netherlands (imports x 1.7), Portugal (exports x 7), Sweden (exports x 3), Spain (exports x 2.4), Romania and France (exports almost x 2). **Appendix 4** presents more details regarding interconnection capacities resulting from this economical perspective.

[26] The 2023 updated draft NECP from France mentions a "nuclear ambition" scenario reaching a total electricity production of 597 TWh only.

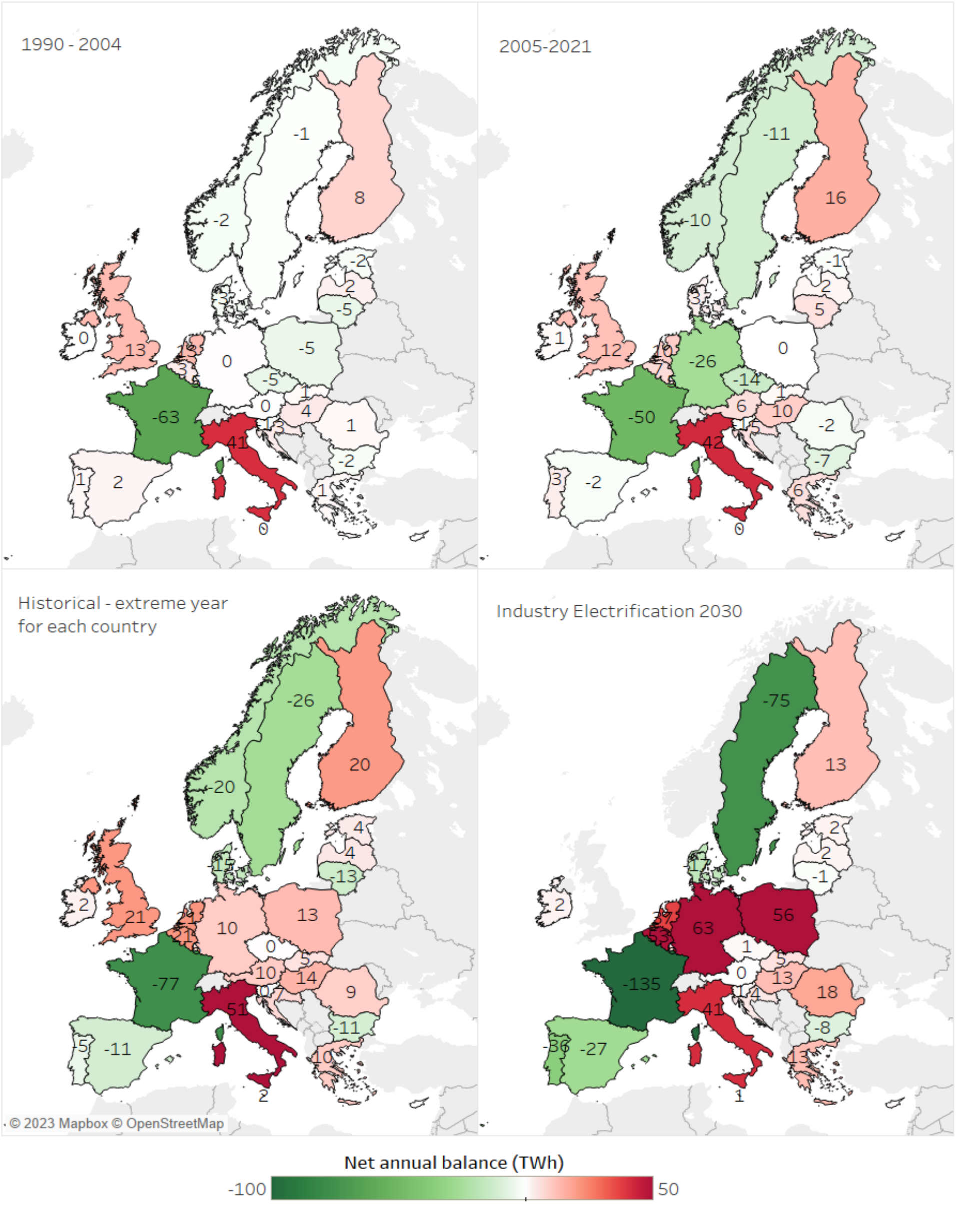


Figure 19 Net annual balance total electricity in historical context and in the Industry Electrification 2030 scenario

6. EVALUATING DRAFT NATIONAL PLANS FOR MEETING THE ELECTRIFICATION NEEDS

National plans from an EU Energy Union perspective

We create a hypothetical scenario that assumes a high level of industry electrification but where the electricity generation is not necessarily taking place locally in the country. We get information on the possible impacts on the energy or electricity flows in the situation without significant hydrogen imports by 2030.

Based on the comparison of RES-E with TYNDP22 Distributed Energy Scenario in chapter 4 and new insights on the total electricity generation from chapter 5, a categorization is defined for the MSs. To do so, we create a hypothetical scenario assuming 1) that the electricity generation in each country will reach the 2030 level of the national plans and 2) that the electricity demand is in line with the Industry Electrification scenario.

The categorization evaluates two indicators from this imaginary situation:

1. the RES-E gap of the Plans to the TYNDP22 Distributed Energy Scenario, and
2. the change of the net annual balance of electricity flows.

The RES-E gap to the Distributed Energy Scenario is useful because the total RES-E from the national plans (2293 TWh) is not enough for the Industry Electrification scenario (2500 TWh). The RES-E gap can be considered a proxy for the expected increase in ambition of some countries.

Large changes can be expected on the net annual import/export of electricity. This indicator is crucial in the situation of a mismatch between supply and demand.

Table 5 Categories for identifying country challenges for the Industry Electrification (* within a 10% margin)

	CHANGE IN NET ANNUAL ELECTRICITY BALANCE	LEVEL OF RES-E ENOUGH ?	KEY MESSAGE
	> 50% imports	NO	• Prepare for high import flows or increase RES-E to cover local demand.
		YES*	• Prepare for high import flows that are needed to cover local demand
	> 50% exports	NO	• Prepare for high export flows • Increase export ambition • Higher RES-E target is advisable to increase total EU generation.
		YES*	• Prepare for high export flows • Increase export ambition through reducing own demand

	< 30%	NO	• Higher RES-E target is advisable to increase total EU generation.
		YES*	• RES-E level OK • No large change in the net annual electricity flow

We create a MS categorization based on a hypothetical scenario combining the new Industry Electrification demands and Latest National plans supply on total electricity. Six colour coded categories are defined based on the two indicators to evaluate a country's ambition levels. The results of this categorization are illustrated in **Figure 20**.

A color is used to indicate the second indicator: change in the net annual balance. The yellow/orange colored countries need to import large amounts of electricity compared to historical levels. This means that the national plans are not enough to provide the local industry with enough electricity by 2030. For the blue toned countries, the opposite is true. These countries present high levels of export compared to historical values. The neutral toned countries present less significant changes in their net annual balance. The intensity of the color is used to represent the first indicator: the RES-E gap of the Latest National Plans to the Distributed Energy Scenario. The darker shades represent countries that need to increase their level of RES-E.

Three countries (the Netherlands, Poland and Romania) are in the orange category with high import flow and room to increase RES-E.

Two countries are in the yellow category (Belgium and Germany). These countries have national plans that result in a RES-E level which is sufficient, while they are not sufficient to cover their local production in 2030. This indicates that local production gaps should be solved with renewable electricity imports. If these countries were to strengthen their national plans further to cover their own local production, they would increase the absolute economical gap value and therefore increase total EU system cost.

Two countries (Spain and France) are in the dark green category indicating that they should prepare for high export flows.

Two countries (Portugal and Sweden) are placed in the light green category. These countries should prepare for high export flows and increase export ambition, mostly through reducing own demand.

Eight countries (names) are in the pink category. A higher RES-E target is advisable to increase total EU generation, however the net annual balance of electricity remains similar to historical values.

Ten countries (names) are in the grey category. These countries require relatively limited action in their national plans.

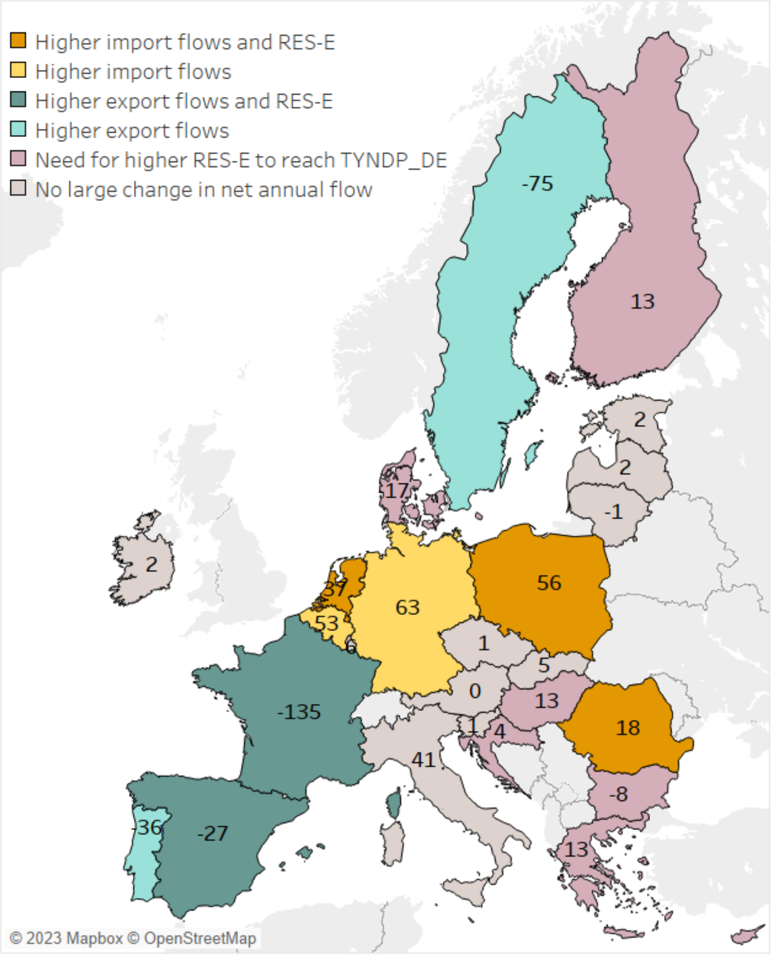


Figure 20 MS categorization when Industry Electrification takes place without changes to the Latest National plans; reference for supply: TYNDP22 Distributed Energy scenario

7. ESTIMATION OF THE IMPACT ON ENERGY GRIDS IN THE TRILATERAL REGION BELGIUM, THE NETHERLANDS AND GERMANY

This chapter discusses the 2030 European interconnection capacity for the Industry Electrification scenario with a focus on the industry cluster Belgium, the Netherlands and Germany. The total electricity gap as presented in Chapter 5 is used as a basis for this interconnection analysis for the Industry Electrification scenario. Annex 3 provides an additional overview for the two alternative outlooks.

All interconnection capacities are provided on a MS level by aggregating all cross-border capacities for each border, considering the direction of the flow.

7.1. METHODOLOGY OF THE SIMULATION MODEL

Context and scope of the exercise

Electricity supply-demand imbalances between countries can be solved in multiple ways distinguished by two aspects. Firstly, the **energy carrier**: a shortage of electricity in one country can be solved by importing electricity directly or indirectly via hydrogen. Secondly, imbalances can be solved from two different perspectives: **interconnections vs. additional supply**. The first perspective tries to solve imbalances through increased interconnections (of all kinds) and thereby assumes energy solidarity between member states. The latter is oriented more towards self-sufficiency, assuming limited support can come from the neighbouring countries.

Figure 21 visualises these different balancing strategies. Our interconnection analysis for the Industry Electrification Scenario will be largely based on the upper left quadrant where we try to solve total electricity supply-demand imbalances through cross-border interconnections. Furthermore, additional insights regarding the three other perspectives are provided as well.

