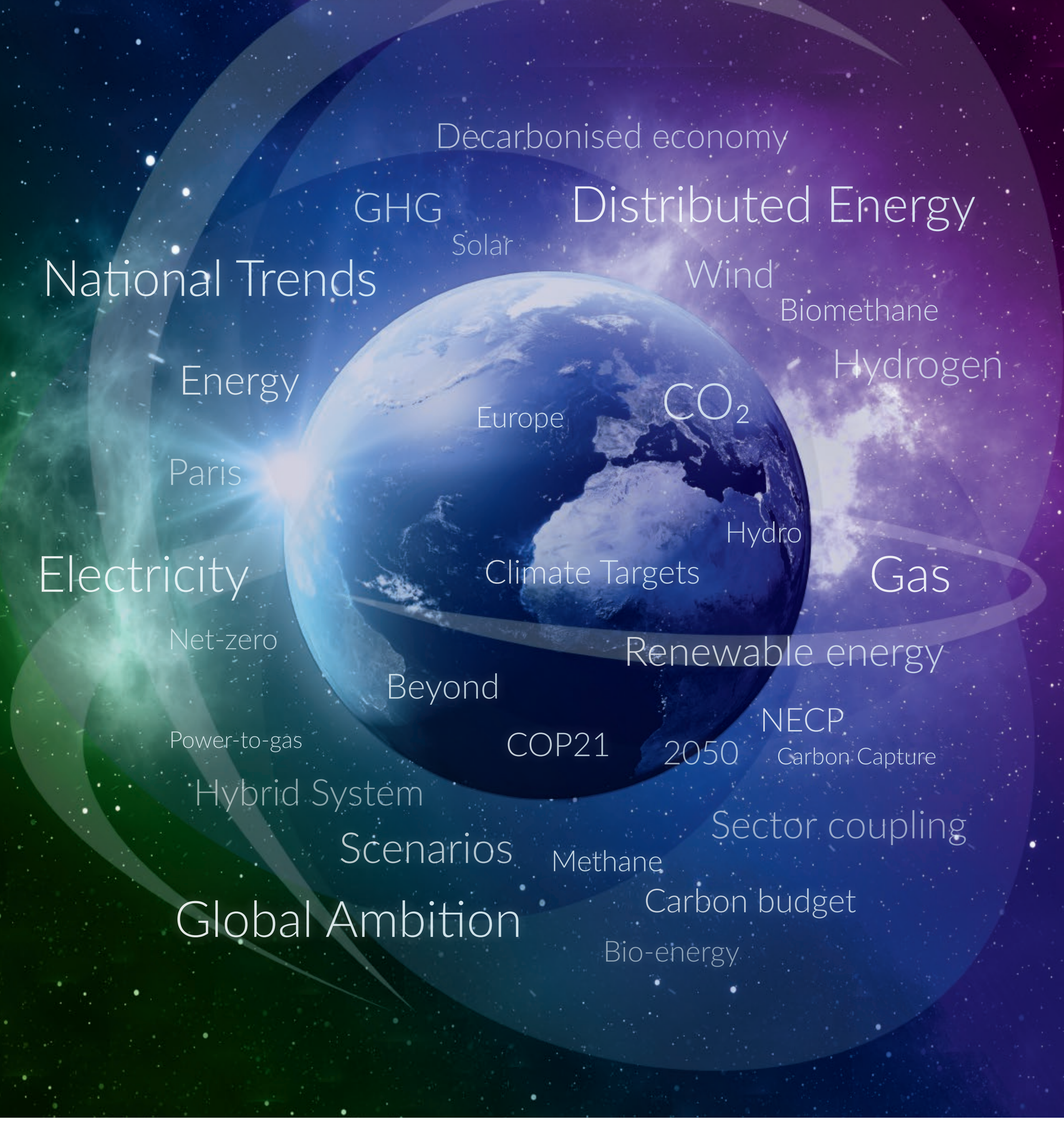
TYNDP 2020

SCENARIO REPORT



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Joint Foreword

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We are delighted to present to you the gas and electricity ENTSOs joint Scenario Report,

the second report of its kind to involve the two ENTSOs working closely together to develop European-focused scenarios. Scenario work is the first important step to capture the interactions between the gas and electricity systems and is therefore paramount to deliver the best assessment of the infrastructure in a hybrid system. The joint work also provides a basis to allow assessment for the European Commission's Projects of Common Interest (PCI) list for energy, as the ENTSOs progress to develop their Ten-Year Network Development Plans (TYNDPs).

Stakeholder collaboration and feedback has been an immensely important element of the process and will continue to be in future editions. The outcomes of the work presented, illustrates the unique position the gas and electricity TSOs are in to provide quantitative and qualitative output: in total over 80 participants, covering more than 35 countries, contributed to the process. The combined expertise and modelling capabilities enabled the ENTSOs joint working group to build a set of ambitious and technically robust scenarios.

A core element of the ENTSO scenario building process has been the use of supply and demand data collected from both gas and electricity TSOs to build bottom-up scenarios. This approach is used for the **National Trends Scenario**, the central policy scenario of this report, recognising national and EU climate targets, notably the draft National Energy and Climate Plans (NECPs). In view of the 1.5°C target of the Paris Agreement, ENTSOs have also developed the **Global Ambition** and **Distributed Energy** Scenarios using a top-down approach with a full-energy perspective.

As the ENTSOs look to the future, it is evident that innovation, integration and efficiency are key to meeting European energy consumers' needs, whilst also achieving EU decarbonisation goals. Both gas and electricity networks connect countries and lead to regional and pan-European solidarity and economies of scale, while ensuring electricity and gas are delivered reliably to customers throughout the year, including peak demand situations. Both networks play a key role in supporting the uptake of new technologies and meeting decarbonisation challenges. Energy conversion projects must progress: Power-to-Gas, for example, allows electricity from renewables to be transformed into renewable gases, to be stored and transported via the gas infrastructure.

Integration of the electricity and gas sector can optimise the assessment and usage of both grids, whilst continuing to meet the European energy policy objectives of sustainability, security of supply and competitiveness. A hybrid energy infrastructure of both electricity and gas systems as cross-border energy carriers will result in flexibility, storage and security of supply.

The integrity of the network development process is reliant on a comprehensive, reliable and contrasted set of possible energy futures - the collaborative efforts of the ENTSOs, energy industries, NGOs, National Regulatory Authorities and Member States have shown the commitment to ensure this is the case. The development of the Scenarios outlined in this report will allow the ENTSOs' TYNDPs to perform a sound assessment of European infrastructure requirements. We look forward to working with you again as we follow the next important steps in the TYNDP process.

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1 Introduction

What is this report about?

ENTSOs' TYNDP 2020 Scenario Report describes possible European energy futures up to 2050. **Scenarios are not forecasts;** they set out a range of possible futures used by the ENTSOs to test future electricity and gas infrastructure needs and projects. The scenarios are ambitious as they deliver a low carbon energy system for Europe by 2050. The ENTSOs have developed credible scenarios that are guided by technically sound pathways, while reflecting country by country specifics, so that a pan-European low carbon future is achieved.

Forward-looking scenarios to study the future of gas and electricity

Scenarios are a prerequisite for any study analysing the future of the European energy system. Regulation (EU) 347/2013 requires that the ENTSOs use scenarios for their respective Ten-Year Network Development Plans (TYNDPs) 2020. ENTSO-E use scenarios to assess electricity security of supply for the ENTSO-E Mid-Term Adequacy Forecast (MAF).

All scenarios head towards a decarbonised future and have been designed to reduce GHG emissions in line with EU targets for 2030 or the United Nations Climate Change Conference 2015 (COP21) Paris Agreement objective of keeping temperature rise below 1.5°C.

Why do the ENTSOs build scenarios together?

The joint scenario report is a basis towards an interlinked model of ENTSO-E and ENTSOG. TYNDP 2018 was the first time ENTSOs cooperated jointly on scenario development. There are strong synergies and co-dependency between gas and electricity infrastructures, it is increasingly important to understand the impacts as European policy seeks to deliver a carbon-neutral energy system by 2050. Joint scenarios allow the ENTSOs to assess future infrastructure needs and projects against the same future outlooks. The outcomes from the joint scenarios provide decision makers with better information, as they seek to make informed choices that will benefit all European consumers. Combining the efforts from gas and electricity TSOs give the ENTSOs an opportunity to tap into cross-sectoral knowledge and expertise that would otherwise be missing. Joint working provides access to a broader range of stakeholders who are actively participating in the energy sector.

First step towards the 2020 edition of electricity and gas TYNDPs

The joint scenario building process has three storylines for TYNDP2020. **National Trends** is the central policy scenario of this report, designed to reflect the most recent EU member state National Energy and Climate Plans (NECP), submitted to the EC in line with the requirement to meet current European 2030 energy strategy targets. **National Trends** represents a policy scenario used in the infrastructure assessment phase of the ENTSOs' respective Ten-Year Network Development Plans (TYNDP) 2020, with a more in-depth analysis as compared to the other scenarios.

In addition, ENTSO-E and ENTSOG have created two scenarios in line with the COP 21 targets (**Distributed Energy** and **Global Ambition**) with the objective to understand the impact on infrastructure needs against different pathways reducing EU-28 emissions to net-zero by 2050. The three scenario storylines developed in consultation with stakeholders are detailed extensively in the ENTSOs Storylines Report[1] released in May 2019.

Visualise and download scenarios data

The joint scenario package provides an extensive data set resource that is used by each ENTSO TYNDP and other studies. Scenario information contained in this report is provided in EU-28 terms unless otherwise stated. The technical datasets submitted to the TYDNP process and available to download extend beyond the EU-28 countries, including countries, such as, Norway, Switzerland and Turkey.

The ENTSOs invite stakeholders to use the scenario data sets for their own studies. All data from the scenarios can be accessed via the visualisation platform[2]. Whereas **Distributed Energy** and **Global Ambition** have been built as full-energy scenarios until 2050, **National Trends** is based on electricity and gas related data from the NECP and developed until 2040.

Methodology in detail

The development of the scenarios builds on storylines and a methodology to translate the storylines into parameters and eventually figures. The TYNDP 2020 Scenario Methodology Report[3] provides full transparency on how the scenarios are developed and how the development of different demand technologies, generation and conversion capacities, renewable shares and all other parameters are considered.

1 https://docstore.entsoe.eu/Documents/Scenarios/190408_WGSB_Scenario%20Building%202020_Final%20Storyline%20Report.pdf

2 https://tyndp-data-viz.netlify.com/

3 https://www.entsos-tyndp2020-scenarios.eu/wp-content/uploads/2019/11/TYNDP2020_Scenario_Methodology_Report.pdf

2 Highlights

1) To comply with the 1.5° C targets of the Paris Agreement, carbon neutrality must be achieved by 2040 in the electricity sector and by 2050 in all sectors. Additional measures to reach net negative emissions after 2050 are necessary.

2) To achieve net-zero emissions, innovation in new and existing technologies is required to:
   - reduce the levelised cost of energy from renewable energy sources
   - increase the efficiency and type of end user appliances
   - support renewable and decarbonised gas
   - develop technologies that will support negative emissions

3) "Quick wins" are essential to reduce global temperature warming. A coal to gas switch in the power sector can save up to 150 $MtCO_2$ by 2025.

4) To optimise conversions, the direct use of electricity is an important option – resulting in progressive electrification throughout all scenarios. Gas will continue to play an important role in sectors such as feedstock in non-energy uses, high-temperature processes, transport and aviation or in hybrid heating solutions to make optimal use of both infrastructures.

5) To move towards a low carbon energy system, significant investment in gas and electricity renewable technologies is required. Further expansion of cross border transfer capacity between markets will contribute to ensuring renewable resources are efficiently distributed and dispatched in the European electricity market.

6) Wind and solar energy will play an important role in the European energy system, however, the scenarios point out that the decarbonisation of gas will have a significant part to play as well. The scenarios show that the decarbonisation of the gas carrier is necessary, employing technologies to increase the share of renewable gases, such as bio-methane and Power-to-Gas, and decarbonised gases associated with Carbon Capture and Storage (CCS).

7) At present gas as an energy carrier is mainly based on methane, as the main component of natural gas. However, in the longer term hydrogen could become an equally important energy carrier towards full decarbonisation of the gas carriers in 2050.

8) Sector Coupling enables a link between energy carriers and sectors, thus it becomes key in contributing to achieving the decarbonisation target. In the long-term, Power-to-Gas will play a key role in both the integration of excess electricity from variable renewables and decarbonising the gas supply. Gas-fired power plants will continue to provide peak power flexibility to support an energy mix based on increasingly variable electricity generation.

9) Today, the EU28 imports most of its primary energy (ca. 55 %[1]). Decarbonisation will also change this pattern. In a way, the "insourcing" of energy production will reduce the import dependency to ca. 20 % to 36 %. However, imports remain an important vector in the future energy supply making use of competitive natural resources outside the EU territory. For gas in particular, import shares increase in all scenarios until 2030 due to the declining natural gas production in the EU.

1 See EUROSTAT (link)

3 Special Focus: Pathways towards a decarbonised economy

3.1 National Trends – the central policy scenario aligned with draft NECPs

Meeting European targets considering current policies

National Trends aims at reflecting the commitments of each Member State to meet the targets set by the European Union in terms of efficiency and GHG emissions reduction for the energy sector. At country level, National Trends is aligned with the draft NECPs of the respective Member States[1], which translate the European targets to country specific objectives for 2030.

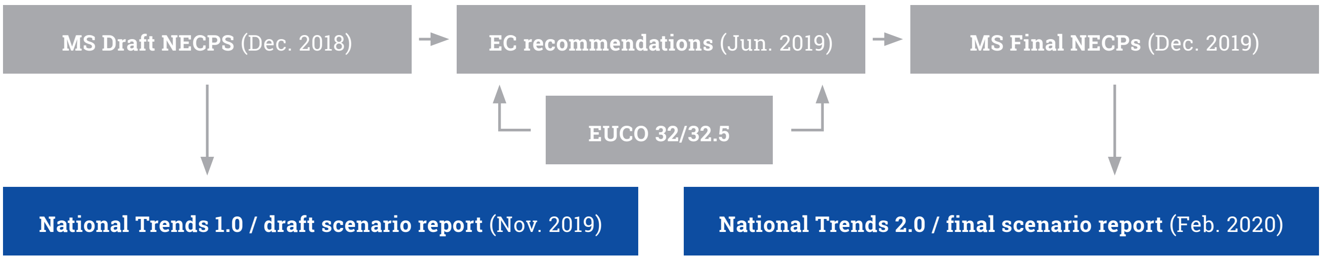


Figure 1: National Trends scenario interactions with NECPs (Draft NECPs and EC recommendations, EUCO reports

1 At the time of drafting the report, those targets are being translated by the Member States in their respective NECPs. In some cases, even though the NECP has been published, the corresponding document is under revision.

3.2 COP 21 scenarios – a carbon budget approach

Below +1.5°C at the end of the century with a carbon budget

Distributed Energy (DE) and Global Ambition (GA) (also referred to as "COP21 Scenarios") scenarios are meant to assess sensible pathways to reach the target set by the Paris Agreement for the COP 21: 1.5° C or at least well below 2° C by the end of the century. For the purpose of the TYNDP scenarios, this target has been translated by ENTSO-E and ENTSOG into a carbon budget to stay below +1.5° C at the end of the century with a 66.7 % probability[2].

A carbon budget defined with environmental organisations

To limit the global warming to +1.5° C by the end of the century, there is a maximum quantity of GHG the EU – including the energy system – can emit. This defines the carbon budget for the EU, and to a more restrictive extent, the share allocated to the energy system that the COP 21 scenarios consider. To define the carbon budget until the year 2100, ENTSO-E and ENTSOG have worked with the environmental NGOs *Renewable Grid Initiative and Climate Action Network Europe*.

A carbon neutral energy system by 2050

The other objective set in the COP 21 scenarios is to reach carbon neutrality[3] of the energy system by 2050. This objective therefore places further demands on the speed of decarbonisation the energy system should reach.

Carbon neutrality can be reached by 2050 within a budget of 63.5 $GtCO_2$ …

Both Distributed Energy and Global Ambition scenarios show that a centralised or decentralised evolution of the energy system can achieve carbon neutrality by 2050. The scenarios also show that, considering different development of technologies – and starting from 2018 onwards – the energy system can limit its emissions to reach not more than 63.5 $GtCO_2$ at EU level until 2050 in Global Ambition, and not more than 62.6 $GtCCO_2$ in Distributed Energy.

… but up to 15 $GtCO_2$ must be compensated after 2050

However, the scenario budget defined to limit the global warming to 1.5° C with a 66.7 % probability considers that the cumulative EU GHG emissions should be limited to 48.5 $GtCO_2$ by the end of the 21st century. This means net negative emissions of 15 $GtCO_2$ have to be achieved between 2050 and 2100 in case of Global Ambition, provided the EU is carbon neutral in 2050.

For Distributed Energy, due to lower cumulative emissions until 2050, 14.1 $GtCO_2$ of net negative emissions are needed to reach the 1.5° C target by 2100.

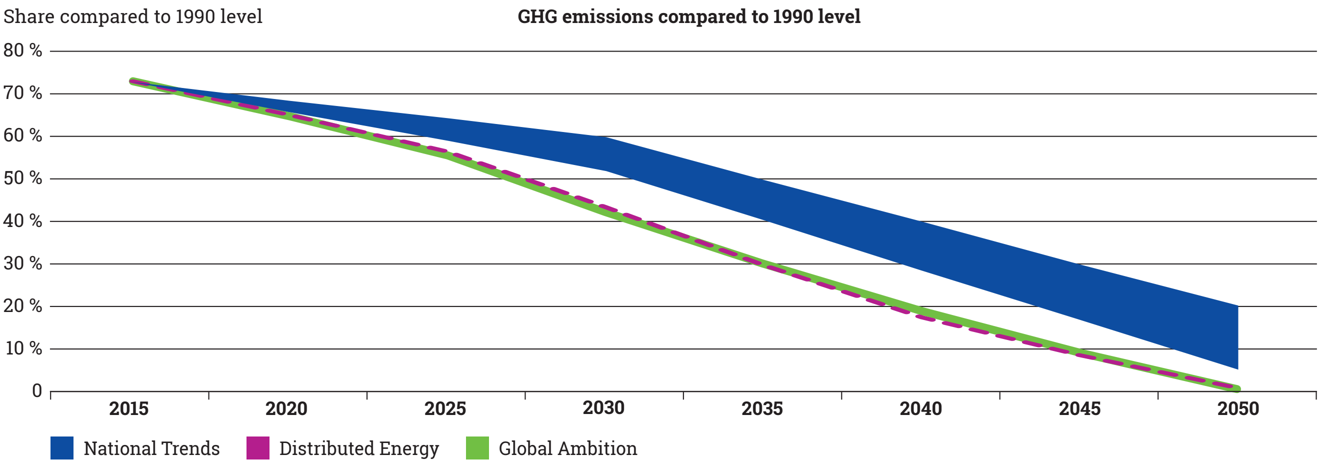
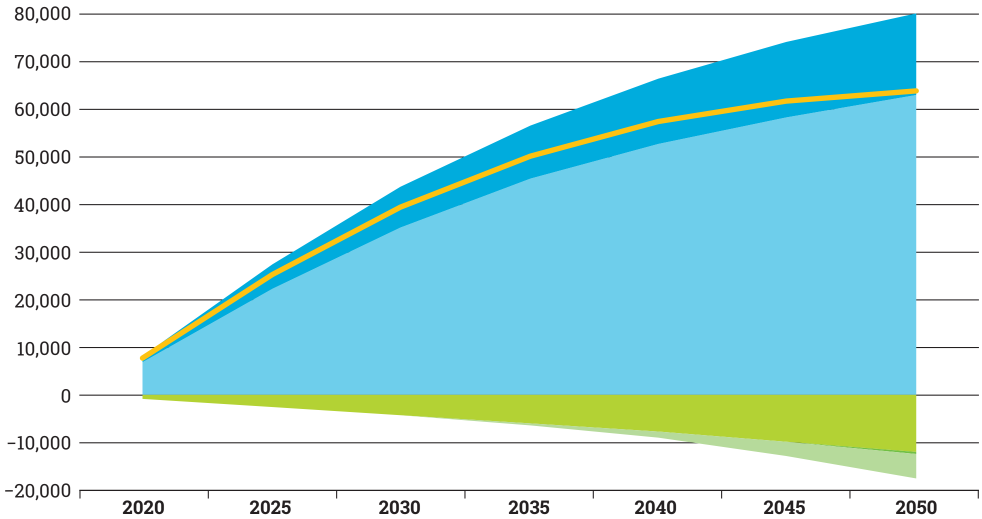


Figure 2: GHG emissions in ENTSOs' Scenarios

2 The Intergovernmental Panel on Climate Change, Special Report, 2018, https://www.ipcc.ch/sr15/

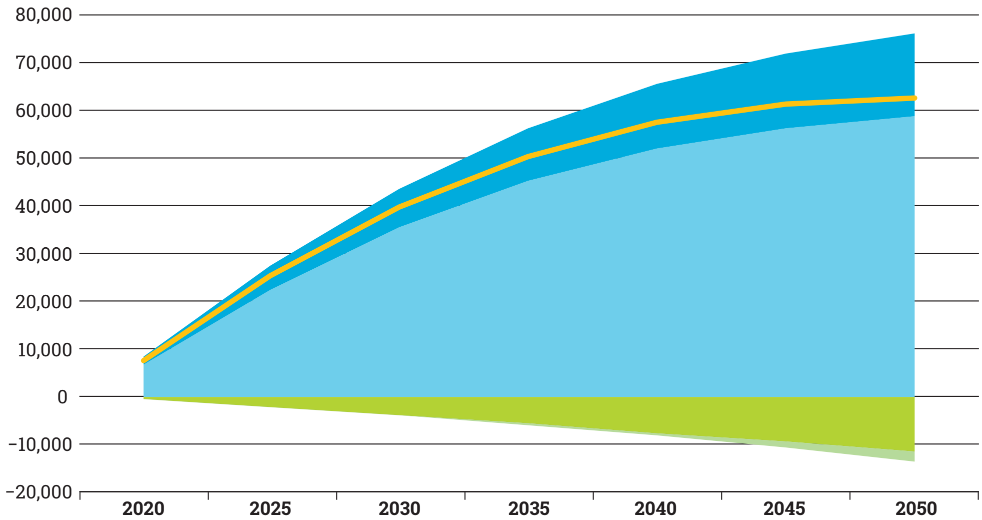
3 "Carbon neutrality (or net zero) means having a balance between emitting carbon and absorbing carbon from the atmosphere in **carbon sinks**. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration. In order to achieve net zero emissions, all worldwide greenhouse gas emissions will have to be counterbalanced by carbon sequestration" (European Parliament (link)). The ENTSOs consider all green house gas emissions measured in terms of their carbon dioxide equivalence.

EU 28 cummulative GHG emissions – Global Ambition



	2020	2025	2030	2035	2040	2045	2050
Cummulative non-CO_2 emissions	1,525	5,086	8,285	11,123	13,599	15,713	17,467
Cummulative CO_2 emissions	6,781	22,286	35,159	45,160	52,669	58,295	62,575
Cummulative credits from pre-and postcombustive CCU/S and BECCS	0	0	-149	-629	-1,426	-2,780	-4,901
Cummulative credits from BECCS	0	0	0	0	0	-178	-731
Cummulative credits from LULUCF	-627	-2,253	-3,963	-5,757	-7,635	-9,598	-11,644
Net Cummulative CO_2eq emissions	7,679	25,119	39,332	49,896	57,206	61,631	63,497

EU 28 cummulative GHG emissions – Distributed Energy



	2020	2025	2030	2035	2040	2045	2050
Cummulative non-CO_2 emissions	1,525	5,086	8,285	11,123	13,599	15,713	17,467
Cummulative CO_2 emissions	6,801	22,441	35,490	45,378	52,154	56,391	58,704
Cummulative credits from pre-and postcombustive CCU/S and BECCS	0	0	-59	-272	-657	-1,201	-1,890
Cummulative credits from BECCS	0	0	0	0	0	-178	-731
Cummulative credits from LULUCF	-627	-2,253	-3,963	-5,757	-7,635	-9,598	-11,644
Net Cummulative CO_2eq emissions	7,699	25,274	39,752	50,471	57,460	61,306	62,636

Figure 3: EU28 Cummulative Emissions in Cop21 Scenarios in $MTCO_2$

3.3 Sector-Coupling – an enabler for (full) decarbonisation

For the ENTSOs, sector coupling describes interlinkages between gas and electricity production and infrastructure. Major processes in this regard are gas-fired power generation, Power-to-Gas (P2G) and hybrid demand technologies.

ENTSOs' scenarios are dependent on further development of sector coupling, without these interlinkages a high or even full decarbonisation in the energy sector will not be reached.

Assuming a switch from carbon-intensive coal to natural gas in 2025, 150 $MtCO_2$ could be avoided in the power generation. With increasing shares of renewable and decarbonised gases, gas-fired power plants become the main "back-up" for variable RES in the long-term. Distributed Energy even shows a further need for CCS for gas power plants to reach its ambitious target of full decarbonisation in power generation by 2040.

On the other hand, P2G becomes an enabler for the integration of variable RES and an option to decarbonise the gas supply. Hydrogen and synthetic methane allow for carbon-neutral energy use in the final sectors. Distributed Energy is the scenario with the highest need for P2G, requiring 840 TWh of power generation per year with more than 300 GW of capacities for wind and solar in 2040 to produce renewable gas.

Sector coupling in National Trends, with the assumption that P2G generation is limited to "curtailed electricity", considers 35 TWh of power generation with 30 GW of P2G to produce renewable gas.

	<2050	2050	>2050	Total
Energy and non-energy related CO_2 emissions	62.4	Carbon-Neutrality	Additional measures needed, e.g.: LULUCF BECCS CCS DAC	
Non-CO_2 GHG emissions (including methane and Fluorinated gases)*	17.5			
Carbon sinks**	−16.5			
Net cumulative emissions	63.5		−15	EU28 carbon budget share based on its population 48.5 $GtCO_2$

* Data for methane and fluorinated gases emissions is taken from the European Commission's most ambitious 1.5Tech and 1.5Life scenarios (average) as published in the "A Clean Planet for all"- Study (link).

** Data for LULUFC is taken from the European Commission's most ambitious 1.5Tech and 1.5Life scenarios (average) as published in the "A Clean Planet for all"- Study (link).

Table 1: Cummulative emissions and required net negative emissions in Global Ambition

4 Scenario description and storylines

To ensure consistency between successive TYNDP reports, it is necessary to preserve the scenarios essence to some degree. Therefore, the 2020 scenarios build on the 2018 scenarios. However, the energy landscape is continuously evolving, and scenarios must keep up with the main drivers and trends influencing the energy system.

Storyline drivers

ENTSOs identified two main drivers to develop their scenario storylines: decarbonisation and centralisation/de-centralisation. Decarbonisation refers to the decline in total GHG emissions while centralisation/de-centralisation refers to the set-up of the energy system, such as the share of large/small scale electricity generation (offshore wind vs. solar PV) or the share of indigenous renewable gases (biomethane and P2G) vs. share of decarbonised gas imports (either pre- or post-combustive). Figure 3 illustrates the relation of the two key drivers for all three scenarios.