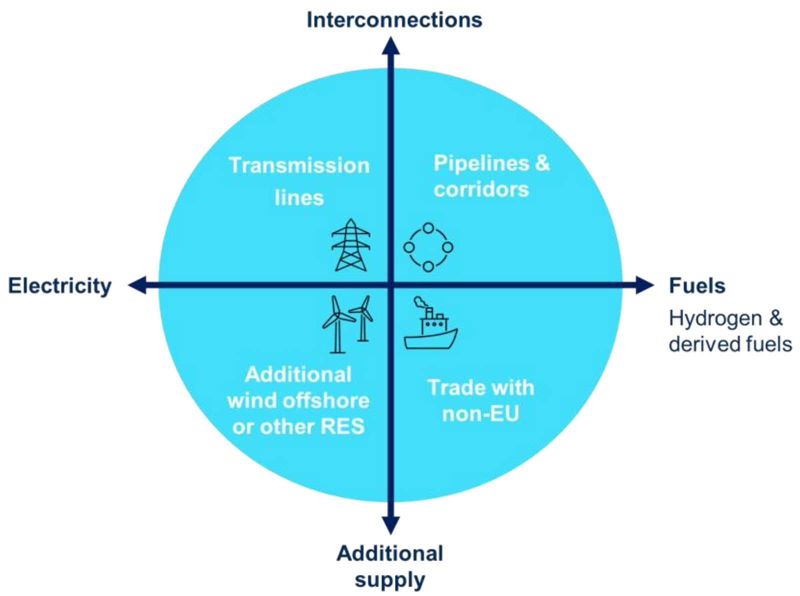


Figure 21 Supply-demand balancing strategies

Simulation model

This exercise attempts to answer the question if the proposed ENTSOs TYNDP24 2030 reference grid is sufficient to comply with the more rapidly electrifying industrial demand from the Industry Electrification Scenario on an annually aggregated level.

To support this analysis, a European interconnection model is developed using TIMES. For consistency, the model includes all countries which were included in the ENTSOs interconnection results. The draft TYNDP24 2030 reference grid includes all cross-border transmission capacities across Europe, according to the data that member TSOs have for 2030. Therefore, the reference grid is used as a representative for the Latest National Plans. The TIMES model will then propose additional grid expansions to close the gap between the Industry Electrification total electricity demand and the Latest National Plans (TYNDP reference grid) total electricity generation.

The simulation model will perform a minimization of the total system cost to balance the annual aggregated supply and demand for imported electricity. Different scenarios are defined by enabling or disabling certain expansion options or costs.

7.2. Results for a scenario with high country interconnectivity

This section presents the results of the Industry Electrification interconnection analysis for the cluster of Belgium, the Netherlands, and Germany. Two main scenarios are presented in this chapter to provide overall conclusions and perspective on the interconnection analysis for the Industry Electrification scenario. Addendum 4 presents further results and an additional scenario to broaden the context.

The first scenario presented in this chapter, in which grid imbalances are solved through additional electricity interconnections, shows that faster deployment of interconnection projects is required to balance the import and export needs in 2030. The results of this scenario are presented in **Figure 14** which shows the additional required interconnection capacity for electricity lines on top of the ones presented by the draft TYNDP24 2030 reference grid. This scenario assumes high costs for investments in lines which are not provided in the list of candidates.

Due to the limited transit capacity between France and Belgium, the model opts to deploy future projects to connect the United Kingdom with Germany (NeuConnect[27]), Belgium (Nautilus[28]) and the Netherlands (Project 260). from these connections, the model does not choose to invest in additional interconnection capacity between the cluster of Belgium, the Netherlands and Germany. This highlights the cost-efficiency of increasing the interconnection capacity of this trilateral region with the offshore capacity of the United Kingdom.

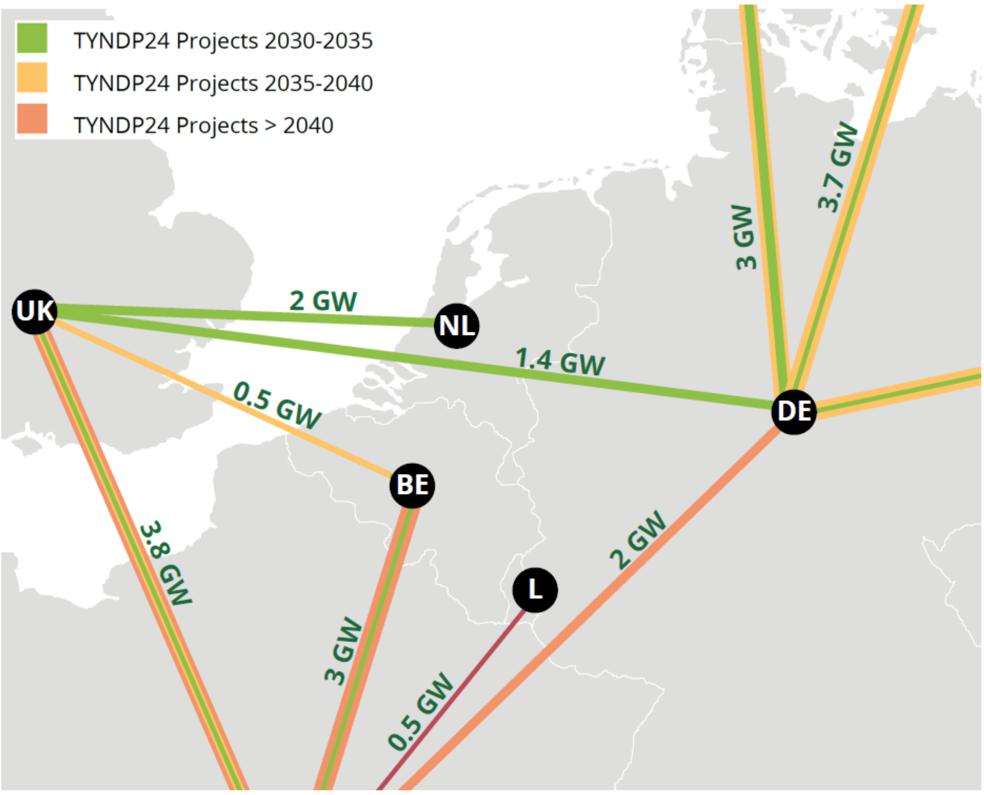


Figure 22 Industry Electrification Scenario 2030 additional interconnection requirements on top of the draft TYNDP24 2030 reference grid for electricity interconnections

Tables 5 and 6 give an overview of the analysis for the trilateral region with additional detail.

[27] "Home," NeuConnect Interconnector, accessed December 8, 2023, https://neuconnect-interconnector.com/.
[28] "About Nautilus | National Grid Group," accessed December 8, 2023, https://www.nationalgrid.com/national-grid-ventures/interconnectors-connecting-cleaner-future/nautilus-interconnector.

Table 6 Results of the interconnection analysis for 2030 by category

CAPACITIES [GW]	BELGIUM	GERMANY	THE NETHERLANDS
IMPORT TRANSMISSION CAPACITY 2030	**14.8**	**58.4**	**14.6**
2025 GRID	*9.9*	*32.9*	*10.9*
TYNDP24 2025-2030 (REFERENCE GRID 2030)	*1.4*	*18.4*	*1.7*
PROJECTS BEYOND 2030	*3.5*	*7.1*	*2.0*
OTHER CONNECTIONS	**5.4**	**26.6**	**20.0**
OFFSHORE CONNECTIONS OWN TERRITORY	*4*	*26.6*	*20.0*
OFFSHORE OUTSIDE TERRITORY	*1.4*	*/*	*/*

*focus only on import capacity, differences to export capacity not presented.

Table 7 Results of the interconnection analysis: detail on the additional required capacity going beyond the TYNDP24 draft plans

CAPACITIES [GW]	BELGIUM	GERMANY	THE NETHERLANDS
TOTAL	3.5	7.1	2.0
NAUTILUS (UK-BE)	0.5		
BE00-FR00 REAL 1 (FR-BE)	1.0		
BE00-FR00 CONCEPT 1 (FR-BE)	1.0		
BE00-FR00 CONCEPT 2 (FR-BE)	1.0		
NEUCONNECT (UK-DE)		1.4	
DE00-FR00 CONCEPT 1 (FR-DE)		1.0	
DE00-FR00 CONCEPT 2 (FR-DE)		1.0	
DE00-DKE1 CONCEPT 1 (DK-DE)		0.5	
DE00-DKE1 CONCEPT 2 (DK-DE)		0.5	
DE00-DKE1 CONCEPT 3 (DK-DE)		0.5	
DE00-DKE1 CONCEPT 4 (DK-DE)		0.5	
DE00-DKE1 CONCEPT 5 (DK-DE)		0.5	
DE00-DKE1 CONCEPT 6 (DK-DE)		0.5	
HANSA POWERBRIDGE 1(SE-DE)		0.7	
PROJECT 260 (UK-NL)			2.0

*focus only on import capacity, differences to export capacity not presented.

7.3. RESULTS FOR A SCENARIO WITH INCREASED OFFSHORE WIND TO SAFEGUARD SECURITY OF SUPPLY

The second scenario translates the interconnection problem to a hypothetical scenario where we explore what is needed in terms of offshore inflow capacity in case no additional electricity or hydrogen interconnections are built by 2030. The scenario matches a faster uptake of the 2035 wind offshore plans with additional demand from industry clusters by 2030. Furthermore, the scenario assumes a perspective of safeguarding security of supply, assuming exports from neighbouring countries are not available.

The results of this scenario are presented in **Figure 15** which illustrate the total offshore connection capacity for the three countries in the cluster. Belgium requires an additional 6 GW of offshore inflow on top of its own maximum offshore potential of 6 GW. The Netherlands requires an additional capacity of 10 GW on top of their own 21 GW, and Germany requires 15 GW additional to their 26 GW potential. These capacities all go beyond what is feasible within the territories of these countries, indicating a need for additional connections to offshore wind islands from the United Kingdom or Norway, for instance, if no additional electricity or hydrogen interconnections are provided by 2030.

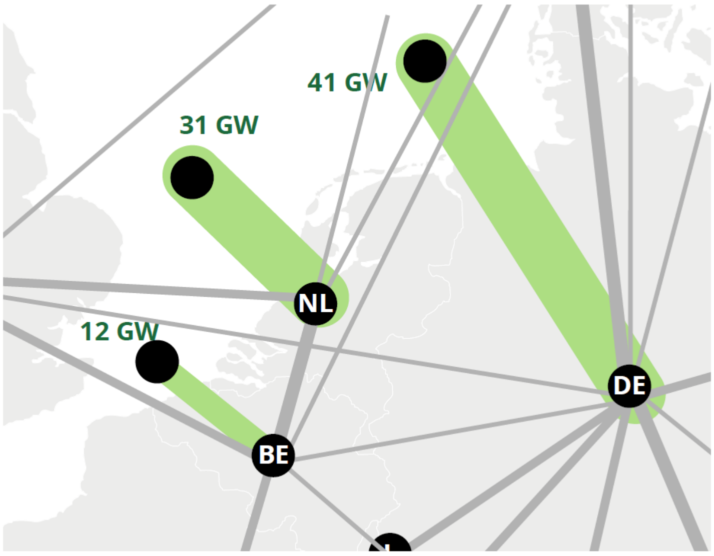


Figure **23** Industry Electrification Scenario 2030 interconnection analysis for the trilateral region

7.4. CONCLUSIONS ON INTERCONNECTION CAPACITIES

Balancing the future discrepancy between supply and demand of electricity can be tackled from different perspectives, depending on the energy carrier and the level of energy solidarity withing the European energy system. Interconnections can refer to either electricity interconnections or fuels, such as hydrogen and derivatives. Low levels of cooperation can lead to a perspective of self-sufficiency resulting in an energy system which deploys additional supply where needed. Higher levels of cooperation can lead to an energy union perspective resulting in a highly interconnected energy system, which decrease the total system cost.

The evaluation of the total electricity gap indicates the need for additional interconnections for the industrial cluster Belgium, the Netherlands and Germany to the United Kingdom to balance the import needs by 2030. To facilitate rapid industry electrification aligning with the goals of REPowerEU, strategic interventions are imperative.

1. **Network Expansion**: Addressing country imbalances necessitates a swift expansion of electricity interconnections. Accelerating the deployment of new interconnections is necessary to support the electrification of industry by 2030. Belgium requires 3.5 GW additional to the draft TYNDP24 2030 reference grid. The Netherlands 2 GW and Germany 7 GW.

2. **Hydrogen Interconnections**: By enhancing the import of hydrogen or its derivatives beyond the assumed 33% of consumption, countries can possibly have a faster uptake of energy imports. If electricity network expansion falls behind, hydrogen can serve as an alternative interconnection strategy.

3. **Additional offshore connections**: Expedited deployment of offshore inflow capacities are required to cover the increasing need for electricity in the trilateral region. If no additional electricity or hydrogen interconnection projects are realised by 2030, Belgium requires an additional 6 GW of offshore inflow on top of its own maximum offshore potential of 6 GW to cover the increasing electricity demand in industry. The Netherlands requires an additional capacity of 10 GW on top of their own 21 GW, and Germany requires 15 GW additional to their 26 GW potential. These inflow capacities go beyond the territorial generation capacity and require connections to extraterritorial offshore wind.