For the short and medium-term, the scenarios include a "Best Estimate" scenario (bottom-up data including a merit order sensitivity between coal and gas in 2025). For the longer term, they include three different storylines to reflect increasing uncertainties.

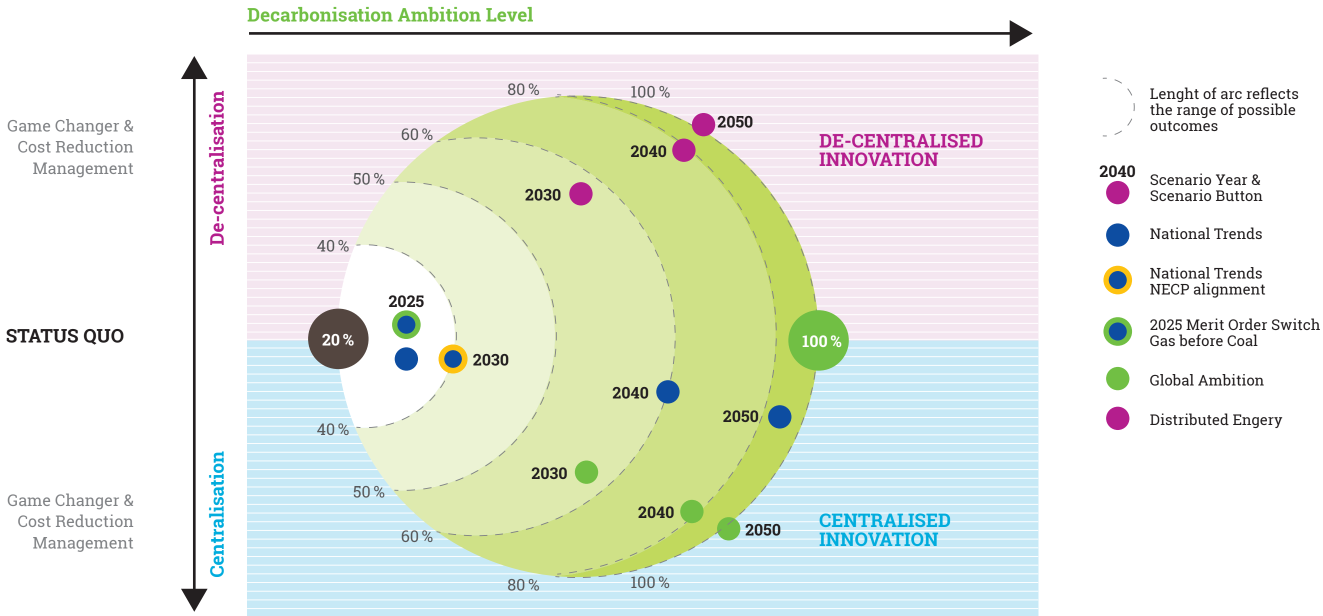


Figure 4: Key drivers of Scenario Storylines

- For 2020 and 2025, all scenarios are based on bottom-up data from the TSOs called the "Best Estimate" Scenario and reflecting current national and European regulations. A sensitivity analysis regarding the merit order of coal and gas in the power sector is included for 2025 following stakeholder input regarding the uncertainty on prices, even in the short term. These are described as 2025 Coal Before Gas (CBG) and 2025 Gas Before Coal (GBC).

- National Trends keeps its bottom-up characteristics, taking into account TSOs' best knowledge of the gas and electricity sectors in compliance with the NECPs[4]. Country-specific data was collected for 2030 and 2040 (when available for electricity) in compliance with the TYNDP timeframe. For gas, further assumptions have been made to compute the demand for 2050 on an EU28-level.

- Distributed Energy and Global Ambition are built as total energy scenarios (all sectors, all fuels) with top-down methodologies. Both scenarios aim at reaching the 1.5° C target of the Paris Agreement following the carbon budget approach. They are developed on a country-level until 2040 and on an EU28-level until 2050.

The storylines for 2030 and 2040/2050 are:

- **National Trends (NT)** is the central scenario based on draft NECPs in accordance with the governance of the energy union and climate action rules, as well as on further national policies and climate targets already stated by the EU member states. Following its fundamental principles, NT is compliant with the EU's 2030 Climate and Energy Framework (32 % renewables, 32.5 % energy efficiency) and EC 2050 Long-Term Strategy with an agreed climate target of 80–95 % CO_2 reduction compared to 1990 levels.

- **Global Ambition (GA)** is a scenario compliant with the 1.5° C target of the Paris Agreement also considering the EU's climate targets for 2030. It looks at a future that is led by development in centralised generation. Economies of scale lead to significant cost reductions in emerging technologies such as offshore wind, but also imports of energy from competitive sources are considered as a viable option.

- **Distributed Energy (DE)** is a scenario compliant with the 1.5° C target of the Paris Agreement also considering the EU's climate targets for 2030. It takes a de-centralised approach to the energy transition. A key feature of the scenario is the role of the energy consumer (prosumer), who actively participates in the energy market and helps to drive the system's decarbonisation by investing in small-scale solutions and circular approaches.

4 In some Member States, gas demand in the draft NECPs is not consistent with gas TSOs best knowledge. To comply with draft NECPs, the gas demand in 2030 was adjusted for some countries. However, the final version of the NEPCs may consider an adjustment of the gas demand. All data can be found on the visualisation platform.

For some countries power generation energy mix for National Trends may differ from the figures given by the NECPs. ENTSOs will provide an overview of final NECP figures for gas and electricity, once the final versions are published.

Category	Criteria	2040 Scenarios		
		Global Ambition	National Trends	Distributed Energy
Primary mix	Coal	–––	––	–––
	Oil	–––	––	–––
	Nuclear	––	––	––
	Hydro	o	o	o
	Geothermal	+	o	++
	Biomass	++	+	+++
	Imported Renewable and decarbonised Gas	+++	+	+
	Natural gas	––	–	–––
	Wind onshore	+++	++	+++
	Wind offshore	+++	+++	++
	Solar	+	++	+++
	Wind for P2G	+		++
	Solar for P2G	+	+	+++
	Imported Green Liquid Fuel	++	+	+
	Total demand (all energy)	–	o	–
High temperature Heat	Electricity Demand	+	+	++
	Gas Demand	++	+	o
	Total demand (all energy)	––	–	––
Low temperature Heat	Electricity Demand	++	+	+++
	Gas Demand	–	–	––
Transport	Total demand	––	–	––
	Electricity Demand	++	+	+++
Power and Lighting	Gas Demand	++	+	+
	Electricity Demand	–	o	–
CCS	CCS for power	++	o	+++
	CCS in Industry			

Change from today	–––	––	–	o	+	++	+++
	Not available	Moderate Reduction	Low Reduction	Stable	Low growth	Moderate growth	High growth

Table 2: Storyline Central Matrix

Scenario Building Central Matrix

The Scenario Building Central Matrix is a tool used to identify the key elements of the storylines. The Central Matrix enables creation of scenarios that are consistent along a pathway, yet differentiated from other storylines.

The Central Matrix is a table that can provide an EU-wide qualitative overview of key drivers for the European energy system in 2050. The matrix uses +/- indicators to show how the primary energy mix and final energy use change compared to sectors are assumed to change from today. It is important to note that country level and/or regional differences will be present, when compared to the EU-28 figures, the differences are driven by factors such as national policy, geographical and/or technical resource constraints.

To understand the matrix notation, the following assumptions must be considered:

- The growth or reduction indications are in relation to what is seen today, but also in relation to the rates observed within that category in comparison to other scenarios. For example, compared to today, solar generation is expected to increase significantly in all scenarios from today, but receives a +++ only in Distributed Energy.

- Equally, growth and reduction rates across the different categories are not directly comparable. For example, two categories with ++ rating may differ significantly in their actual percentage increase from today, based on the starting point and ultimate potential.

Further information on how to read the Central Matrix can be found in the annex document Scenario Methodology Report.

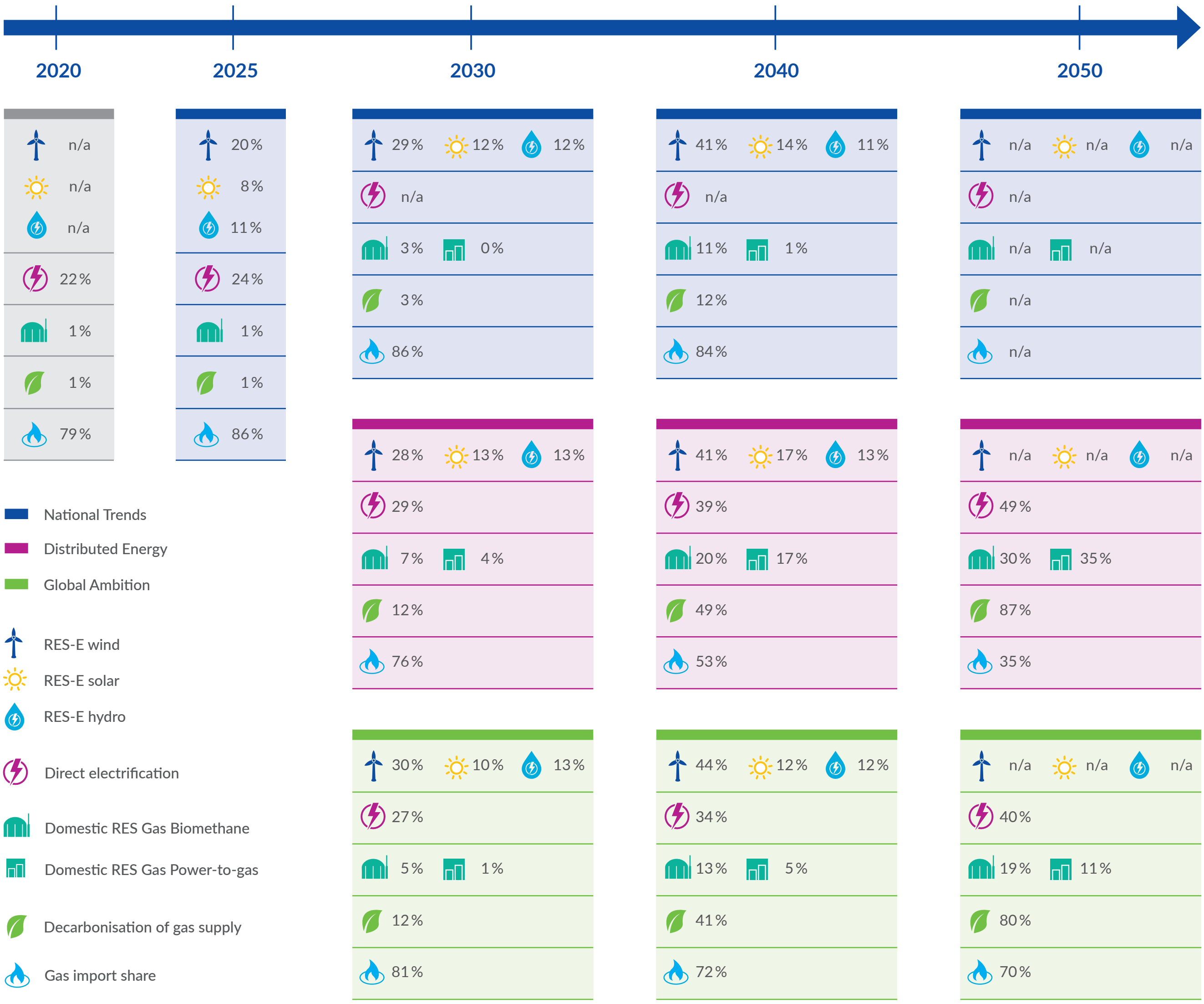


Figure 5: The TYNDP 2018 scenarios for 2030 and 2040 are defined by three storylines

5 Scenario Results

The level of detail provided for each scenario depends on the approach to building the data set.

The National Trends bottom-up collection uses gas and electricity demand data from TSOs in line with draft NECPs. The final energy demand supplied by other primary fuels, such as that for heat and transport, is not available to TSOs; therefore sector by sector energy demand splits cannot be reported. The bottom up data is based on member state draft NECPs, this underpins the assumption that the bottom up gas and electricity demand data contributes fairly towards the EU28 Clean Energy Package targets for 2030; 32 % renewable energy along with 32.5 % energy efficiency.

The new top-down scenario building approach provides the ENTSOs with new opportunities to report on total primary energy and the sector splits for final energy demand. The top-down energy modelling approach evolves in five year steps from historical energy balance data, so it is possible to report on the sectoral final energy demand over time.

5.1 Demand

Note: All gas figures are expressed in gross calorific value. Where needed, external scenario figures have been converted to gross calorific values by applying a factor of 110 %.

5.1.1 Final Energy Demand

The chart below shows the total energy sector demand for the storylines Distributed Energy and Global Ambition. A key driver in how the final energy demand volumes are derived is a EU28 target specifying a 32.5 % reduction in final use energy demand by 2030 compared to 2005. The final use demand for the EU28 according to DEE2012/27/EU(10309/18)[5] should be around 11,100 TWh. The final use energy demand figure does not include the energy requirement for non-energy uses. When this adjustment is taken into account, final energy demand in 2030 for Distributed Energy is 10,800 TWh and Global Ambition 10,900 TWh.

Final energy demand can achieve ambitious reductions in energy volume due to changes to end user devices and energy efficiency measures. The scenario storylines capture themes such as, but not limited to:

- Converting from less efficient heating options to heat pump technologies, such as gas, electric and hybrid (electric heat pump associated with condensing gas boiler)

- Switching from low efficiency transport options to more efficient modes of transport

- Energy efficiency product standards; continue to deliver energy efficiency gains for end-user appliances

- In the built environment, thermal insulation reduces demand for heat, while ensuring comfort level are maintained

- Behavioural changes where consumers actively reduce demand either by utilising more public transport or modifying heating and cooling comfort levels.

Although overall final energy demand is decreasing, gas and electricity show different trends. For gas, at least until 2025 as well as for electricity in the long-run, the energy demand growth is driven by factors such as underlying gross domestic product (GDP) growth, additional energy demand from low temperature heat and transport sectors as these sectors switch away from carbon-intensive fuels, such as coal and oil. The storylines assume that at an EU level underlying GDP growth is tempered by the strong energy efficiency measures, so that final energy demand (which includes electricity demand) is reduced to meet the EU28 32.5 % energy efficiency target for 2030.

The National Trends energy figures are based on the TSO data compatible with the latest available data from member state NECPs. The annual energy volumes come from national forecasts, that are summed to provide information at EU28 level.

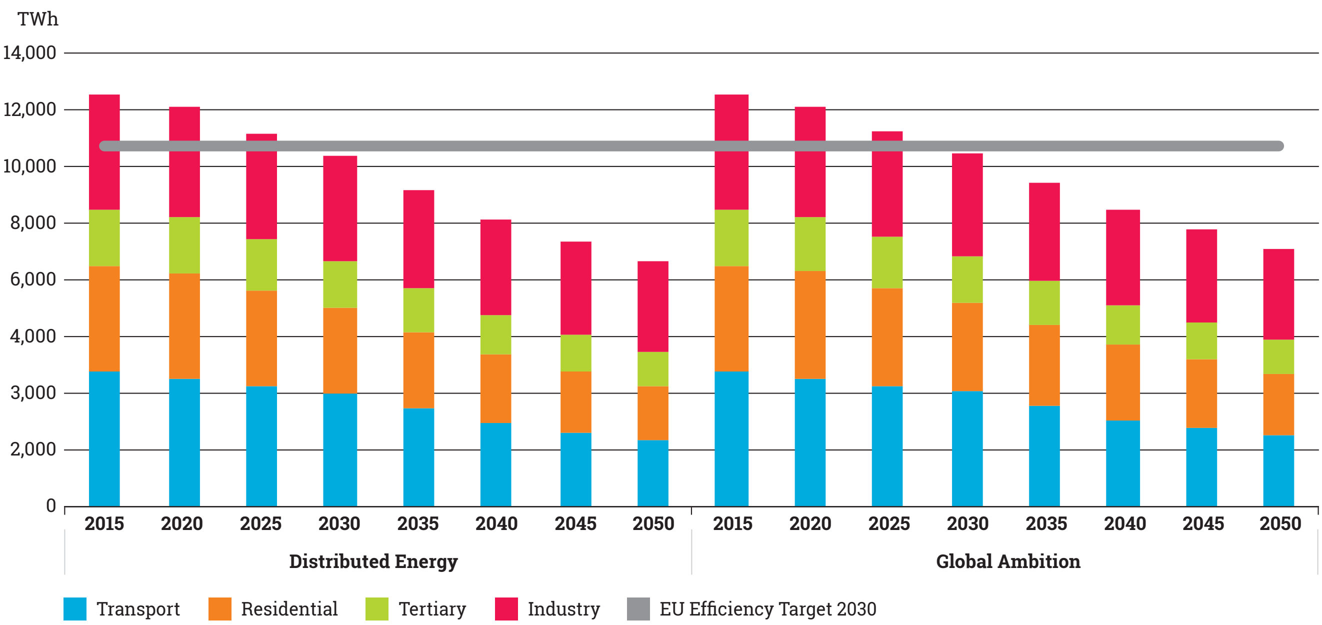


Figure 6: Final energy demand in COP21 scenarios

5 https://ec.europa.eu/energy/en/topics/energy-efficiency/targets-directive-and-rules/eu-targets-energy-efficiency

Scenario	EU-28 Annual Electricity Demand (TWh)			Compound Annual Growth Rate	
	2015	2030	2040	2015–2030	2030–2040
Historical Demand	3,086				
National Trends		3,237	3,554	0.3 %	0.6 %
Global Ambition		3,283	3,476	0.4 %	0.5 %
Distributed Energy		3,464	3,829	0.8 %	0.9 %

Table 3: Annual EU-28 electricity demand volumes and the associated growth rate

5.1.2 Direct Electricity Demand[6]

The scenarios show that higher direct electrification of final use demand across all sectors results in increase in the need for electricity generation.

Distributed Energy is the scenario storyline with the highest annual electricity demand hitting around 3,800 TWh by 2040. The results for scenarios show that there is the potential for year on year growth for EU28 direct electricity demand. The table provides annual EU-28 electricity demand volumes and the associated growth rate for the specified periods.

The growth rates for the storylines show that by 2040 National Trends is centrally positioned in terms of growth between the two more-ambitious top-down scenarios Distributed Energy and Global Ambition. The main reason for the switch in growth rates is due to the fact that Global ambition has the strongest levels of energy efficiency, whereas for Distributed Energy strong electricity demand growth is linked to high electrification from high uptake of electric vehicles and heat pumps, dominating electrical energy efficiency gains.

Peak electricity demand is defined as the highest single hourly power demand (GW) within a given year. Peak demand growth in the future will be impacted in a number of ways, for example;

- The roll out of smart metering, these may provide more opportunities for time of use supplier charging, so consumers can make more efficient choices.

- High growth rates for passenger electric vehicles lead to pressures on the electrical grid, both at distribution and transmission levels. The scenarios assume that there is an inherent level of smart charging that shifts consumer behaviour away from peak periods.

- Electric and hybrid heat pumps. The demand time series created are weather dependent. The results show that electric heat pumps can add pressure to demand; i.e. there is more heat demand when outside temperatures are low. There are a number of options to support direct electric heating, such as, thermal storage, or hybrid heating systems. For example: Hybrid systems can help mitigate the adverse impact on the electricity grid by switching to gas during extreme cold periods (typically less than 5°C).

- New peak demand changes may stem from additional new baseload demand, such as data centres, especially as digitalisation continues to sweep across the globe.

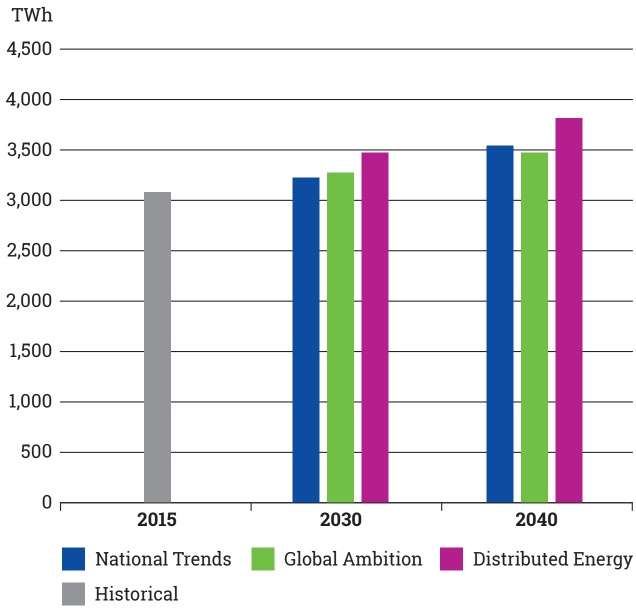


Figure 7: Direct electricity demand per scenario 2030 and 2040 (EU28)

6 Direct Electricity Demand refers to the electricity end use in sectors such as residential, tertiary, transport and industry.

The hourly demand charts show that the historical effects of GDP and energy efficiency continue influence electricity demand growth in industry, tertiary and residential sectors. The scenarios show that direct electrification of transport and heating sectors starts to have a significant impact on the hourly profiles.

It is clear from the future demand profile composition that the impact of electric vehicles is noticeable across each season. The impact for heat pumps is however dependent on the outside weather temperature. It can be seen that there is a reduced demand for heat in the summer, but electrified water heating remains part of the composition during summer periods.

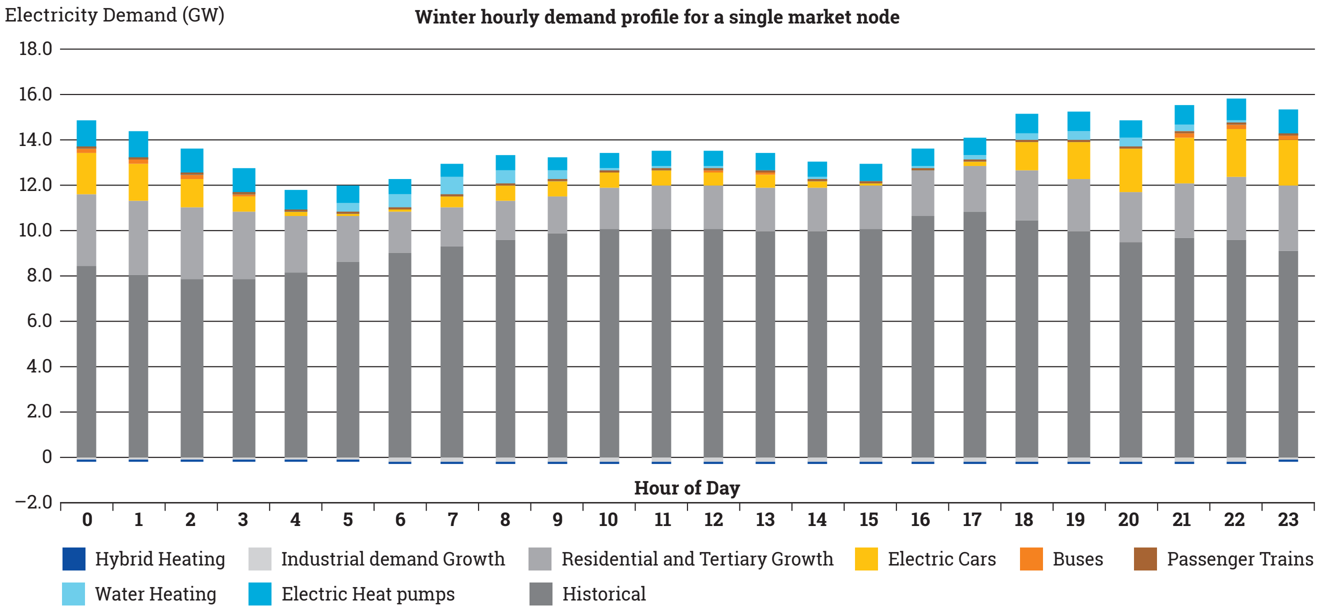


Figure 8: Example winter hourly demand profile for a single market node – impact of direct electrification in heating and transport sectors

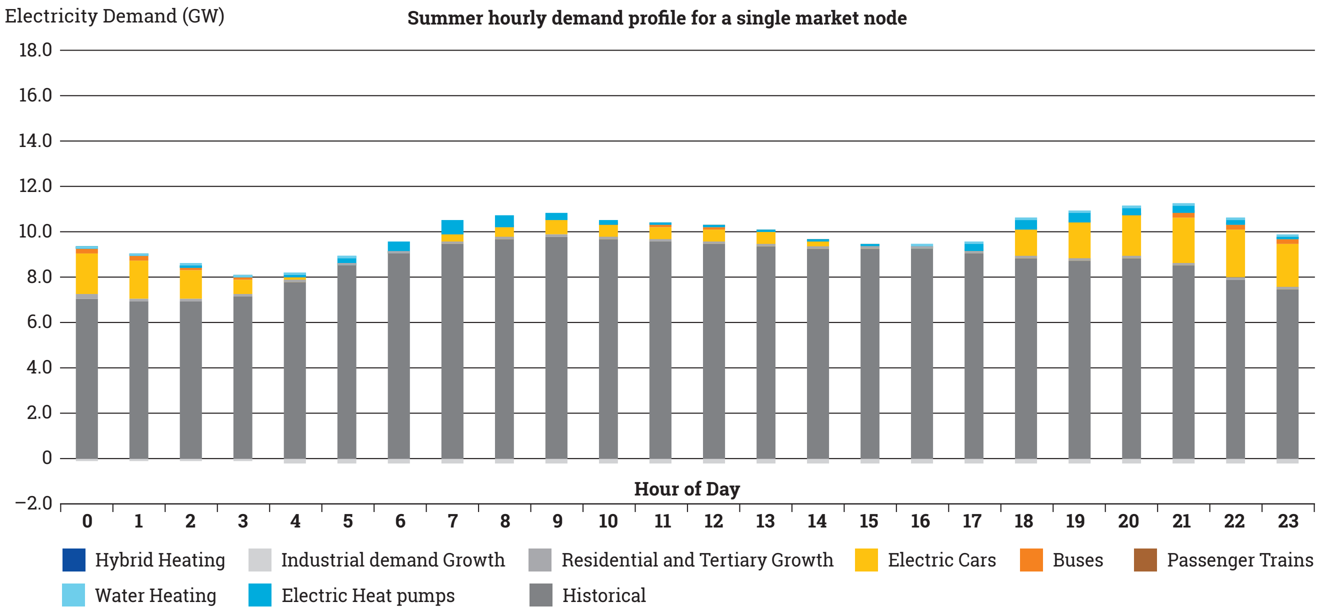


Figure 9: Example summer hourly demand profile for a single market node – impact of direct electrification in heating and transport sectors

Peak demand for electricity grows between 2030 and 2040 for each storyline. The electrification of heat and transport are two significant drivers in growth of electricity peak demand. The storyline assumptions mean that GDP related peak demand growth is moderated by energy efficiency. The impact of demand side response on peak electricity is modelled as a priced demand side response unit directly in the ENTSO-E power market tools.

The National Trends demand profiles are developed from the TSOs input based on latest available member state draft NECPs and where available national projections for 2040. For the top-down scenarios the ENTSOs assume a high uptake of smart charging for transport, which will moderate peak demand growth rates. The demand profiles account for outside temperature and the impact on peak demand; this is important as the share of electricity within the heating sector increases.