4. **Integrated Approach**: An integrated approach that combines the above strategies. By fostering collaboration and adopting a mix of solutions, we can fortify our energy infrastructure against potential disruptions.

The EU already recognizes that resilient energy networks are vital for its internal market and green transition. The proposed EU Action Plan for Grids[29], initiated in November 2023, emphasizes efficient and rapid deployment of electricity grids to support the European Green Deal. Anticipating a 30% increase in electricity consumption by 2030, the plan addresses challenges such as digitalization, decentralization, and accommodating diverse energy resources. With 40% of our distribution grids more than 40 years old and cross-border transmission capacity due to double by 2030, €584 billion in investments are necessary. The Action Plan outlines specific measures for grid planning, regulatory incentives, finance accessibility, and streamlined permitting to expedite the transition toward cleaner and more interconnected energy systems, aligning with 2030 objectives.

[29] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6044

8. KEY CONCLUSIONS

The EU has set ambitious climate targets that imply a strong electrification of different sectors. In this report we analyse how strong electricity demand will grow and if EU member states move fast enough to get in place the needed investments in additional renewable capacity. As we approach 2030, the risk of electricity shortages in certain countries demands strategic interventions. Achieving rapid industry electrification, aligned with REPowerEU goals, hinges on critical power system and network conditions. This study covers all industrial sectors, including the EU process and fuel manufacturing industries. Final numbers include the energy to produce transportation fuels, but do not include the energy content of the transportation fuels itself[30].

Industries need to shift from decades of stable electricity use to embrace a 50% increase.

Over the past three decades, the energy and electricity use of the EU industry sector has remained relatively stable. Fuel manufacturing stands out with the most substantial increase, reaching 82 TWh, driven by the production of hydrogen using green electricity and the generation of e-fuels. Following closely are the chemical and petrochemical sectors, with an 81 TWh increase.

Total electricity generation should rise by approximately 30%, while renewable electricity needs to more than double (a factor of 2.3).

At EU level, it is projected that total electricity generation could increase by 30%, with the share of renewable electricity rising by 80% by 2030 (reaching 69% compared to 37.5% in 2022). Combining these factors, the total electricity generation from renewable sources is expected to more than double, reaching a factor of 2.3 increase.

At EU level, the renewable electricity gap is around 20%, resulting in a shortage of 250 TWh.

Based on the incorporation of REPowerEU ambitions, it is anticipated that the future renewable electricity (RE) supply will be insufficient to meet the energy needs of the process industry and the needs of e-fuel production. In national projections considering existing measures, the increase in RES-E falls significantly short, amounting to only 65% of the required increase, resulting in a substantial shortage of 500 TWh. Similarly, in scenarios encompassing national plans, the RES-E increase is projected to be 80% of the required increase, resulting in a shortage of 250 TWh. The gap for renewable electricity at EU level is around 15-35% when compared to the necessary increase of 1400 TWh.

Four countries have a renewable electricity shortage of more than 50%

The gap can be remarkably higher in at country level. The analysis reveals a disparity between the Latest National Plans and the Industry Electrification Scenario. Despite national plans, most Member States must enhance ambitions to meet the demand. Notably, Luxembourg, Belgium, Slovakia, and Poland face substantial shortages exceeding 50%, while Portugal's plans position it to surpass the demand, transitioning from a 3% shortage to a 38% surplus in renewable electricity.

[30] The production of "light liquid fuel" using co-electrolysis demands 59 GJ electricity per ton of e-fuel, surpassing the fuel's 42 GJ energy content.

This underscores the need for heightened national ambitions to bridge the existing disparities and meet industry electrification targets.

An average 100 GW/yr additional renewable capacity from 2023 to 2030 is required

In the transition period of 2030, there is a notable risk of facing a shortage in the supply of renewable electricity to the process industry. To address this shortfall, an average additional renewable capacity of 100 GW per year is necessary between 2023 and 2030. These findings underscore the need for substantial efforts and investments to expand renewable electricity generation to meet the growing demands of the process industry and achieve sustainability goals.

By 2030, significant risk of shortage of electricity in some countries, even considering latest national plans

Examining total electricity, the EU level shows minimal or no shortages based on the latest NECP updates with "additional measures" plans. However, at the country level, substantial regional gaps exist, ranging from 15% to 35% of future expected electricity needs.

Network expansion is required to solve high country imbalances in the trilateral region Belgium, the Netherlands and Germany

Increased electricity imports may be necessary, especially for Germany (imports x 6), Poland (imports x 4), Belgium (imports x 2.5), Romania (imports x 1.8), and the Netherlands (imports x 1.7).

To address country imbalances, immediate network expansion is imperative. This entails the swift adoption of new electricity interconnections, establishment of hydrogen interconnections, or the incorporation of additional offshore wind. A balanced mix of these measures is vital for ensuring energy security and realizing the targets set by REPowerEU. The balance between efforts towards expansion of the electricity or hydrogen grid will depend on efficiency considerations but also on the speed of deployment, in other words how much GigaWatt can be connected in a timeframe of 6 or 7 years. Intense collaboration are essential to fortify the EU energy infrastructure against potential shortages and enhance overall energy security.

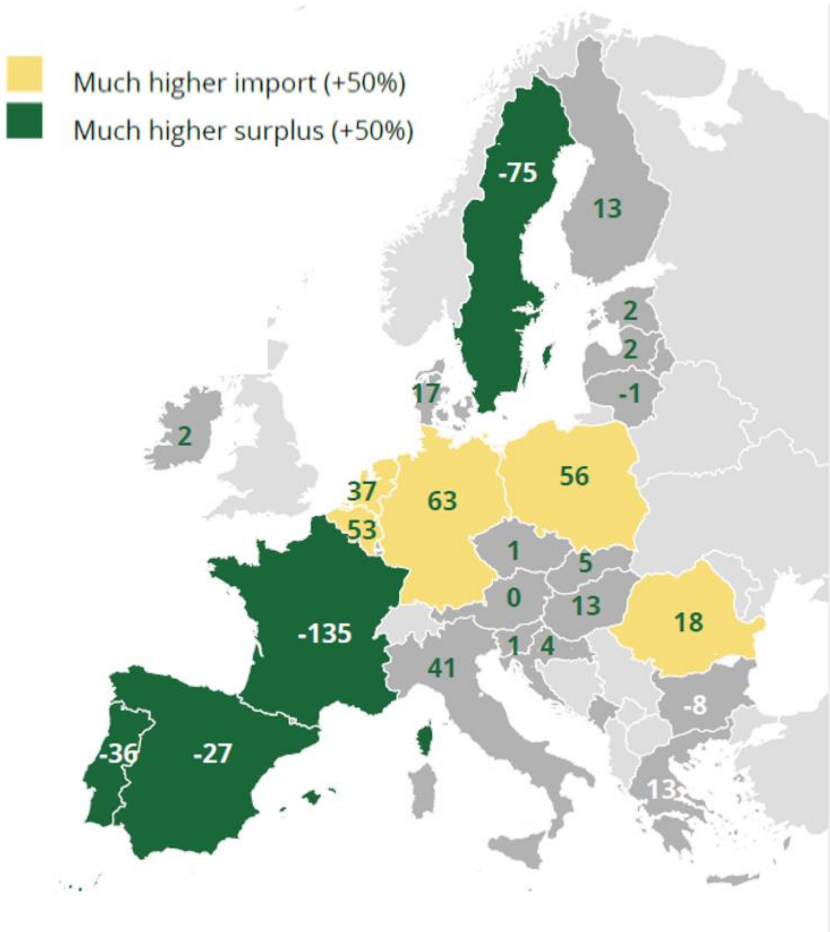


Figure 24 Total electricity import needs (or export options if negative) based on the Industry Electrification Scenario and latest updated National Plans for 2030

Country specific assessment

Combining the assessment of both renewable and total electricity, a categorization framework is established for all countries. This involved creating a hypothetical scenario that envisions 1) electricity generation in each country reaching the 2030 level outlined in national plans, and 2) electricity demand aligning with the Industry Electrification scenario from this report. The categorization assesses two key indicators within this hypothetical context: 1. the Renewable Energy Sources in Electricity (RES-E) gap between Plans and the TYNDP22 Distributed Energy Scenario, and 2. the variation in the net annual balance of electricity flows.

Prioritize Import Strategies: The Netherlands, Poland, and Romania should focus on enhancing import strategies while simultaneously increasing their RES-E capacity.

Strengthen Local Production: Belgium and Germany need to strengthen their national plans to cover local production gaps, ensuring a robust and self-sufficient energy landscape by 2030.

Boost Export Infrastructure: Spain, France, Portugal, and Sweden should prepare for high export flows, with a particular emphasis on infrastructure development and increasing export ambitions.

Optimize RES-E Targets: Eight countries should consider adjusting their RES-E targets upwards to contribute to increased EU generation while maintaining a stable net annual balance.

Maintain Stability: Ten countries can maintain relatively stable national plans with limited additional actions required, ensuring a balanced approach to industry electrification.

Process industries can de-risk through securing their energy supply needs

To mitigate this risk and ensure a smooth transition, several measures can be implemented. First and foremost, it is crucial to reinforce innovation efforts aimed at enhancing energy efficiency in material production. This will contribute to optimizing energy consumption and reducing the overall demand for renewable energy.

Additionally, there is a need to intensify the electrification of industrial processes, focusing on improving their efficiency and exploring innovative approaches. This includes adopting flexible strategies to enhance the adaptability and resilience of industrial processes and on-site electricity supply.

To alleviate the pressure on renewable electricity resources, alternative solutions should be sought to reduce the increased reliance on renewable electricity in the process industry. This could involve exploring other energy sources or employing energy-saving techniques and technologies.

Furthermore, facilitating the integration of non-EU semi-processed raw materials becomes essential. By allowing the preparation of energy-intensive raw materials in regions outside the EU with abundant renewable energy resources, the dependence on EU-based renewable energy supply for the entire production process can be reduced.

These measures, taken collectively, can help address the risk of renewable energy shortage in the process industry during the transition period of 2030, ensuring a sustainable and efficient path towards a greener industrial landscape.

9. GLOSSARY

AIDRES	Advancing industrial decarbonization by assessing the future use of renewable energies in industrial processes
Biofuel	Liquid fuel for transport produced from biomass
Biogas	Gaseous fuels produced from biomass
Bioliquid	Liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass
Biomass fuel	Gaseous and solid fuels produced from biomass
GHG	Greenhouse gas
Low carbon fuel	Derived from non-renewable sources, such as nuclear energy. The specific criteria for determining low carbon fuel will be established in 2024
MS	Member State
NECP	National energy and climate plans
Recycled carbon fuel	Energy derived from unavoidable industrial processes, such as hydrogen from steelmaking or CO from steelmaking
RED	Renewable Energy Directive
Renewable fuel	Energy derived from sources such as hydro, solar, and wind, as long as they are not from biomass (RED) Biofuels, bioliquids, biomass fuels and renewable fuels of non-biological origin
RES	Renewable Energy Source
RES-E	Renewable Electricity
TWh	Terra-Watthour
TYNDP	Ten-Year Network Development Plan, in compliance with Regulation (EU) 347/2013. For the TYNDP 2022, ENTSOG and ENTSO-E collaboratively developed scenarios to assess energy system infrastructure needs, emphasizing interactions between gas and electricity systems.

APPENDIX 1 METHOD - INDUSTRY ELECTRIFICATION SCENARIO - EU LEVEL

GENERAL APPROACH INDUSTRY ELECTRIFICAITON SCENARIO 2030

The Industry Electrification 2030 scenario is constructed in two main steps. In a first step we generated a 'REPowerEU like' scenario based on Energyville assumptions to estimate the main characteristics of electricity supply and generation. In a second step, we swap the industry demand by our own bottom-up analysis that is explained in 12.2.

The demand for renewable electricity is 2499 TWh, as the sum of the non-industry part (2031 TWh) and the additional electricity demand from the outlook for industries (468 TWh).The following are taken to construct the total EU renewable electricity demand in 2030:

1. We generated a 'REPowerEU like' scenario with a gross electricity generation (3523 TWh) in line with REPowerEU (3450 TWh[31]). We keep the electricity demand for non-industry components fixed.

2. For the industries sector, an outlook is created based on AIDRES data and a bottom-up analysis, discussed in the next section.