For the top-down scenarios there is rational spread in peak demand growth rates between 2030 and 2040. Global Ambition is the scenario with the lowest levels of heat pumps, coupled with higher energy efficiency, the effect is that the scenario has the lowest peak demand growth between 2030 & 2040. In Distributed Energy the main driver for higher peak demand is the higher rates of electrification across all sectors, however, it is important to note this can provide additional opportunities for demand side response, such as vehicle to grid or demand flexibilities at domestic level.

The peak demand growth rate in National Trends between 2030 and 2040 indicates a 1.0% year on year growth in peak demand. The growth rate for National Trends lies firmly in between the demand growth rates for Distributed Energy and Global Ambition. The spread in peak demand provides an opportunity for all three scenarios to enhance the understanding on the long-term impacts for the European transmission system.

Scenario	EU-28 Annual Peak Demand (GW)		CAGR
	2030	2040	2030–2040
National Trends	568	625	1.0 %
Global Ambition	543	570	0.5 %
Distributed Energy	572	644	1.2 %

Table 4: Annual EU-28 electricity peak demand and the associated growth rate for the specified periods

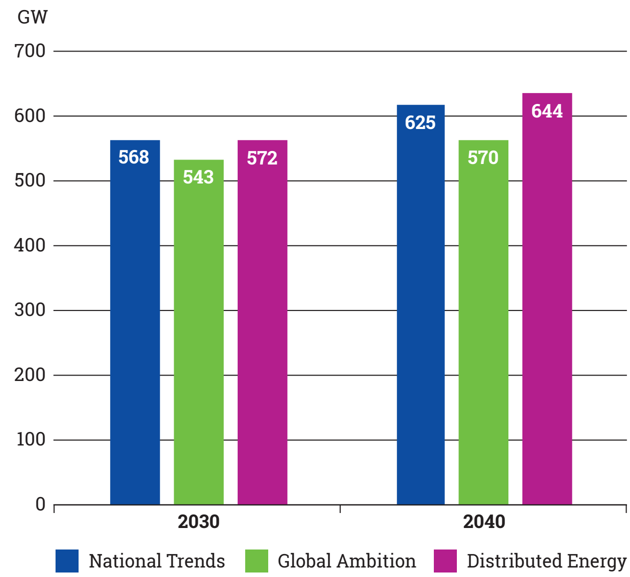


Figure 10: Peak electricity demand (GW) per scenario 2030 and 2040

Direct electrification of transport and heat

Electrification of heat and transport are two key areas necessary to decarbonise the European energy system. The information received from the TSOs and the COP21 scenarios show that electric vehicles and heat pumps have the greatest impact on electricity demand. The charts show how the scenario electric vehicles and heat pumps compare to external scenarios referenced in the chart as "range".

The scenarios aim to reduce emissions in line with the European targets and COP21 pathways. To achieve ambitious emission reductions in the heating sector a shift away from fossil fuels is required. The scenarios show that moving away from oil and coal is a quick win to reduce emissions in heating sector. The top-down and bottom up scenarios highlight the need for consumers to change how they heat their homes and businesses. The scenarios require a large shift towards electric and hybrid heat pumps, which reduce both primary energy demand and final use energy demand due to the impact of heat pump co-efficient of performance. Heat pump technologies are used for space heating and sanity water heating.

Distributed Energy has the highest electrification with 245 Million electric vehicles and around 50 million heat pumps by 2040. The volumes relating to electric vehicles and heat pumps provide insight into why the Distributed Energy electricity demand reaches 3,800 TWh by 2040.

Global Ambition is a scenario where there is strong uptake of electric vehicles reaching around 200 million by 2040 but lower heat pump uptake at around 25 million devices. The scenario assumes more uptake of alternative low carbon heating to ensure that the emissions levels for the scenarios are achieved.

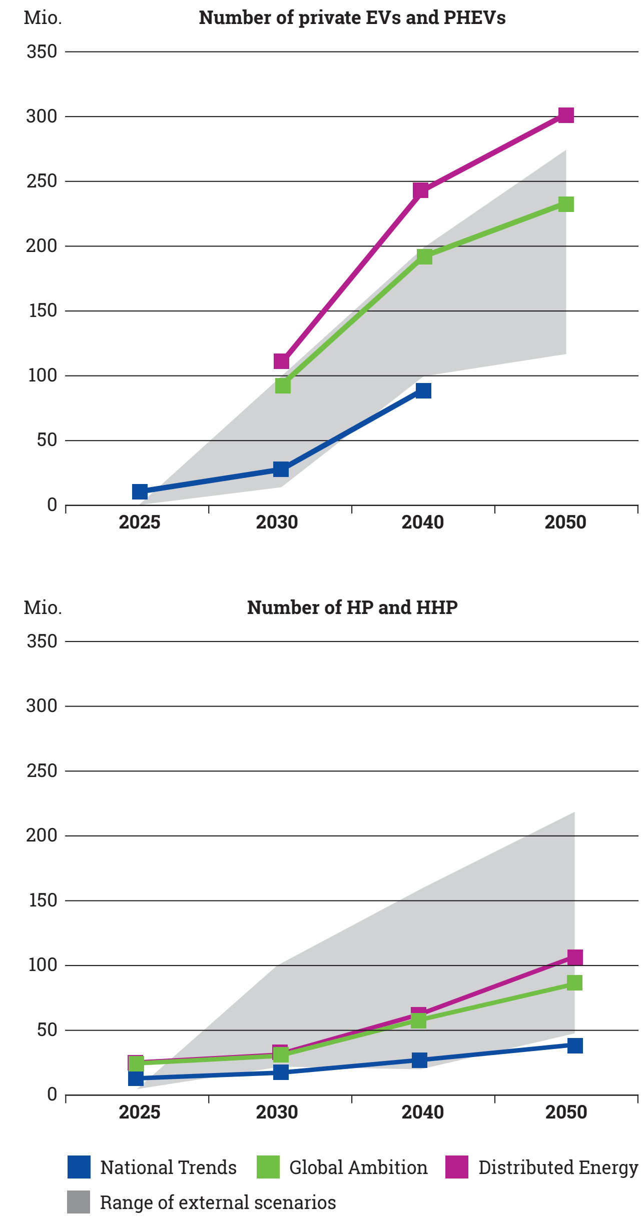


Figure 11: Number of Electric and Plug-in Hybrid Passenger Vehicles (above) and Number of Electric and Hybrid Heat Pumps (below) compared to a range based on analysis of third party reports

The National Trends scenario is based on TSO data and shows that there is a lower level of ambition for electrification of the transport sector around 100 million electric vehicles with around 60 million heat pumps by 2040.

The scenario numbers for electric vehicles and electric and hybrid heat pumps technologies are shown on the charts. The shaded area represents a range of minimum and maximum values from third party studies, see section 8 for further information. The charts show that the input assumptions for heat pumps and electric vehicles numbers lie within credible values.

5.1.3 Gas Demand

Total gas demand[7] is split up into final demand (residential, tertiary, industry incl. non-energy uses and transport) and demand for power generation. While scenarios can show a decrease or increase for the total gas demand, the different sectors can evolve independently and in different directions.

By 2030, National Trends has the lowest total gas demand. In contrary to that, Global Ambition and Distributed Energy reach higher decarbonisation levels of the energy system with more gas. This is due to a faster switch from carbon-intensive fuels, such as coal and oil, to gas, but also due to higher shares of renewable and decarbonised gases in the gas mix.

When comparing the sectoral split, all scenarios register a decrease in the residential and tertiary sector, but the uptake of gas demand in the transport sector can compensate parts of it in the COP21 Scenarios. These trends remain until 2040, resulting in lower demand for all scenarios with National Trends and Distributed Energy below 4,000 TWh (−20 % compared to today's level). Percentage-wise the transport sector has the highest change from 2020 to 2040. In all scenarios, gas demand for transport increases, most significantly in Global Ambition.

It is worth mentioning, that the development of final gas demand differs from region to region. Due to a high dependency on coal, gas demand for heating increases in Central and Eastern Europe, whereas other regions head towards more electrification in the private heating sector. To give an example coal has a share of up to 50 % in the heating sector and 80 % in the power generation in Poland.

A switch from carbon-intensive coal to natural gas with lower carbon intensity by 2025, results in 290 TWh additional gas demand. However, this would lead to emissions reduction in electricity generation of up to 150 $MtCO_2$. At least until 2030 gas demand for power generation is increasing with the level of decarbonisation and electricity demand. Therefore, Distributed Energy as the scenario with the highest electricity demand has up to 42,7 % more gas demand for power generation than National Trends with the lowest gas demand for electricity generation. Same trend can be seen for 2040.

7 Total gas demand can also be referred to as "Gross Inland Consumption" of gas as done by Eurostat (link)

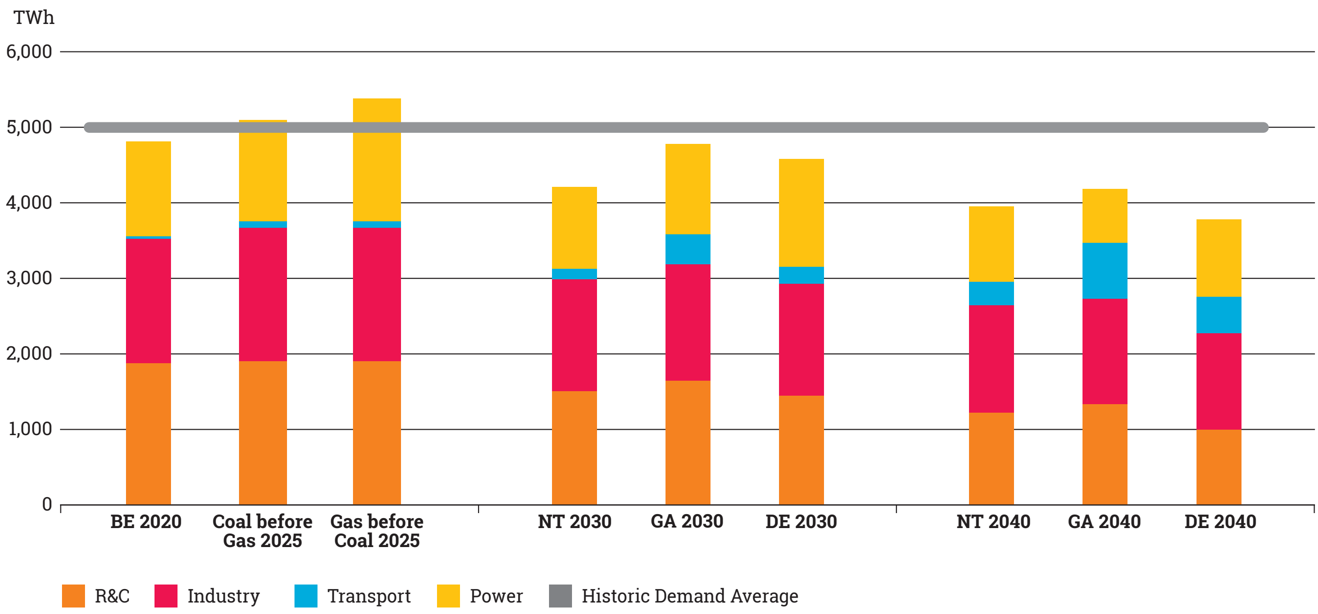


Figure 12: Sectoral breakdown of total gas demand in EU28

Peak demand generally follows the annual trends

The high daily-peak and 2-week demand requirements[8] reflect the changing nature of residential and commercial demand, as temperature-dependent space heating typically drives peak gas consumption. As a result, final demand for peak day and 2-week decreases in all scenarios due to efficiency measures with with the largest decrease in Distributed Energy, due to a higher penetration of electrical heat pumps. National Trends observes the most limited change as consumers have invested in more traditional technologies, although they are considered less efficient.

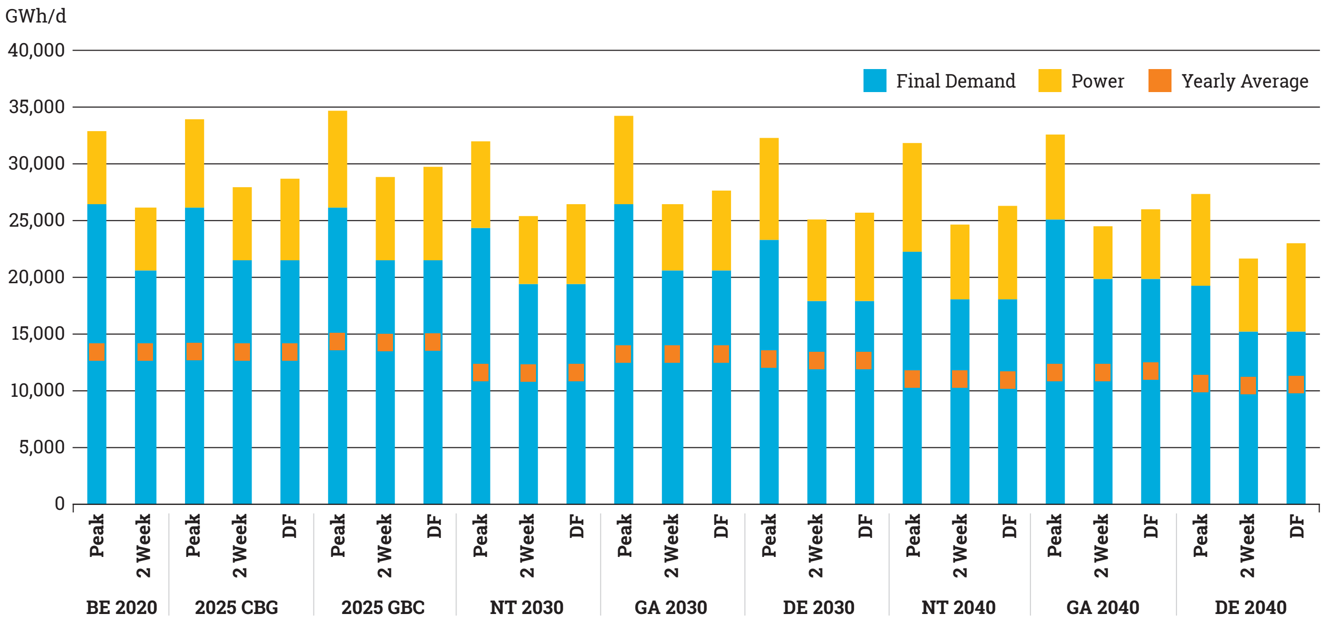


Figure 13: Gas demand in high demand cases (Peak, 2-Week cold spell, Dunkelflaute*)

* "Kalte Dunkelflaute" or just "Dunkelflaute" (German for "cold dark doldrums") expesses a climate case, where in addition to a 2-week cold spell, variable RES electricity generation is low due to the lack of wind and sunlight.