METHODOLOGY FOR THE INDUSTRY

The outlooks for the sectors covered by AIDRES are derived from the AIDRES technologies database and are based on a variant of the AIDRES EU Mix 2030 (see **Appendix 5**). AIDRES considers various scenarios for energy integration and decarbonization. Among these scenarios, the AIDRES EU Mix serves as a hypothetical illustration that balances energy, feedstock input, and CO_2 emissions.

The scenario presented in this report exhibit a higher deployment of hydrogen compared to AIDRES EU MIX and a lower deployment of hydrogen compared to the REPowerEU plan. The rationale behind this is the choice to integrate the hydrogen use from the RePowerEU initiative for some subsectors (see **Table 8**). The REPowerEU plan envisions that the EU will produce 10 million metric tons (Mt) per year of green hydrogen domestically. Additionally, 6 Mt per year of green hydrogen imports are anticipated, along with an additional 4 Mt per year of green ammonia imports.

[31] Source: Non paper on complementary economic modelling undertaken by DG ENER analysing the impacts of overall renewable energy target of 45% to 56% in the context of discussions in the European Parliament on the revision of the Renewable Energy Directive, June 2022. https://energy.ec.europa.eu/system/files/2022-06/2022_06_20%20RED%20non-paper%20additional%20modelling.pdf

Table 8 Projected hydrogen use by sector

<table>
<tr><th></th><th colspan="2">Total</th><th colspan="2">Produced in EU[32]</th><th>Comments</th></tr>
<tr><td>Mton hydrogen</td><td>REPowerEU</td><td>Industry Electrification 2030</td><td>REPowerEU</td><td>Industry Electrification 2030</td><td></td></tr>
<tr><td>Fuel manufacturing (refineries - hydrogen production)</td><td>2.3</td><td>2.3</td><td>1.4</td><td>1.4</td><td></td></tr>
<tr><td>Fuel manufacturing E-fuels</td><td>1.8</td><td>1.8</td><td>1.1</td><td>1.2</td><td>Total use of 3.6 mtoe E-fuels</td></tr>
<tr><td>Petrochemicals (Ammonia)</td><td>3.2</td><td>2.3</td><td>2.0</td><td>1.6</td><td>Different process characterisation</td></tr>
<tr><td>Blast furnaces</td><td>1.5</td><td>1.4</td><td>0.9</td><td>0.9</td><td></td></tr>
<tr><td>Industrial Heat</td><td>3.6</td><td>0</td><td>2.2</td><td>0</td><td>AIDRES EU Mix in subsectors</td></tr>
<tr><td>Transport</td><td>2.3</td><td rowspan="5">Not relevant</td><td>1.4</td><td rowspan="5" colspan="2">Not relevant</td></tr>
<tr><td>Power generation</td><td>0.1</td><td>0.1</td></tr>
<tr><td>Blending</td><td>1.3</td><td>0.8</td></tr>
<tr><td>Import (as ammonia), mostly for Bunker fuels</td><td>4.0</td><td>0.0</td></tr>
<tr><td>Total</td><td>20.0</td><td>10</td></tr>
</table>

The outlooks for the sectors not covered by AIDRES are bottom-up electricity use estimates done by EnergyVille, taking into account REPowerEU and inputs from the sector federations.

ASSUMPTIONS FOR SECTORS COVERED BY AIDRES DATABASE

Fuel manufacturing

Refinery operations are significantly impacted by the declining use of fossil fuels in the transport sector, resulting in reduced production rates of light liquid fuels for 2030 and 2050. The decrease aligns with the anticipated lower demand due to extensive transport electrification, as outlined in the EU Climate Target Plan MIX scenario[33]. Consequently, light liquid fuel production is expected to decline from 362 Mt in 2018 to 106 Mt in 2050. Other elements considered in the calibration and projection are:

- Calibration 2018 based on Eurostat categories LPG, gasoline, kerosene-type jet fuel, diesel oil and fuel oil.

[32] The same share of local production and import is assumed for each subsector
[33] Impact Assessment Report Annexes Accompanying the Proposal for a Directive of the European Parliament and of the Council as Regards the Promotion of Energy from Renewable Sources, and Repealing Council Directive (EU) 2015/652’. SWD(2021) 621 final, Figure 42, Annex 12.

- The 2030 demand (304 mtoe) consists of a fossil part from EU Climate Target Plan MIX scenario oil products (276 mtoe) and 28.4 mtoe of renewable fuels:
  - First generation biofuel: Ethanol/FAME Concawe's assessment of Low-carbon fuel demand in 2030 (17 mtoe)
  - Advanced biofuel: based on calculation difference between total biofuel of 8% as in CTP MIX and first generation biofuel (8 mtoe)
  - RFNBO synfuel (E-fuel): 3.6 mtoe as in REPowerEU

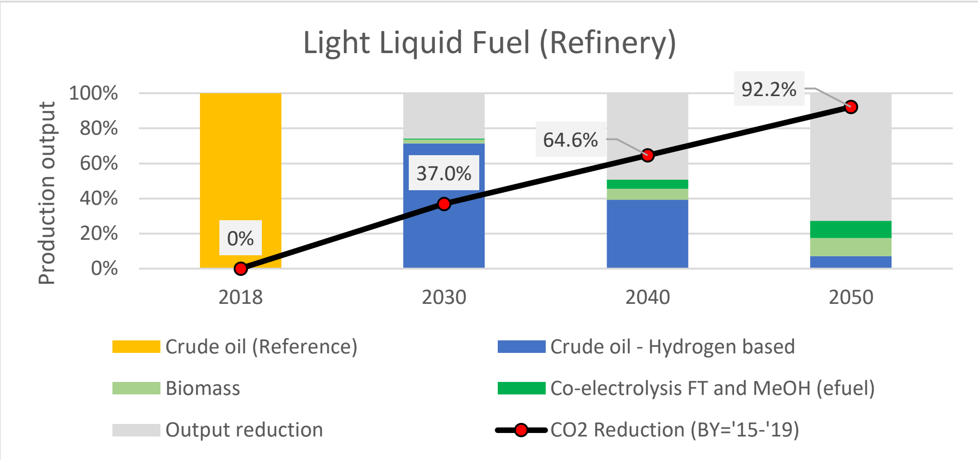


Figure 25 AIDRES EU mix production categories for Fuel Manufacturing, namely the production of light liquid fuel for 2030, 2040 and 2050

Chemical & petrochemical

Scope: AIDRES considers the production of three main products: poly-ethyl-acetate, polyethylene and olefins. The olefins includes ethylene, propylene and other olefins products. Ethylene is an intermediate in the production of poly-ethyl-acetate and polyethylene. The production of methanol from biomass and coelectrolysis is considered as well to produce olefins. For the purpose of this analysis, it was not needed to add subsectors within chemical & petrochemical that are not covered by AIDRES.

Following assumptions are made for 2030:

- Olefins: 2% Naphta Improved, 2% Naptha with CCS, 8% biomass based, 20% Methanol of which 10% based on co-electrolysis.
- Polyethylene & PolyEthylAcetate: 13% hydrogen furnace and 13% CCS based.

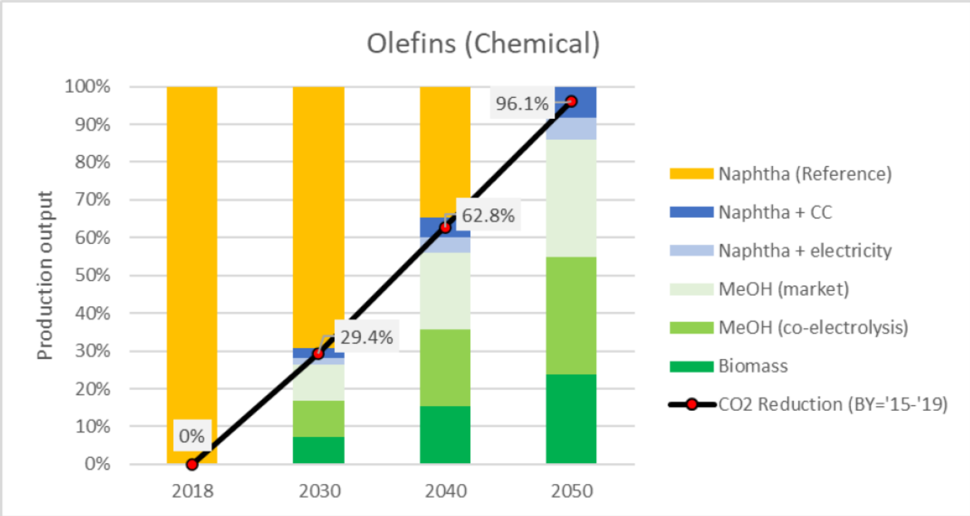


Figure 26 AIDRES EU mix production categories for olefins for 2030, 2040 and 2050

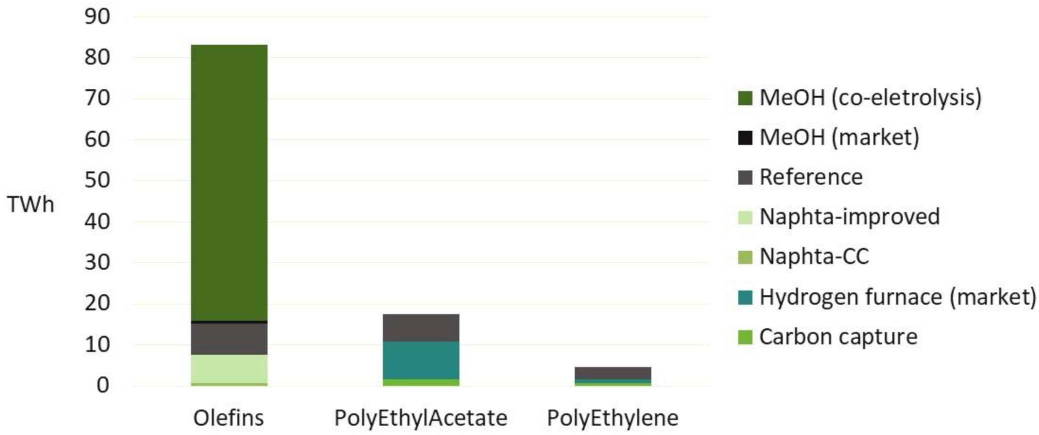


Figure 27 AIDRES EU mix electricity consumption for 2030 by product and production route

Chemical - fertilizer

A transition to a 100% hydrogen-based fertilizer production is envisioned by 2030. This transformative shift comprises two distinct pathways: one-third of the green ammonia relies on an (H2)NH3, employing a system with Cooling Tower electrolyzers, ASU Elec Fertilizer. The remaining two-thirds adopt the (H2)NH3-AEL route, featuring an Alkaline Electrolyzers.

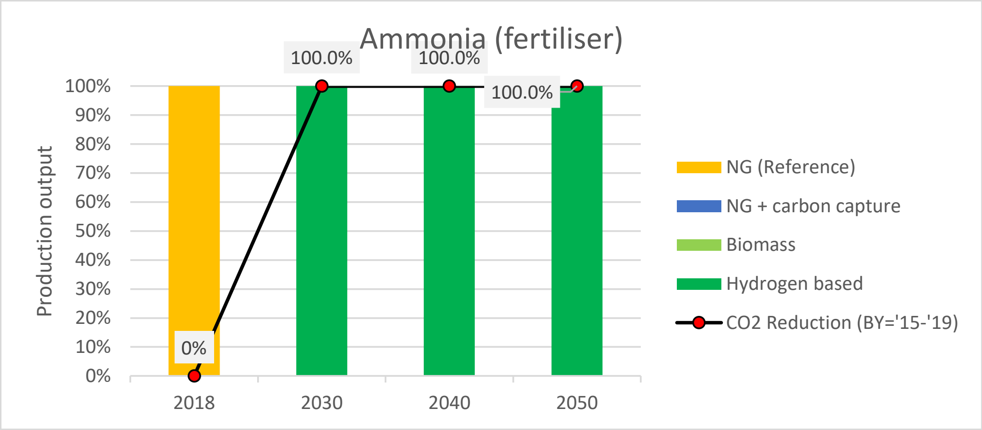


Figure 28 Industry Electrification shifting Ammonia production directly to fully hydrogen based as from 2030

Iron and steel

Like AIDRES, the analysis encompasses primary and secondary steel production sites, excluding steel finishing sites. We deviate from the AIDRES EU Mix data for primary steel production as we calibrate the share of hydrogen-based steel production until we have a hydrogen consumption similar to REPowerEU, 1.5 Mt, of which 0.9 Mt produced with green electricity in the EU. Another important route is natural gas based Direct Reduced Iron, comprising 8% by 2030.

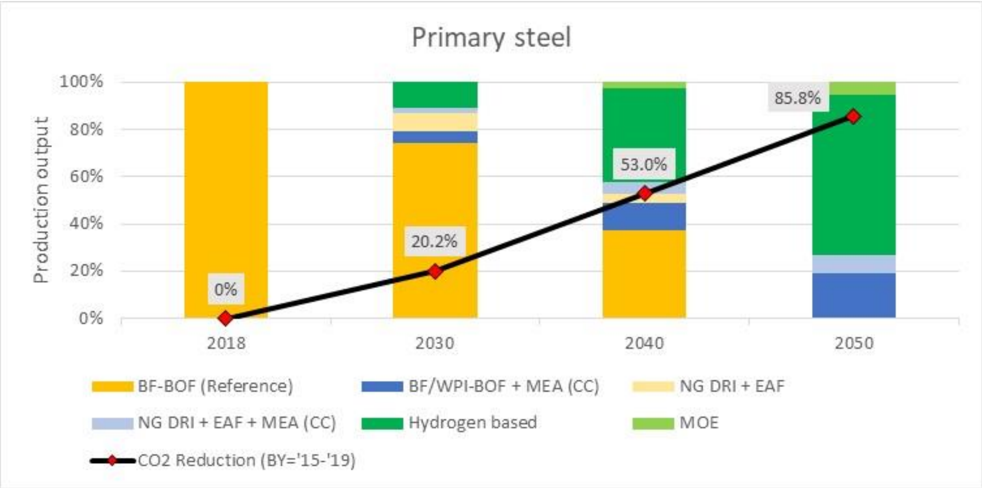


Figure 29 Industry Electrification production categories for steel for 2030, 2040 and 2050

NM minerals - glass

The European glass federations, including Glass for Europe and the European Container Glass Federation (FEVE), emphasize reducing production emissions through carbon-free energy, hydrogen, and electrification. Although not providing a definitive 2050 production route, the AIDRES project adopts a technology-agnostic approach, evenly distributing contributions from CCUS, hydrogen, and electricity, achieving a 93.2% emissions reduction by 2050. Process emissions, constituting 25%, require carbon capture for further reduction, aligning with the glass sector's innovative solutions and pilot projects.

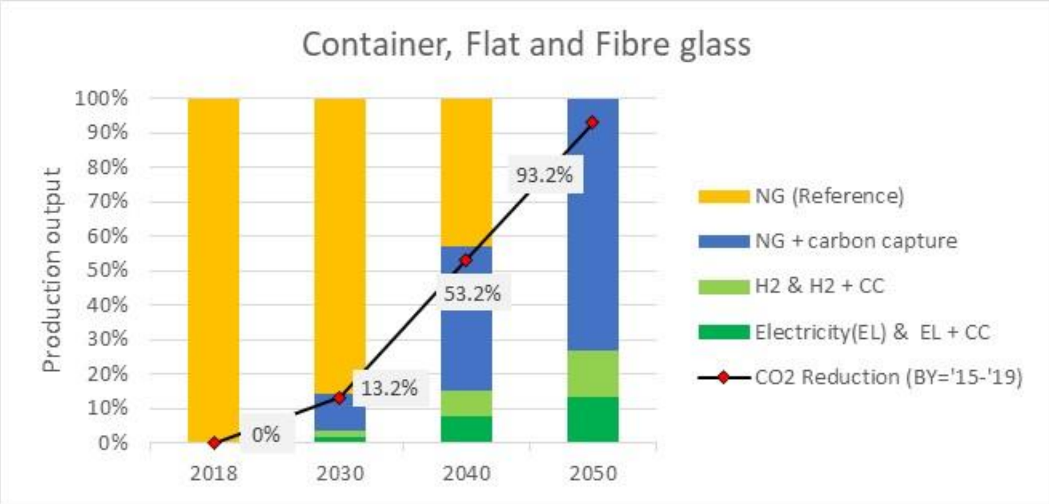


Figure 30 Industry Electrification production categories for steel for 2030, 2040 and 2050

NM minerals - cement

In the Industry Electrification scenario, the total electricity consumption is 18 TWh, which is a 4 TWh increase compared to the historical consumption. CCS makes up 18% of all cement production routes.

Table 9 Cement routes in the Industry Electrification scenario

PRODUCTION CATEGORY	PRODUCTION ROUTE	MIX 2030	TWH EL. 2018	TWH EL. 2030
REFERENCE		71%	14.00	9.87
CCUS	Dry Kiln, Coal, Oxycombustion	4%		1.38
	Dry Kiln, Coal, Oxy combustion,Calcium looping carbon capture	4%		1.14
CCUS + ALT.FUEL	Dry Kiln, Alternative NG, monoethanolamine carbon capture	2%		0.63
	Dry Kiln, Alternative biogas, monoethanolamine carbon capture	2%		0.66
	Dry Kiln, Alternative NG, Calcium looping	2%		0.52
	Dry Kiln, Alternative biogas, Calcium looping	2%		0.54
	Dry Kiln, Alternative NG, monoethanolamine carbon capture	2%		0.92
	Dry Kiln, Alternative biogas, monoethanolamine carbon capture	2%		0.97

	Dry Kiln, Alternative NG, Oxycombustion,Calcium looping carbon capture	2%		0.74
	Dry Kiln, Alternative Biogas, Oxycombustion,Calcium looping carbon capture	2%		0.78
LC3	Limestone Calcined Clay Cement - clinker-to-cement ratio of 50%	1%		0.36
TOTAL		100%	14.00	18.49

ASSUMPTIONS FOR THE OTHER SECTORS

For the other sectors, we follow a simplified approach where we assume a 10% point increase of the electrification rate. The 10% point is arbitrary however is based on the idea In 2018, the machinery sector consumed 112 TWh of electricity and 90 TWh of non-electricity, with an electrification rate of 55%. By 2030, this sector is projected to increase its electrification rate to 65%, resulting in a total electricity consumption of 132 TWh, with an addition of 20 TWh. Similarly, the food, beverages, and tobacco sector had an electrification rate of 33% in 2018, with electricity and non-electricity consumption of 109 TWh and 217 TWh, respectively. By 2030, the electrification rate is expected to rise to 43%, leading to a total electricity consumption of 142 TWh, with an addition of 33 TWh. The paper, pulp, and printing sector, non-ferrous metals, NM minerals, and other sectors follow similar trends, showcasing a shift towards increased electrification by 2030. Overall, the total electricity consumption is projected to reach 825 TWh by 2030, with an addition of 189 TWh across various sectors.

Table 10 Projected electricity use by sector

[TWH]	ELECTRICITY	NON-ELECTRICITY	ELECTRIFICATION RATES	ELECTRICITY TOTAL	ELECTRICITY ADDITIONS	
SECTORS	2018	2018	2018	2030	2030	2030
MACHINERY	112	90	55%	65%	132	20
FOOD, BEVERAGES & TOBACCO	109	217	33%	43%	142	33
PAPER, PULP AND PRINTING	105	269	28%	38%	143	37
NON-FERROUS METALS	63	47	57%	67%	74	11
NM MINERALS - OTHER	37	328	10%	20%	74	37
OTHER	209	300	41%	51%	260	51
TOTAL (TWH)	**636**	**1252**			**825**	**189**

APPENDIX 2 METHOD - INDUSTRY ELECTRIFICATION SCENARIO - MS LEVEL

START FROM THE ESTIMATION AT EU LEVEL

From the analysis at EU level, the total demand for electricity from renewable sources amounts to +-2500 TWh. This number is used as a starting point for our analysis.

Due to confidentiality constraints regarding the use of the REPowerEU data on a MS level, it is impossible to repeat the methodology used in the EU level assessment on a MS level. Therefore, this section attempts to construct similar data using two different methods. Each method provides a different perspective on the distribution of the RES-E between the Member States (MSs).

METHOD 1: LOCAL RES-E PRODUCTION TO FULFIL INDUSTRY DEMANDS

The first method is characterized by an industry perspective: national gaps can be solved by increasing electricity generation depending on industrial activity.

The first method builds upon the Fit-For-55 (FF55) legislation, considering the renewable electricity generation demand by MS as a starting point. According to FF55[34], the total renewable electricity demand equals 2051 TWh by 2030 on an EU level. According to the results from WP1-3 of this research, which is largely based on REPowerEU data, the total renewable electricity demand by 2030 equals 2499 TWh on an EU level. This leaves 449 TWh of residual RES-E to be distributed over the MSs to create a scenario in line with the REPowerEU total renewable electricity demand.

The distribution of this residual amount is based on the REPowerEU hydrogen and e-fuels consumption in all sectors[35]. The hydrogen consumption is divided by an efficiency of 70% and the e-fuels are divided by an efficiency of 60% to get an estimated green electricity demand for these two products by MS. These numbers are provided in the following table:

Table 11 Renewable electricity for REPowerEU hydrogen and e-fuel demand. Data obtained from ENTSOs TYNDP24 national trends and energy mix survey. Efficiency equals 0.70 for hydrogen electricity demand and 0.60 for e-fuels electricity demand

MEMBER STATE	RENEWABLE ELECTRICITY FOR HYDROGEN [TWH]	RENEWABLE ELECTRICITY FOR E-FUELS [TWH]	TOTAL [TWH]	SHARE OF EU-27 TOTAL [%]
AUSTRIA	18	2	20	3%
BELGIUM	41	2	43	7%
BULGARIA	5	1	6	1%
CROATIA	5	1	6	1%

[34] The version we use is the MIX-scenario; this one has open data.
[35] ENTSOs, "Download | ENTSOs TYNDP 2024 Scenarios," July 3, 2023, https://2024.entsos-tyndp-scenarios.eu/download/.

CYPRUS	0	0	0	0%
CZECH REPUBLIC	13	2	14	2%
DENMARK	4	1	5	1%
ESTONIA	0	0	1	0%
FINLAND	10	1	11	2%
FRANCE	61	11	71	11%
GERMANY	123	12	136	21%
GREECE	6	2	8	1%
HUNGARY	13	1	14	2%
IRELAND	4	1	5	1%
ITALY	61	8	68	10%
LATVIA	1	0	1	0%
LITHUANIA	17	0	17	3%
LUXEMBOURG	2	0	2	0%
MALTA	0	0	0	0%
NETHERLANDS	63	3	66	10%
POLAND	61	5	66	10%
PORTUGAL	2	2	4	1%
ROMANIA	17	2	19	3%
SLOVAKIA	8	1	8	1%
SLOVENIA	1	0	2	0%
SPAIN	40	7	48	7%
SWEDEN	10	2	12	2%
EU-27	**585**	**68**	**653**	**100%**

The rightmost column indicates the share of the total EU renewable electricity demand for hydrogen and e-fuel production with renewable electricity. These shares now represent the relative industrial activity by MS, indicating which MS should get attributed a larger share of the residual renewable electricity demand to fulfil their industry need for renewable electricity. Using these shares to distribute the residual 449 TWh, results in the following table:

Table 12 Residual renewable electricity distribution by member state to achieve REPowerEU total of 2499 TWh

MEMBER STATE	FF55 [TWH]	RESIDUAL RENEWABLE ELECTRICITY [TWH]	TOTAL [TWH]
AUSTRIA	73	13	86
BELGIUM	48	30	77
BULGARIA	14	4	19
CROATIA	16	4	20
CYPRUS	3	0	3
CZECHIA	26	10	36
DENMARK	49	4	53

ESTONIA	6	0	6
FINLAND	58	7	65
FRANCE	262	49	310
GERMANY	429	93	522
GREECE	45	5	51
HUNGARY	15	10	24
IRELAND	35	3	38
ITALY	234	47	281
LATVIA	7	1	8
LITHUANIA	10	12	22
LUXEMBOURG	3	1	5
MALTA	0	0	1
NETHERLANDS	122	45	167
POLAND	89	45	134
PORTUGAL	51	3	53
ROMANIA	49	13	62
SLOVAKIA	11	6	17
SLOVENIA	9	1	10
SPAIN	260	33	293
SWEDEN	126	8	134
EU-27	**2051**	**448**	**2499**

The rightmost column presents the renewable electricity demand by MS as defined by the 'Industry Electrification 2030' scenario developed in this section.

METHOD 2: USING ALTERNATIVE ELECTRIFICATION OUTLOOKS

A second method to provide us with renewable electricity demand data on a MS level, is the use of alternative electrification outlooks from other studies. This second method takes on a different perspective: national gaps can also be solved by increased electricity generation in regions with a high availability of renewable sources combined with further development of grid interconnections. To represent this second perspective, two scenarios were selected from two different studies: the Technology Driven Scenario by Ember (New Generation: Building a clean European electricity system by 2035[36]) and the Distributed Energy Scenario by ENTSOs (TYNDP 2022[37]). The results for the renewable electricity demand of these two scenarios are presented in the following table.