8 The "2-week demand" refers to a two-week period during a cold spell with very low temperatures resulting in high heating demand

The gas system can support the high development of variable RES.

The significant development of variable electricity RES capacities in both scenarios influences the role of the gas infrastructure to back-up the variable power generation. With significant variable RES-E capacities in the energy system, the gas demand may be impacted by Dunkelflaute events more often and more intensely.

Decarbonisation of the energy system comes with an uptake of the hydrogen demand

As a consequence of an increasing volume of hydrogen generation, the COP 21 scenarios consider contrasted development of the hydrogen demand that could materialise to make use of this potential:

- Distributed Energy scenario considers a higher penetration of P2G technologies with significant volumes produced more locally and thus a similar development of the Hydrogen demand.

- Global Ambition scenario considers a more centralised decarbonisation where the Hydrogen demand is mainly driven by the need for pre-combustion decarbonisation with a partial shift of the final demand to Hydrogen.

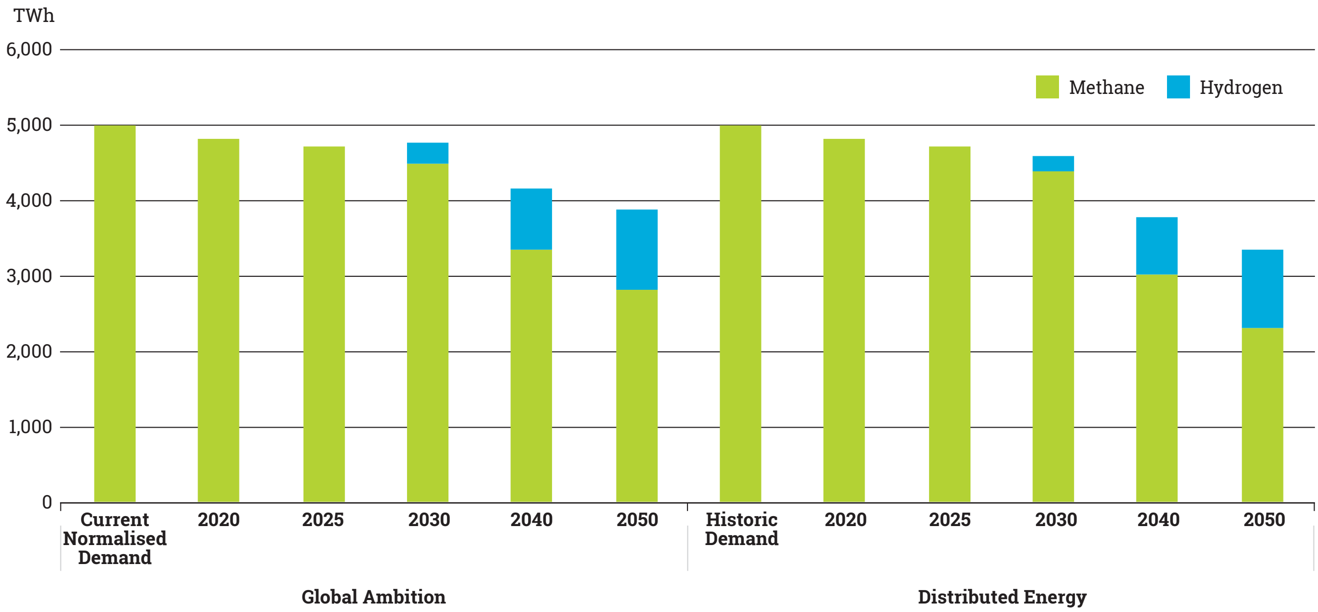


Figure 14: Methane and hydrogen demand in COP21 scenarios

5.2 Supply

5.2.1 Primary energy supply

For the COP21 Scenarios, the overall energy mix becomes carbon-neutral by 2050. To fully decarbonize, both COP21 Scenarios register a significant increase in both renewables and further CO_2 removal technologies, while reducing primary energy demand. Whereas both scenarios reach similar levels of demand decrease of around 42 % to 43 %, the RES share in Global Ambition reaches 64 % by 2050 but is still outbid by Distributed Energy with a RES share of 80 %.

The vast majority of energy is from renewables. Wind, solar and hydro cover roughly 45 % of primary energy demand in Europe in Distributed Energy and above 31 % in Global Ambition, while nuclear contributes approximately 10 % in both scenarios. Biomass and energy from waste materials contribute significantly – in Distributed Energy they cover 35 % and in Global Ambition 33 % of the primary energy mix. Biomass can be directly used in industrial processes, or as feedstock to produce biofuels or biomethane – both can be used in all sectors, with a main focus in power generation, transport and heating. Since coal is phased out already by 2040, remaining demand is covered by oil, nuclear and gas imports. The increase in renewable energy production results in declining import shares, from 55 % to 60 % nowadays, to ca. 20 % in Distributed Energy and 36 % in Global Ambition[9].

A key enabler for the transition is the conversion of wind and solar power to P2G, which balances the variable electricity supply with energy demand and allows utilization of energy sourced from renewable electricity in final consumption sectors when there is no electricity demand.

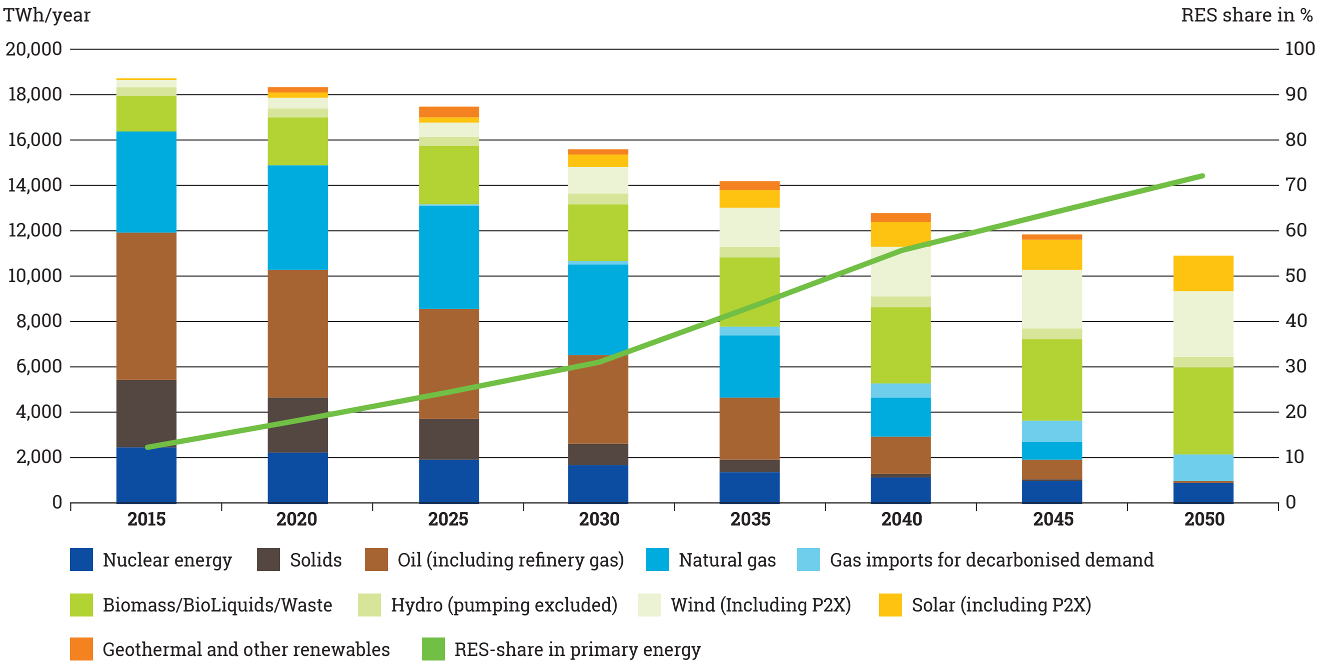


Figure 15: Primary energy mix in Distributed Energy and its RES-share (Solids: coal, lignite, peat and coke)

5.2.2 Electricity

In the COP21 Scenarios, the electricity mix becomes carbon neutral by 2040. In EU-28, electricity from renewable sources meets up to 63 % of power demand in 2030 and 83 % in 2040. Variable renewables (wind and solar) play a key role in this transition, as their share in the electricity mix grows to over 40 % by 2030 and over 55 % by 2040.

The remaining renewable capacity consists of biofuels and hydro. All figures stated above exclude power dedicated for P2X use, which is assumed to be entirely from curtailed RES, and newly build renewables that are not grid-connected, and therefore not considered in this representation.

9 For the calculation of import shares, it is assumed that all oil and nuclear energy is imported in 2050.

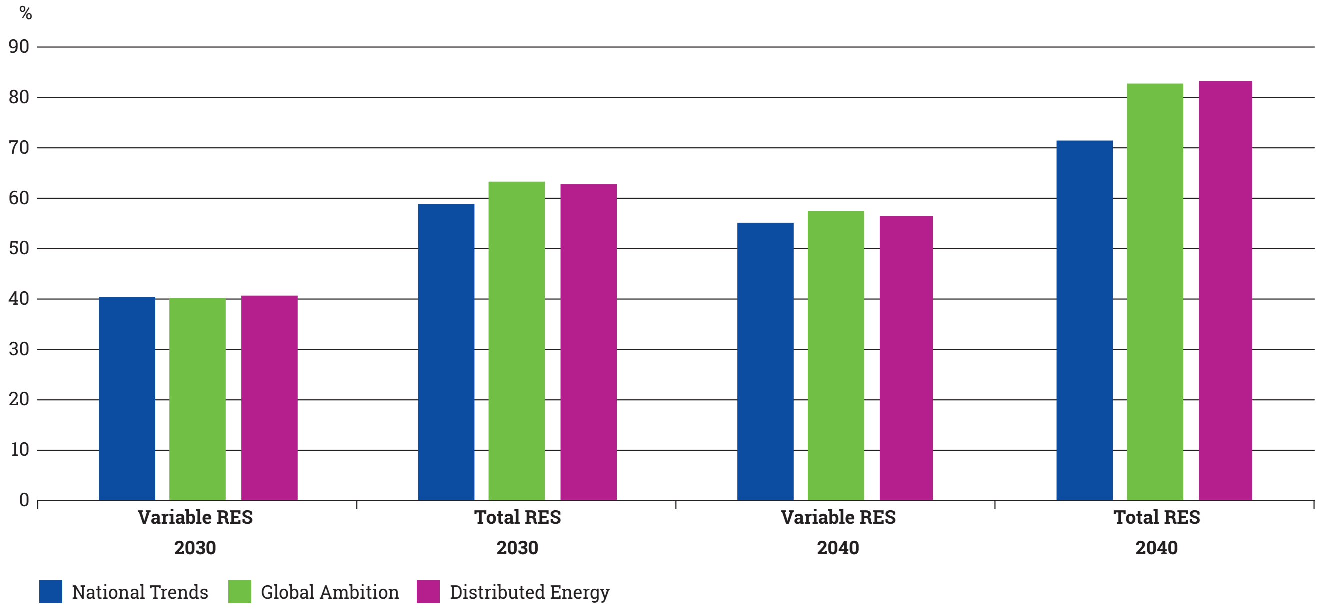


Figure 16: Percentage share of electricity demand covered by RES

There is an increase in renewable capacity foreseen in all scenarios…
… but the speed of the uptake is contingent on the storyline associated with each scenario.

Distributed Energy is the scenario with the highest investment in generation capacity, driven mainly by the highest level of electrical demand. Distributed Energy mainly focuses on the development of Solar PV, this technology has the lowest load factor, as result Solar PV installed capacity will be higher compared to offshore or onshore wind, to meet the same energy requirement. The scenario shows a larger growth in Onshore Wind after 2030.

In 2030, 13 % of electricity is produced from Solar and 28 % from wind, 41 % in total. In 2040 17 % of the electricity is generated from solar and 41 % from wind 58 % in total. The scenario also sees the least amount of electricity produced from nuclear out of the three scenarios, providing 15 % of electricity in 2030 and 9 % in 2040.

Global Ambition has a lower electricity demand, with a general trend of higher nuclear and reduced prices for offshore wind. Consequently, the capacity required for this scenario is the lowest as more energy is produced per MW of installed capacity in offshore wind, and nuclear is used as base load technology providing 18 % of energy in 2030 and reducing to 10 % in 2040. In 2030, 10 % of electricity is produced from Solar and 30 % from wind, 40 % in total. In 2040 12 % of the electricity is generated from solar and 44 % from wind 56 % in total.

National Trends is the policy-based scenario. The variable renewable generation is somewhere between the two top down scenarios. In 2030, 12 % of electricity is produced from Solar and 29 % from wind, 41 % in total. In 2040 14 % of the electricity is generated from solar and 41 % from wind 55 % in total. A lot of electricity is still produced from nuclear in 2030 20 % reducing to 12.5 % in 2040, this makes National Trends the scenario with the highest nuclear production in all timeframes.