Table 13 Technology driven Scenario (Ember) and the Distributed Energy Scenario (ENTSOs)

MEMBER STATE	RENEWABLE ELECTRICITY 2030 [TWH] TECHNOLOGY DRIVEN SCENARIO (EMBER)	RENEWABLE ELECTRICITY 2030 [TWH] DISTRIBUTED ENERGY SCENARIO (ENTSOS)

[36] "New Generation | Clean Power Europe 2035."
[37] ENTSO-E, "TYNDP 2022 Scenario Report."

AUSTRIA	80	67
BELGIUM	39	51
BULGARIA	23	21
CROATIA	23	26
CYPRUS	3	3
CZECHIA	21	32
DENMARK	96	94
ESTONIA	5	6
FINLAND	63	111
FRANCE	322	294
GERMANY	546	522
GREECE	71	73
HUNGARY	20	32
IRELAND	51	40
ITALY	275	252
LATVIA	10	4
LITHUANIA	8	20
LUXEMBOURG	2	2
MALTA	0	1
NETHERLANDS	115	140
POLAND	93	108
PORTUGAL	82	71
ROMANIA	38	72
SLOVAKIA	16	9
SLOVENIA	8	3
SPAIN	367	321
SWEDEN	108	182
EU-27	**2485**	**2559**

OVERVIEW AND COMPARISON

Table 14 gives an overview of the different scenario descriptions, elaborating on their different perspectives regarding the industry electrification by 2030. The Industry Electrification 2030 Scenario by EnergyVille is described as having a local and rapid industry electrification which means the industry sector has a large increase in renewable electricity demand by 2030 which is fulfilled by local or inland production. The Technology Driven Scenario by Ember is described as having a slower (but still fast increasing) industry electrification than the Industry Electrification Sceanrio. A more rapid electrification is now observed in the transport and buildings sector. Instead of local production, the electrification needs by 2030 are covered with a stronger focus on interconnections and intra-EU trade. Lastly, the Distributed Energy Scenario by ENTSOs presents a rapid electrification in all sectors and, like the Ember scenario, focusses on intra-EU trade aside from local production.

Table 14 Scenario description overview

SCENARIO NAME	INDUSTRY ELECTRIFICATION (ENERGYVILLE)	TECHNOLOGY DRIVEN (EMBER)	DISTRIBUTED ENERGY (ENTSOS)
DESCRIPTION	A local and rapid industry electrification	Stronger interconnections and a rapid electrification of transport and buildings	Rapid electrification in all sectors
SOURCE ADDITIONAL ELECTRICITY USE INDUSTRIES	Local*	Local and intra-EU trade	Local and intra-EU trade
INDUSTRY ELECTRIFICATION (BOTH DIRECT AND INDIRECT)	Rapid	Fast	Rapid
ELECTRIFICATION OTHER SECTORS	Fast	Rapid	Rapid

* Based on REPowerEU hydrogen and e-fuel demand at MS level

The following table presents more detailed and quantified data on the different scenarios, which were used to construct **Table 14**. The Technology Driven Scenario shows a slower industry electrification (1212 TWh) compared to the Industry Electrification (1450 TWh) and Distributed Energy (1372 Twh) scenarios. In return, the Ember presents a higher electrification rate in all other sectors, as well as the ENTSOs scenario. As a result, the Distributed Energy scenario by ENTSOs has the highest value (3703 TWh) of total electricity generation in 2030 and the Technology driven scenario the lowest (3466 TWh). In conclusion, all scenarios present similar total renewable electricity generation values for 2030, approximating 2500 TWh.

Table 15 Scenario overview and comparison for Industry Electrification (left), Technology Driven (middle) and Distributed Energy (right) scenarios

SCENARIO	INDUSTRY ELECTRIFICATION (ENERGYVILLE)	TECHNOLOGY DRIVEN (EMBER)	DISTRIBUTED ENERGY (ENTSOS TYNDP22)
ELECTRICITY GENERATION			
RENEWABLE ELECTRICITY	2499 TWh	2485 TWh	2559 TWh
NON-RENEWABLE ELECTRICITY	1089 TWh	981 TWh	1144 TWh
EU TOTAL ELECTRICITY GENERATION	+30% 3588 TWh	+26% 3466 TWh	+34% 3703 TWh
ELECTRIFICATION			

INDUSTRY ELECTRIFICATION (BOTH DIRECT AND INDIRECT)	+48% wrt 2018 (1450 TWh)	+23% wrt 2018 (1212 TWh; est.)	+40% wrt 2018 (1372 TWh)
ELECTRIFICATION OTHER SECTORS	+389 TWh wrt 2018	+505 TWh wrt 2018	+508 TWh wrt 2018
HYDROGEN			
TOTAL HYDROGEN DEMAND	478 TWh All green hydrogen	246 TWh 53% green hydrogen	290 TWh
INDUSTRY HYDROGEN DEMAND	310 TWh	102 TWh (est.)	200 TWh
HYDROGEN IMPORTS	1/3rd	No imports ?	24 TWh
ELECTROLYSER CAPACITY	Undefined	55 GW	65 GW
OTHER			
OTHER SPECIFICITIES	Strong reduction of natural gas (REPowerEU like)	No differentiation at subsector level; no energy system approach	High use of biogas in industries (419 TWh)

APPENDIX 3 METHOD - RENEWABLE ELECTRICITY SUPPLY ASSESSMENT

EXISTING MEASURES DATA

The table lists the renewable electricity generation by MS in 2030 according to the WEM scenario of the national projections of anthropogenic GHG emissions[38]. Data is reported for 21 MSs. A total of 1978 TWh of renewable electricity is achieved by 2030 on an EU level. This is a factor 1.8 higher than the 2021 value from Eurostat.

Table 16 Renewable electricity from the 'Existing measures' WEM scenario of the national projections of GHG emissions.
(*) Note: data from Stated Policy scenario Ember
(**) Note: data from draft update NECP

MEMBER STATE	REN. ELECTRICITY 2030 [TWH]
AUSTRIA	70*
BELGIUM	37
BULGARIA	13
CROATIA	14**
CYPRUS	2
CZECHIA	21
DENMARK	72
ESTONIA	3*
FINLAND	56
FRANCE	192
GERMANY	548**
GREECE	29
HUNGARY	15
IRELAND	32*
ITALY	160**
LATVIA	7
LITHUANIA	25**
LUXEMBOURG	2
MALTA	0.4*
NETHERLANDS	119
POLAND	41
PORTUGAL	52
ROMANIA	38
SLOVAKIA	9*
SLOVENIA	6
SPAIN	247*
SWEDEN	168
EU-27	**1978**

[38] "Reportnet 3," accessed August 22, 2023, https://reportnet.europa.eu/public/dataflow/890.

LATEST NATIONAL PLANS DATA

For the other countries, we use Ember's 'Target Tracker' based on the latest policies that go beyond the original, 2019 based, NECP data on a MS level. Additionally, the data is corrected to make sure that the renewable electricity generation according to the latest national plans is always larger than the existing measures. To this end, a correction is applied for Latvia and Sweden. This results in a EU-total of 2293 TWh of renewable electricity by 2030 according to the latest national plans.

presents the latest national plans on renewable electricity generation in 2030 by MS. Draft updates of the National Energy and Climate Plans (NECPs) were used (article 14 of the same regulation) and data is available for most countries.

Table 17 Latest National Plans for EU-27 member states from Ember power sector target tracker with Vito correction

MEMBER STATE	DRAFT UPDATE NECP (OR WAM FROM TABLE 3)	EMBER NATIONAL PLANS 2019 TRACKER [TWH]	EMBER NATIONAL PLANS 2022 TRACKER [TWH]	FINAL DATA USED [TWH]
AUSTRIA	No info	79	**91**	91
BELGIUM	**(48)**	38	45	48
BULGARIA	No info	13	**17**	17
CROATIA	**16**	13	13	16
CYPRUS	**2**	2	2	2
CZECHIA	No info	13	**30**	30
DENMARK	**72**	52	53	72
ESTONIA	**9**	4	7	9
FINLAND	**56**	50	50	56
FRANCE	**197**	245	245	197
GERMANY	**558**	377	486	558
GREECE	No info	38	**47**	47
HUNGARY	**17**	11	11	17
IRELAND	No info	30	**38**	38
ITALY	**238**	187	217	238
LATVIA	No info	6	6	7
LITHUANIA	**27**	7	7	27
LUXEMBOURG	**3**	2	2	3
MALTA	No info	0	0	0
NETHERLANDS	**119**	91	130	119
POLAND	No info	64	72	72
PORTUGAL	**86**	62	71	86
ROMANIA	No info	38	**50**	50

SLOVAKIA	No info	10	**10**	10
SLOVENIA	**10**	8	10	10
SPAIN	**259**	254	254	259
SWEDEN	**168**	124	124	168
EU-27		**1818**	**2089**	**2245**

For the other countries, we use Ember's 'Target Tracker' based on the latest policies that go beyond the original, 2019 based, NECP data on a MS level.[39] Additionally, the data is corrected to make sure that the renewable electricity generation according to the latest national plans is always larger than the existing measures. To this end, a correction is applied for Latvia and Sweden. This results in a EU-total of 2293 TWh of renewable electricity by 2030 according to the latest national plans.

[39] "EU Power Sector 2030 Targets Tracker."

APPENDIX 4 METHOD - INTERCONNECTIONS

ALTERNATIVE OUTLOOKS INTERCONNECTION CAPACITY

For the first two scenarios, the interconnection capacities by 2030 are provided in their respective studies as illustrated in **Figure 31**. ('New Generation: Building a clean European electricity system by 2035[40]' by Ember and the 'Ten-Year Network Development Plan 2022[41]' (TYNDP) by ENTSOs). For comparability, the Ember study 2020 reference grid is presented in both graphs.

The Ember study reports using the list of candidate projects in the TYNDP 2020[42] as input data for its own analysis to assure technical feasibility while allowing their model to invest in new capacity above these existing plans. The list of candidate projects includes all types of projects: under construction, in permitting, planned but not yet permitted and under consideration.

Due to this link between the two studies, the two graphs show different but similar results. In general, both scenarios indicate vertically driven interconnection expansions. Both graphs show new interconnections going from Norway to the United Kingdom (2.8 GW for Ember and 1.4 GW for ENTSO), where it connects to France (2+3.4 for Ember and 2+5.4 GW for ENTSOs) and Spain (2.6+5.4 GW for both). Both scenarios suggest a new interconnection between Greece and Cyprus: 0.067 GW for Ember and 1 GW for ENTSOs. Additionally, the Ember scenario indicates an expansion of the interconnection capacity between Belgium and France (3.3+4 GW for FR->BE and 1.8+5.8 GW for BE->FR) and between Germany and Poland (2.5+4 GW for PL->DE and 0.5+6 GW for DE->PL), while the ENTSOs scenario does not. Instead, ENTSOs indicates a new interconnection between the United Kingdom and Denmark (2.8 GW) as well as an expansion in the interconnection between Germany and Austria (5+1.9 GW).

[40] "New Generation | Clean Power Europe 2035."
[41] ENTSO-E, "TYNDP 2022 Scenario Report."
[42] "TYNDP 2020 Project Collection," accessed September 1, 2023, https://tyndp2020-project-platform.azurewebsites.net/projectsheets/transmission.