Shares of coal for electricity generation decrease across all scenarios. This is due to national policies on coal phase-out, such as stated by UK and Italy or planned by Germany. Coal generation moves from 10 % in 2025, to 4 % - 6 % in 2030 and negligible amounts in 2040 which represents an almost complete phase out of coal.

Gas, however, has a share of 22 % in 2025, which reduces in 2030 to a range of 12 % – 18 %, and finally a share of 9 % – 12 % in 2040. It is important to note that the level of decarbonised and renewable gases in the gas mix, increases to 13 % in 2030 and 54 % in 2040. Distributed Energy starts to show a need for CCS in 2040, which will lead to negative emissions in plants burning biomethane.

Considerations on Other Non-Renewables (mainly smaller scale CHPs) source are important for decarbonisation. As it stands, carbon-based fuels are still widely used in CHP plants throughout Europe. This includes oil, lignite, coal and gas. In order to follow the thermal phase-out storylines, oil, coal and lignite should be phased out by 2040 and replaced with cleaner energy sources. Gas will contribute to decarbonisation by increasing shares of renewable and decarbonised gas.

Other RES contains generation technologies such as marine, small biofuel and geothermal. The generation from this collection of technologies remains stable in all scenarios.

Generation from hydro increases in 2030 due to an increase in capacity from 145 GW in 2025 to 174 GW in 2030, but remains stable after 2030. As hydro potential is determined by very specific conditions, therefore bottom up data is used for all scenarios.

The scenarios include repowering of renewable generation technologies from 2025 until 2040 with higher full load hours.

Thermal capacities are reduced, not only due to national phase-out policies, but the fact that some generation units will no longer be economically viable due to reduced running hours or will reach the end of their lifetime.

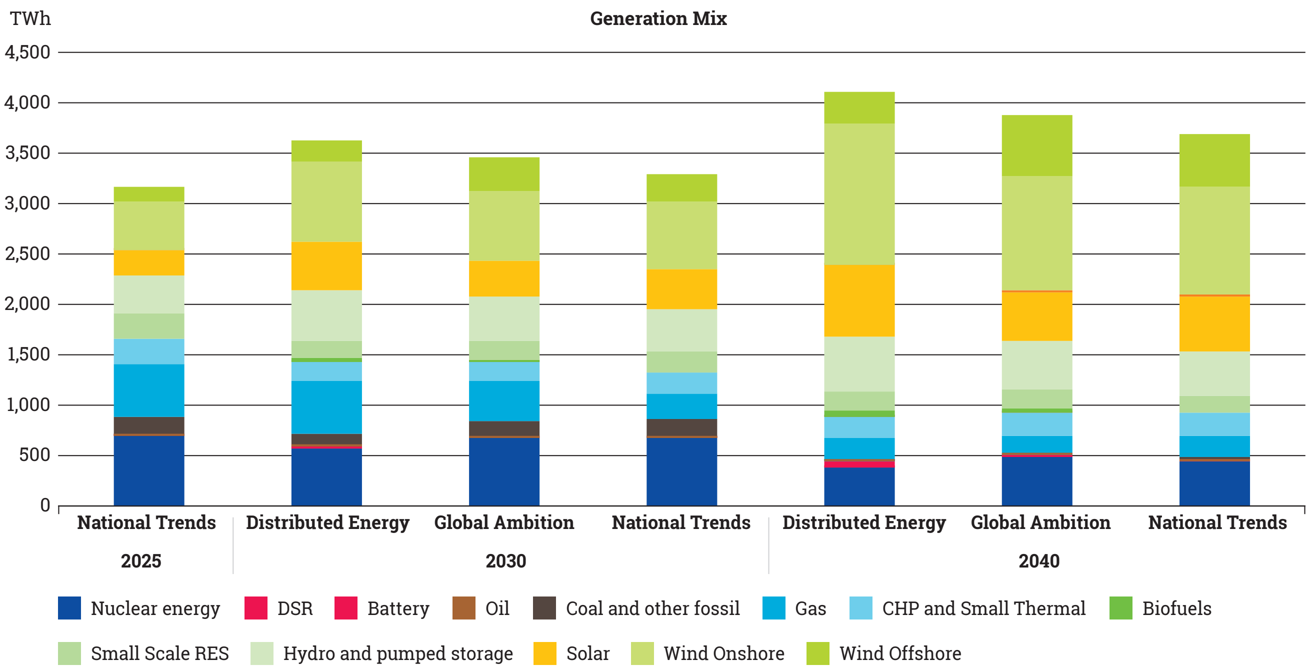


Figure 17: Electricity generation mix (TWh)

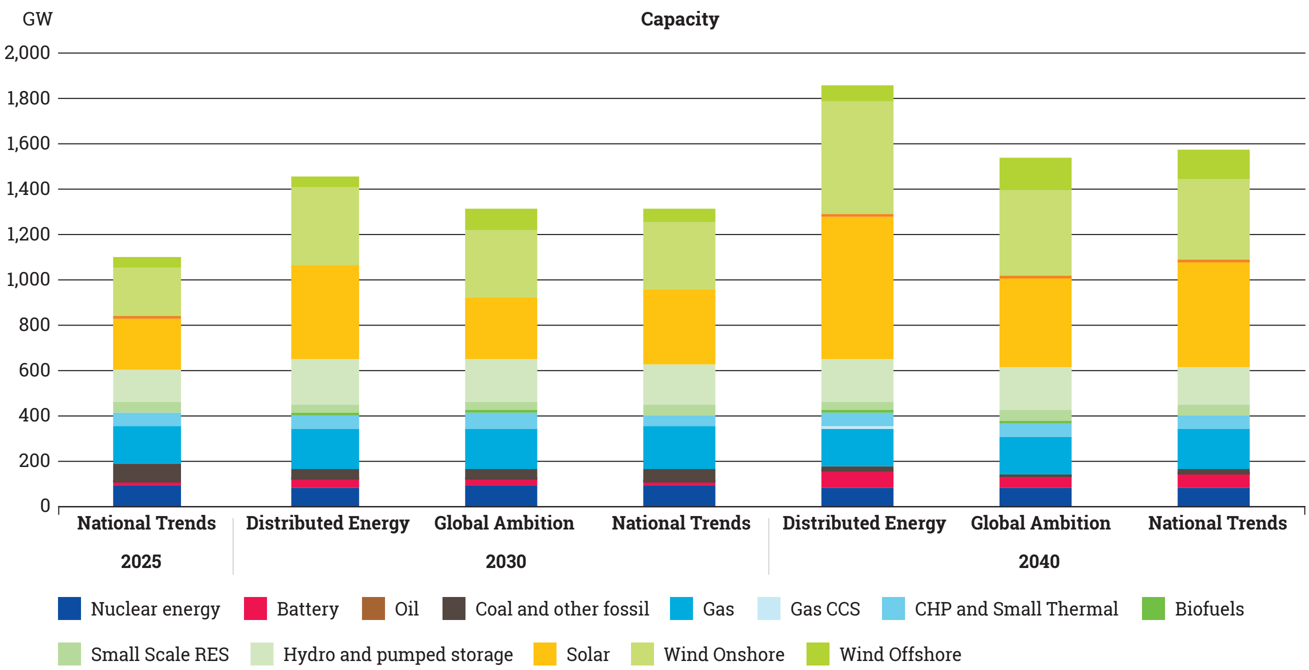


Figure 18: Electricity capacity mix (GW)

The scenarios show that there is potential for demand side technologies and batteries to take part in the market and help to smoothen demand peaks and level prices. Whilst the energy from these technologies may be low, it shows potential to reduce generation from carbon based peaking units, supporting decarbonisation, contributing towards system adequacy at lower costs and helping to integrate increasing variable renewables.

Distributed Energy shows the highest increase in usage of these technologies in 2030, whilst the other scenarios show relatively moderate to low usage. Distributed Energy shows more use of demand side resources as the cost of residential solar and battery systems are discounted. In 2040, there is a much larger increase in use of battery technologies in all scenarios, the most noticeable are Distributed Energy and National Trends.

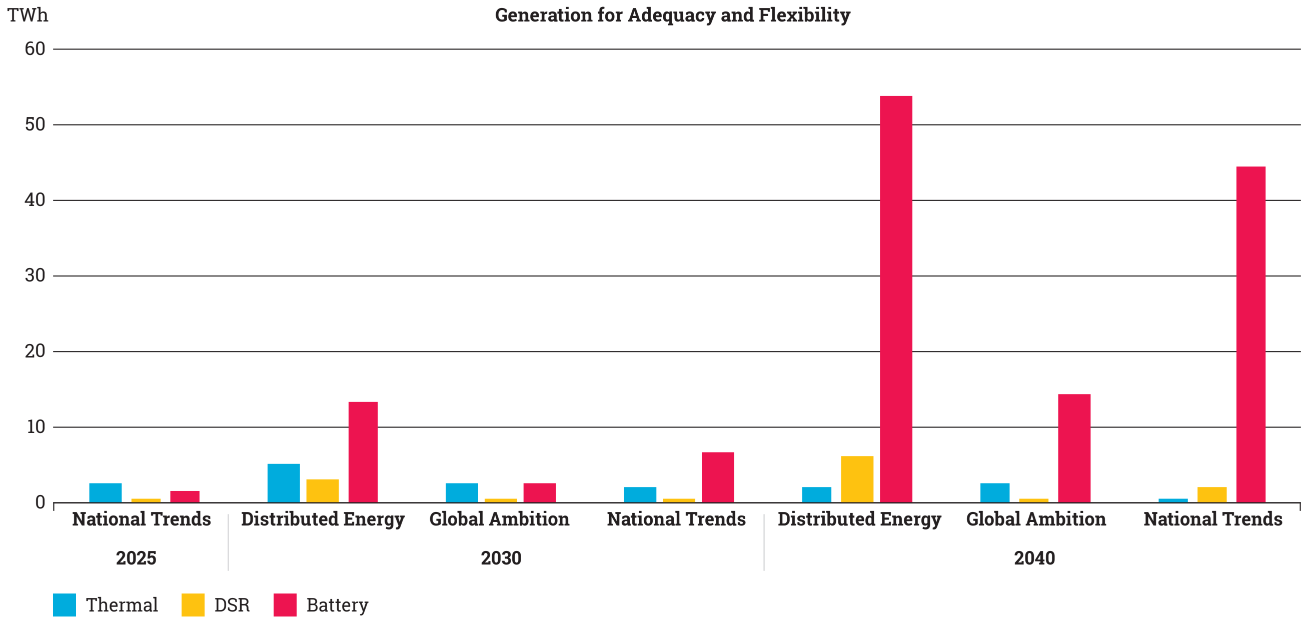


Figure 19: Peak load, demand side response & battery technology (TWh)

5.2.3 Gas

5.2.3.1 Gas supply potentials

Indigenous production: contrasted views captured by the COP 21 scenarios

All scenarios consider a similar decrease of the conventional indigenous production. However, the assumptions on the indigenous renewable gas generation, such as biomethane and P2G differ across the scenarios:

- 2020 and 2025 rely on Best Estimates from the TSOs. Due to the decreasing domestic conventional gas production and rather stable gas demand, gas imports will increase.

- National Trends relies on bottom-up data for the indigenious production for natural gas (including unconventional gas, such as shale gas) and biomethane. Additionaly, P2G is added assuming that curtailed electricity will be used to produce hydrogen and synthetic methane.

- Distributed Energy considers a significant uptake of decentralised renewable gas generation to account for 65 % of the EU gas consumption in 2050. Considering a gradually decreasing gas demand after 2025, gas imports decrease by 70 % compared to today's level.

- Global Ambition scenario considers the uptake of renewable gas generation capacities to a lesser extent with a more import oriented vision and large scale decarbonisation. Imports represent 70 % of the EU gas consumption in 2050. Considering a gradually decreasing gas demand after 2025, gas imports decrease by 30 % compared to today's level.

The contrasted approach towards the supply configurations is essential when assessing the infrastructure for the next twenty years since it directly impacts the way the European gas system is used.

Enough gas potential to satisfy the EU demand until 2050

All scenarios consider a maximum utilisation of indigenous production in the European gas supply mix until 2050. The supply potential assessment run by ENTSOG and discussed with stakeholders in July 2019[10] concludes that for all scenarios, the import potentials are high enough to ensure the supply and demand adequacy of the EU until 2050. This is despite the decline of the conventional indigenous production. In this regard, it can be highlighted that the Dutch Government has decided to stop production at Groningen, Europe's largest onshore natural gas field, by 2022. Additionally, the supply mix will be further diversified with new sources looking towards 2050.

Furthermore, whilst Norwegian supply is produced in Europe, it is considered as an import source to the EU since Norway is not a Member of the European Union.

The import supply mix will be dominated by gas from Russia, Norway and LNG.

Even though the supply mix will be diversified, the import supply mix will still be dominated by the current three largest supply sources: Russia, Norway and liquefied natural gas (LNG). These sources will be dependent on market prices, and the supply chain's adaptation of the growing demand for decarbonised gases.

Figures 20, 21 and 22 highlight the adequacy of scenario specific gas demand and supply. Supply is split into three categories:

- Total EU indigenous Production covers all domestic production of conventional natural gas, biomethane and P2G for both hydrogen and methane.

- Minimum Extra-EU Supply Potentials: minimum gas imports based on long-term contracts and their assumed prolongation

- Additional Supply Potential: additional gas imports options which will be used based on arbitrage

All scenarios show enough supply potentials to meet the future demand.