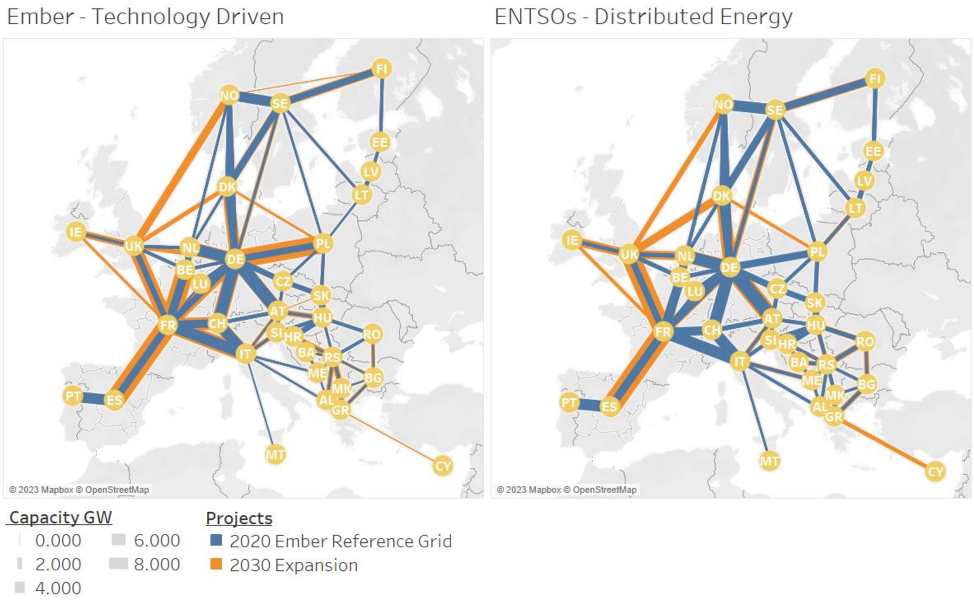


Figure 31 2030 Interconnection capacities for Technology Driven (left) and Distributed Energy (right) scenarios

In conclusion, both scenarios show a vertically driven interconnection backbone with countries such as Norway, Denmark, Sweden, the United Kingdom and France playing a crucial role. Certain interconnections are selected in both models, indicating their importance in the backbone: Norway – United Kingdom, France – Spain, Denmark – Poland, Sweden – Germany, Ireland – France are prime examples.

For the interconnection between Norway and the United Kingdom, two projects are provided in the list of candidate projects in the TYNDP 2020[43]. The first is the North Sea Link which is a 1.4 GW HVDC interconnection which was commissioned in 2021. The second project is called the NorthConnect [44]which is another 1.4 GW interconnection which was set to be commissioned by 2024. Permitting, however, has delayed the project as the Norwegian government has rejected the project's license application in 2023.

The interconnection expansion between France and Spain is planned to be expanded from 2.8 GW to 5 GW HVDC in the 5 GW by 2027 in the Biscay Gulf project[45]. Two more 1.5 GW HVDC projects are planned to be commissioned by 2029 and 2030. The Celtic Interconnection[46] is an HVDC project for a new interconnection between France and Ireland. Its construction has started in 2022 and the line is due to be commissioned by 2026. Furthermore, the existing 0.6 GW Baltic Cable[47] connection between Sweden and Germany is set to be expanded up to 1.3 GW with the Hansa

[43] "TYNDP 2020 Project Collection."
[44] "NorthConnect," NorthConnect English, accessed September 4, 2023, https://northconnect.co.uk/.
[45] Red Eléctrica, "Spain-France Submarine Interconnection," Red Eléctrica, accessed September 4, 2023, https://www.ree.es/en/activities/unique-projects/submarine-interconnection-with-france.
[46] "EirGrid Group," EirGrid Group, accessed September 4, 2023, https://www.eirgridgroup.com/the-grid/projects/celtic-interconnector/whats-happening-now/.
[47] "Baltic Cable |," accessed September 4, 2023, https://balticcable.com/.

PowerBridge I project[48]. Remarkably, no projects are foreseen in the 2020 list of candidate projects for the link between Denmark and Poland by 2030 even though all three scenarios indicate a connection should be built. However, a 0.6 GW project is provided to be commissioned by 2033, which both the Ember and the ENTSOs scenarios have adopted in their results, indicating that the project speedup.

SIMULATION MODEL ARCHITECTURE AND INPUT DATA

The annual aggregated import and export quantities result from subtracting the annual total electricity demand from the annual total electricity generation per country, as described in Chapter 5. Countries with a shortage of total electricity become importers and countries with an excess of total electricity become exporters. The need for imported electricity is modelled as a demand per country, while the excess electricity from exporting countries is provided on the market. As a result, the model will try to provide exported electricity to the countries who have a need for import and balance the grid on an annual basis. All lines in the model get an availability factor of 60% for reasons of security and to take into account that residual capacity should be available for peak flows.

The TIMES model includes the 2030 European cross-border capacities as presented by the current status of the TYNDP24 reference grid. Note that the TYNDP24 data used in this study are draft data since the final TYNDP24 study has not been published yet. Therefore, the TYNDP24 reference grid is complemented with the 'Triton' link between Belgium and Denmark. In the previous TYNDP22 study, this link was included in the list of projects with a commissioning year in 2031 and a capacity of 1.4 GW. In the draft TYNDP24 documents, the project was removed from the list of candidates and moved up to the 2030 reference grid. The capacity, however, is currently set to zero. The value is assumed to be corrected in the final TYNDP24 study results and, for this reason, our analysis assumes a capacity of 1.4 GW in the 2030 reference grid.

Furthermore, the TIMES model is fed with the draft list of candidate projects in the TYNDP24. This means the model has the option to invest in projects which have a commissioning year beyond 2030, in case the reference grid in 2030 does not suffice. The projects are constrained by their capacities and an availability factor of 60%. The investment cost of the projects increases with the commissioning year to motivate the model to prioritize investments in earlier projects. Additionally, the model has the option to invest in new capacity which is not included in the list of candidates. The cost of these 'new projects' is higher than any of the existing projects which incentivises the model to only invest in this kind of capacity when all other options are exhausted. Varying this cost of new projects results in different scenarios for the interconnection analysis.

Alternative to increasing the interconnection capacity, the model is provided with the option to invest in additional offshore inflow capacity. This option answers the question to what extent a faster uptake of wind offshore can ameliorate the situation in case interconnection expansions fall behind. Similarly to the electricity interconnections, the model is fed with the draft TYNDP24 projected offshore expansions projects by 2035.

48 "Hansa PowerBridge," accessed September 4, 2023, https://www.50hertz.com/en/Grid/Griddevelopement/Offshoreprojects/HansaPowerBridge.

INDUSTRY ELECTRIFICATION SCENARIO INTERCONNECTION RESULTS

This part of the addendum provides additional results on the interconnection analysis presented in **section 7.1** for two scenarios.

The first scenario computes a solution which includes a high cost for lines to be installed which are not yet included in the list of candidate projects reported by the draft TYNDP24. The results are presented in **Figure 32** and **Figure 33** which show the total grid overview and the additional requirements respectively.

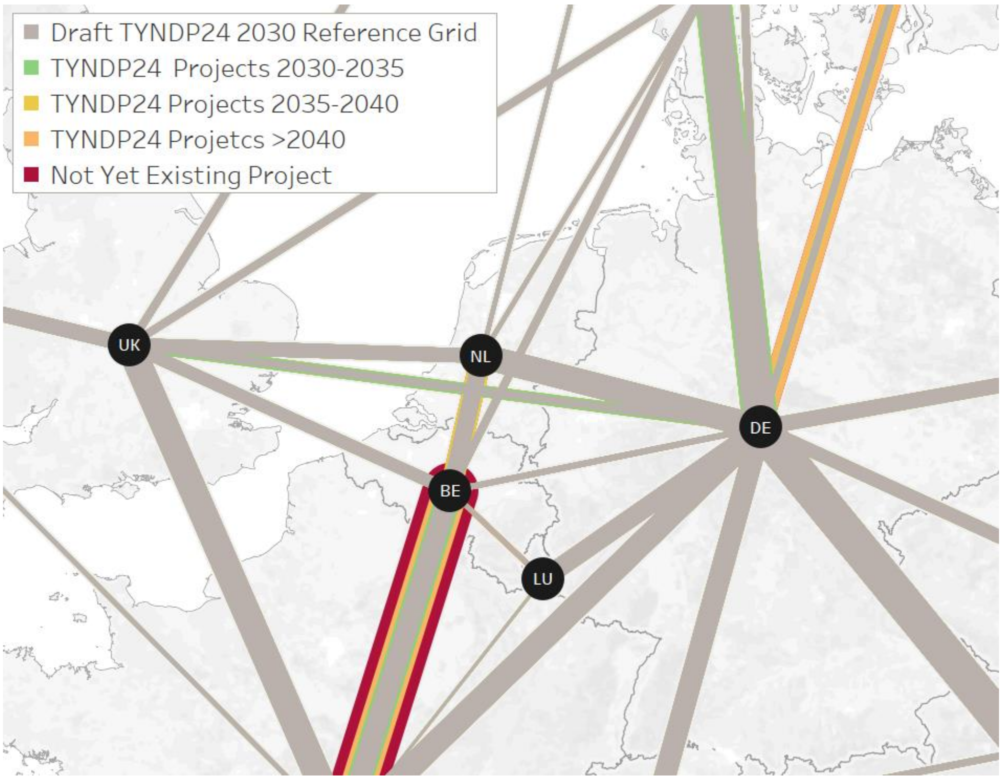


Figure 32 Interconnection results for scenario 1 including draft TYNDP24 2030 reference grid

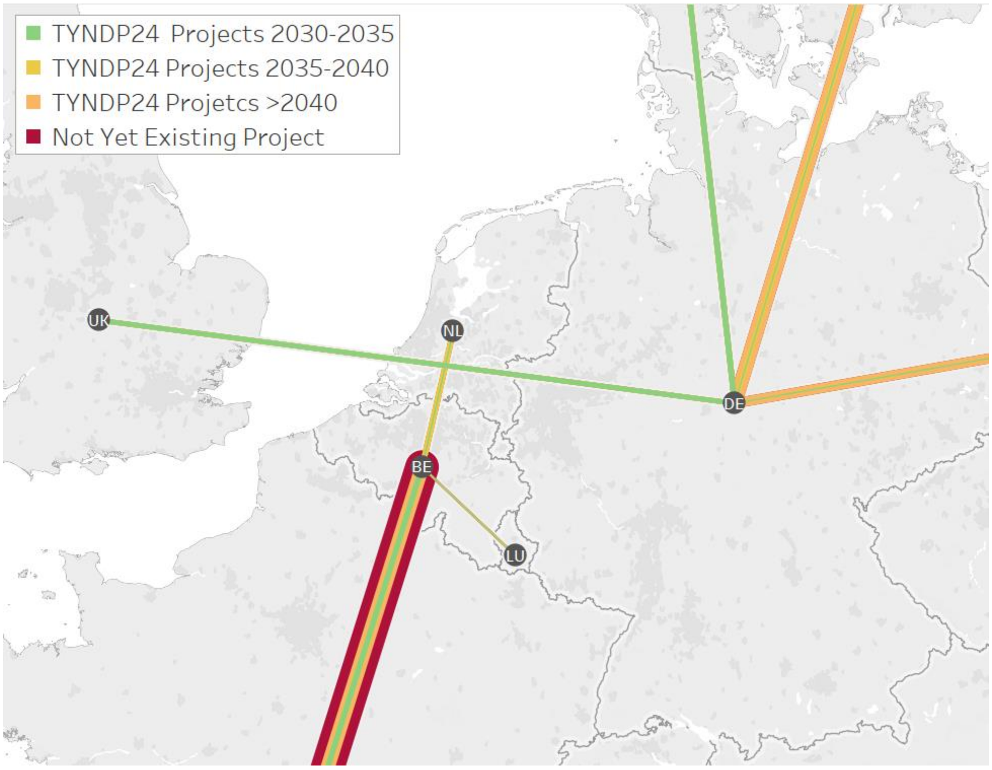


Figure 33 Interconnection results for scenario 1 excluding draft TYNDP24 2030 reference grid

In the second scenario, this cost for these kinds of interconnections is increased further to demotivate the model to invest in them, presenting a solution which is oriented more towards the existing projects. This second scenario was selected as a representative for the Industry Electrification scenario grid analysis in chapter 7. The additional grid expansions to the draft TYNDP24 reference grid have been discussed previously and the full grid overview, which includes the reference grid, is provided in this addendum in **Figure 34**.

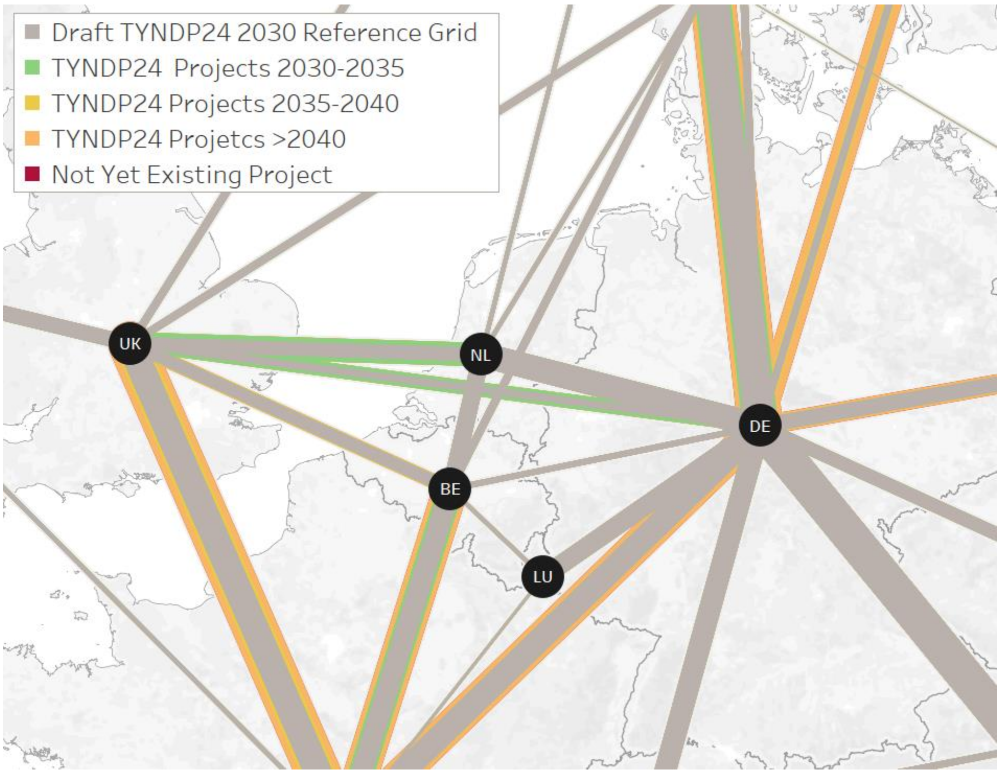


Figure 34 Interconnection results for scenario 2 including draft TYNDP24 2030 reference grid

APPENDIX 5 METHOD - THE AIDRES PROJECT

THE AIM OF THE AIDRES PROJECT

The AIDRES project, aimed at supporting the EU-27's integrated industrial strategy, provides a valuable database for the European Commission and industries. The full name of the project is *"Advancing industrial decarbonization by assessing the future use of renewable energies in industrial processes"*. It focuses on key sectors such as steel, chemical, cement, glass, fertilizers, and refineries, offering insights into innovation pathways to achieve carbon neutrality by 2050. By developing a spatially explicit database, AIDRES considers the geographical distribution of production at the EU-NUTS3 regional level.

The AIDRES data will mainly support research on the scale of renewable energy demand required for potential technological innovations in energy-intensive industries to achieve carbon neutrality.

This comprehensive project takes a holistic approach, analyzing future renewable energy demands and pathways for carbon neutrality in energy-intensive industries. It identifies the renewable energy demand required for technological innovations in these sectors by 2030 and 2050, considering effectiveness, efficiency, and investment needs. The project explores potential symbiotic relationships between sectors to optimize resource utilization.

Work Package 1 focuses on the systematic analysis of technological innovation paths, developing models for present and future technologies and considering industrial symbiosis opportunities.

Work Package 2 maps the future demand for renewable energy inputs by analyzing the locations of industrial plants, enabling precise identification of energy and feedstock requirements and symbiosis opportunities.

The integration of industry-specific models, spatial analysis, and comprehensive data in the AIDRES project aims to facilitate the transition of Energy Intensive Industries towards renewable and sustainable operations. The findings will contribute to the EU's carbon neutrality goals outlined in the Green Deal and Fit for 55 strategies, fostering a more sustainable and resilient industrial sector.

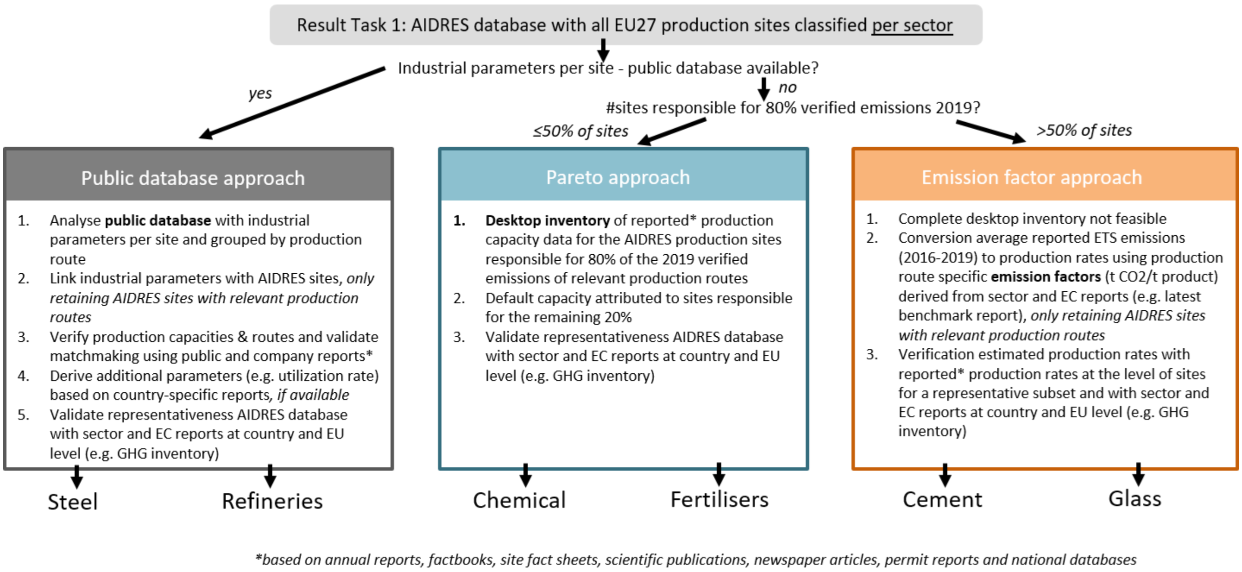
GENERAL METHODOLOGY

The reference case (baseline) is first evaluated, and alternative production routes are generated using process integration techniques to size the equipment of a wide range of predefined typical production routes. The production routes are characterized by their process investment/size, consumption of energy resources, direct CO2 emissions (Scope 1), and the amount of captured and stored CO2 (CCS). This results in the creation of a per-ton-of-product database that contains information on energy supply, direct emissions at the plant, amount of captured CO2, and the associated investment.

In the second step, the operating cost, total cost, and total emissions (including direct emissions at the plant and indirect upstream emissions) are evaluated for both the reference case and eight predefined EU scenarios for the period of 2030-2050 (§1.2). This allows the identification of production routes with the lowest total cost.

The database provides information on typical production routes and their main values, which can be selected by the user to create a mix of production routes for a given NUTS3 region.

METHODOLOGY TO MAP THE INDUSTRIAL PLANTS IN THE EU



AIDRES EU MIX 2030 AND AIDRES EU MIX 2050

The AIDRES project focuses on projecting future production routes for the EU industrial sectors, considering energy and feedstock inputs, emissions, and cost factors. To demonstrate a low-emission pathway for these sectors, two synthetic production routes have been developed: AIDRES EU Mix 2030 and AIDRES EU Mix 2050. These routes comprise a selection of single production routes applied to mapped production sites at the NUTS3 level, providing a European-level comparison and understanding.

These routes align with the emission reduction targets set by the European Commission in 2021, following the Fit for 55 and EU Green Deal roadmap. The AIDRES sector CO_2 emission reduction targets, including energy and process-related emissions, are sector specific.

The concept of AIDRES EU Mix routes addresses the uncertainty surrounding future production methods at individual industrial sites. Rather than applying a single production route across all sites, the AIDRES EU Mix routes serve as a hypothetical alternative that balances energy, feedstock input, and CO2 emissions.

To define these routes, external reports and studies were consulted since the AIDRES industrial blueprint models do not include an optimization module covering the entire model time horizon. The models converge when maximum process integration, heat recovery, and material re-use are achieved within industrial clusters, resulting in a unified solution for all sites. The AIDRES EU single and mixed production routes have been reviewed and shared with a group of external industrial experts from sector organizations.

WHERE CAN I FIND THE AIDRES INFORMATION AND DATA?

AIDRES project final report - Assessment and geo-mapping of renewable energy demand for technological paths towards carbon neutrality of EU energy-intensive industries https://op.europa.eu/s/yZuw

The AIDRES database is available in SQL format Joint Research Centre Data Catalogue - AIDRES - Advancing industrial decarbonization by a... - European Commission (europa.eu)) and simplified XLS format on The database "Advancing industrial decarbonisation by assessing the future use of renewable energies in industrial processes" (AIDRES) (europa.eu)

Visualisation on EIGL - Direct link to AIDRES layers: preselected for NUTS3 total energy demand – AND - NUTS2 total energy demand per sector: https://europa.eu/!kTr9xT.

APPENDIX 6 ARE COUNTRIES DOING ENOUGH FOR FITFOR55 ?

This addendum presents the gap of the existing measures and the latest national plans compared to the modelling analysis for the FF55 legislation. These results are presented to provide context on the level of ambition of the legislation in contrast to the scenarios which are presented in this report.

For the existing measures, the graph already presents some green countries: Sweden (-25%), Denmark (-31%), Portugal (-2%), Germany (-23%) and Hungary (-2%). Poland is the only country which surpasses the 100% mark with a 115% gap which means Poland would need to double its existing measures to be able to mee the numbers from the modelling analysis for the FF55 legislation by 2030. Lithuania (60%), Greece (54%), Luxembourg (56%) and Slovenia (50%) surpass the 50% mark.

Since the latest national plans are always more ambitious or equal to the existing measures, the right graph shows smaller gaps. New green countries with a negative gap appear. Belgium (-1%), Slovenia (-10%), Greece (-4%), Czechia (-13%), Bulgaria (-17%) and Romania (-1%) have turned green, closing the gap with the FF55 targets. Ireland (-8%), Estonia (-10%) and Austria (-19%), which had no data for the existing measures, present an excess of renewable electricity as well. Slovakia (14%) and Latvia (4%), which also had no data for the existing measures, turn red indicating a gap is present. Furthermore, the Netherlands (3%), Finland (4%), Spain (2%), France (7%) and Italy (8%) all present gaps which are nearly closed for the latest national plans. The three countries with the largest gaps are Lithuania (55%), Luxembourg (49%) and Poland (24%).

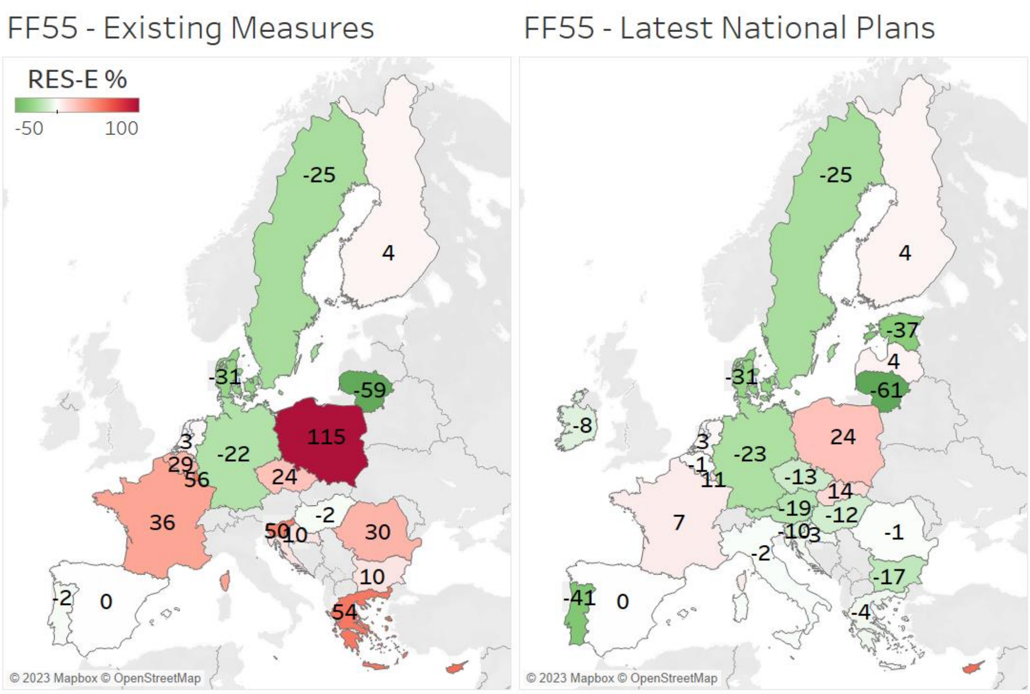


Figure 35 Percentage gap of Existing Measures (left) and Latest National Plans (right) to FF55 MIX scenario. Note missing data for Austria, Estonia, Ireland, Italy, Malta and Slovakia

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ISBN 978-2-87567-186-8
9 782875 671868 >