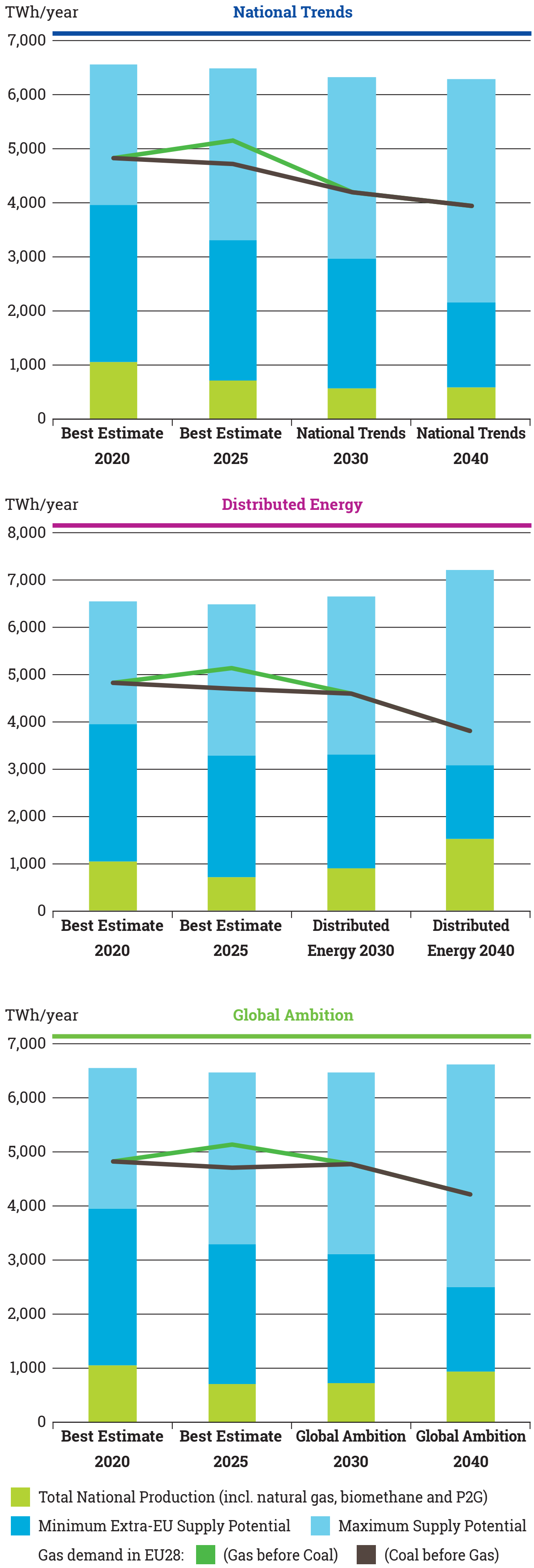


Figure 20–22: National Trends, Distributed Energy, Global Ambition

10 https://www.entsog.eu/entsog-workshop-supply-potentials-and-market-related-assumptions-tyndp-2020

5.2.3.2 Gas supply composition

A technology neutral approach

The decarbonisation of the gas supply can be done in many ways. Gas can either be produced from renewable energy such as biomethane or hydrogen from P2G, but it can also be decarbonised from conventional natural gas with different technologies such as steam methane reforming (associated with carbon capture and sequestration process) or pyrolysis.

Each technology comes with its level of decarbonisation that is considered in the computation of the GHG emissions of each scenario to keep track of their carbon budget expenses. For instance, biomethane can be considered as carbon neutral or carbon negative if associated with CCS (therefore included in Bio-Energy Carbon Capture and Sequestration (BECCS) category). However, CCS processes come with efficiency factors to account for the part of the CO_2 that cannot be captured in the process and that is therefore released in the atmosphere.

In order to capture all possible impacts of the development of one or another technology, the scenarios come with contrasted assumptions regarding the penetration of renewable or decarbonised gases in the supply mix of the EU.

A source neutral approach

TYNDP 2020 scenarios consider contrasted possible developments of the gas demand including different gas qualities. The ENTSOs have improved their methodology and introduced a more detailed breakdown of the gas demand between methane and hydrogen.

However, there are different technological ways both these demands can be satisfied. Methane and hydrogen demands can of course primarily be satisfied respectively by methane and hydrogen production. On one hand, depending on the penetration of the different generation technologies, methane can be decarbonised to generate hydrogen and therefore satisfy the hydrogen demand. On the other hand, hydrogen can be methanised to create methane and therefore satisfy the methane demand. It should be noted that any conversion process comes with an efficiency factor considered when building the scenarios.

In line with the neutral approach of ENTSOG towards the infrastructure submitted to TYNDP, the scenarios are technology neutral. Therefore, unless a piece of infrastructure is actually commissioned no choice is made by ENTSOG and the scenarios do not pre-empt the location of the conversion of the gas supply to satisfy the demand. The conversion could therefore be centralised at transmission level or be decentralised at city/consumer gate.

5.2.3.2.1 National Trends

The gas supply mix considered in National Trends reflects the current European targets and respective Member States' draft NECPs. The level of information regarding the gas supply mix can be very different depending on how the targets are set in the draft NECPs. Thus, due to lack of consistency between the draft NECPs, the gas supply mix for National Trends is not split into different gas qualities. In any case, based on information available for demand and national production, National Trends shows an increasing import dependency for gas, peaking in 2030 with 4,300 TWh and then decreasing down to 3,000 TWh in 2040 (500 TWh below 2015). imports).

5.2.3.2.2 Distributed Energy Scenario

As a decentralised scenario, Distributed Energy considers a high level of indigenous production of renewable gas. Imports are reduced by 70 % between 2020 and 2050, accounting for 2,000 TWh in 2040, and 1,100 TWh in 2050. The level of imports is the lowest of all the scenarios. Thus, reaching carbon neutrality by 2050 means that the remaining imports, whether renewable or to be decarbonised is limited to 1,100 TWh of the gas supply. However, aiming for decarbonisation requires a significant increase in renewable electricity generation to meet the P2G demand.

5.2.3.2.3 Global Ambition Scenario

As a centralised scenario, Global Ambition considers a higher level of total imports for energy, with a 30 % decrease of the gas imports by 2050 compared to current levels (−1,100 TWh). The increasing imports, up to 4,000 TWh in 2030, compensate for the decline of the conventional indigenous production. To reach carbon neutrality in 2050, the gas imports to be decarbonised or renewable by then must be of a larger scale than in Distributed Energy (2,700 TWh/y).

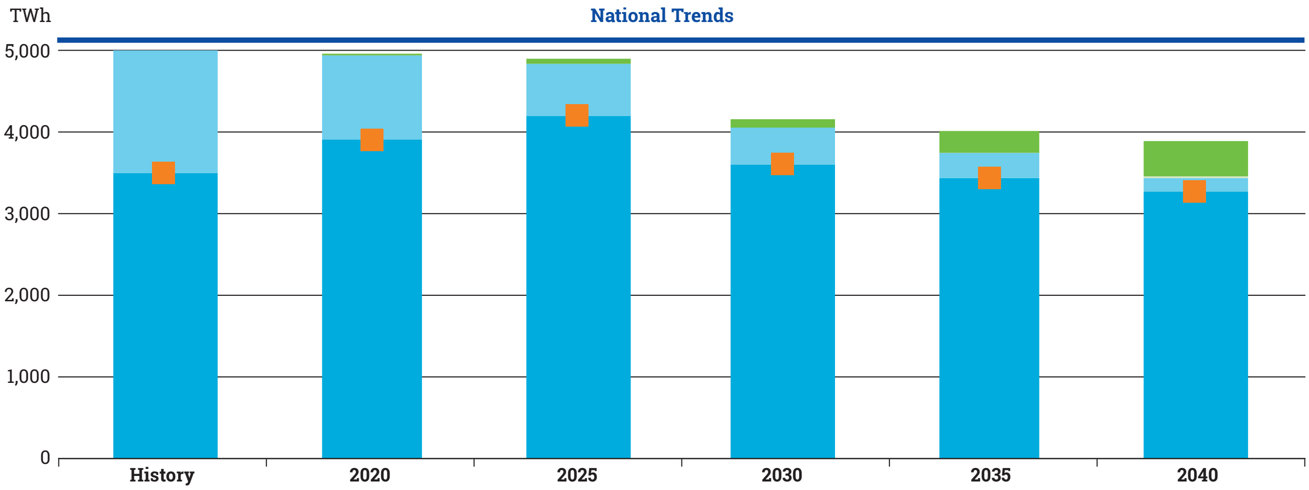


Figure 23: Gas source composition: National Trends

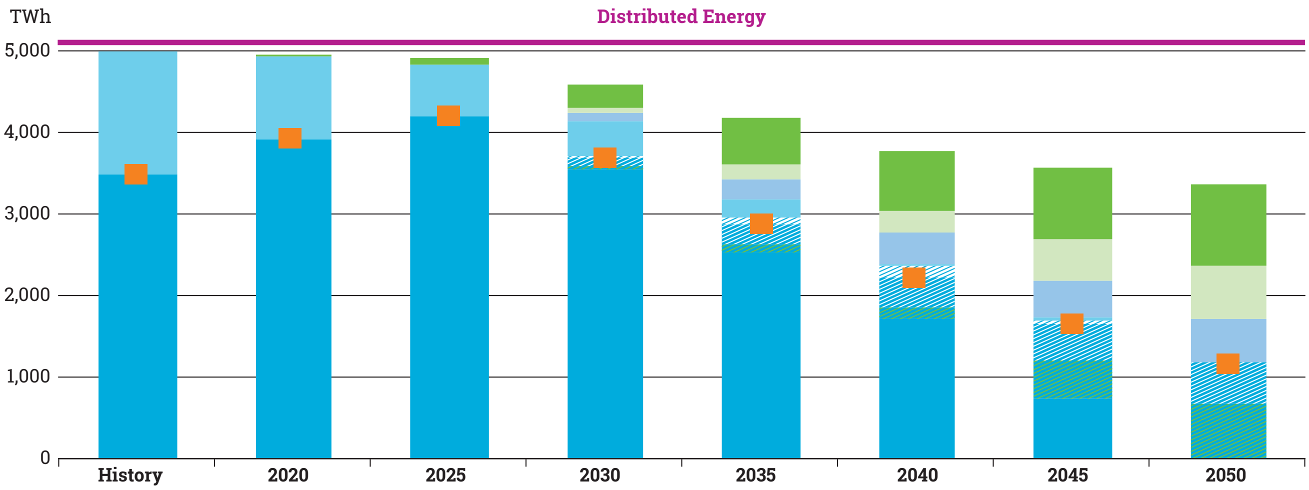


Figure 24: Gas source composition: Distributed Energy

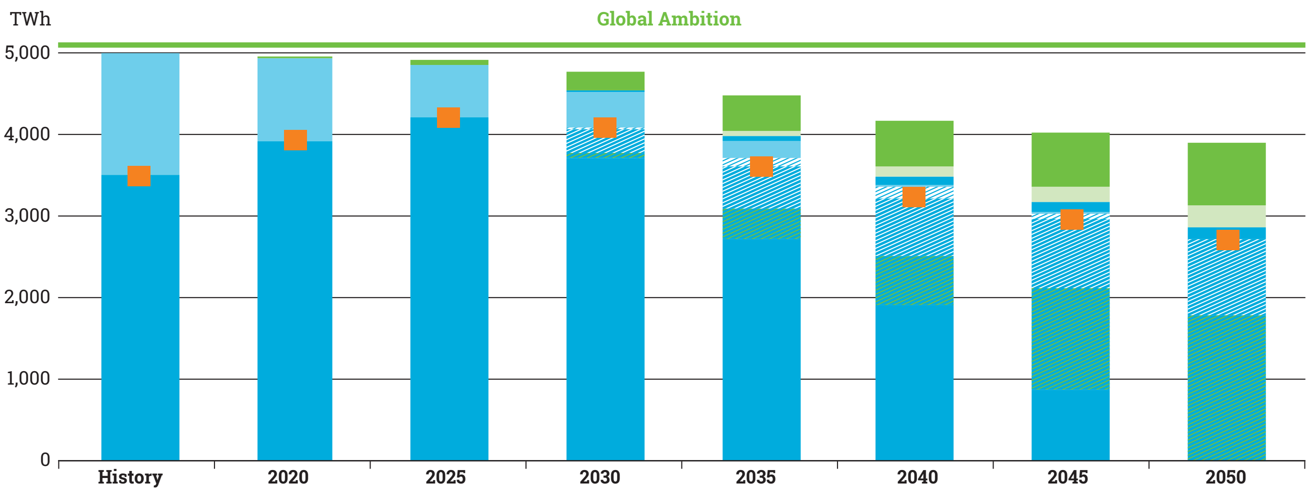


Figure 25: Gas source composition: Global Ambition

Imported Natural Gas: Unabated
Indigenous Natural Gas: Unabated, Abated
Power-to-Hydrogen
Power-to-Methane
Biomethane
Imports (incl. Norway)
Imports for Methane Demand*
Imports for Hydrogen Demand**

*decarbonised, either by natural gas imports with post-combustive CCU/s or any other technology
**natural gas converted to hydrogen at import point/city gate or direct hydrogen imports

5.3 Sector Coupling: Capacity and Generation for P2G

Distributed Energy has a significantly higher demand for EU produced hydrogen and synthetic methane than Global Ambition in 2030 and 2040. The Distributed Energy storyline assumes a reduction by 70 % of gas imports by 2050 (from 4,000 TWh in 2020 down to 1,200 TWh in 2050) combined with the decarbonisation of the gas supply.

Distributed Energy and Global Ambition have a specific demand for domestically produced hydrogen. In these scenarios, power to gas plants are operated outside the energy markets, using dedicated renewables, but the curtailed electricity from the market is used to feed these power-to-gas plants. National Trends does not have a specific top down demand for hydrogen, therefore the Power to Gas plants are built solely based on curtailed renewables.

In the COP21 scenarios, the main source used for electrolysis is offshore wind, but where regional constraints exist, onshore wind and solar PV will be the alternative. The generation profiles match the capacities build. There is more RES capacity in Distributed Energy 2040 therefore it is natural that there is more curtailed energy in this scenario.

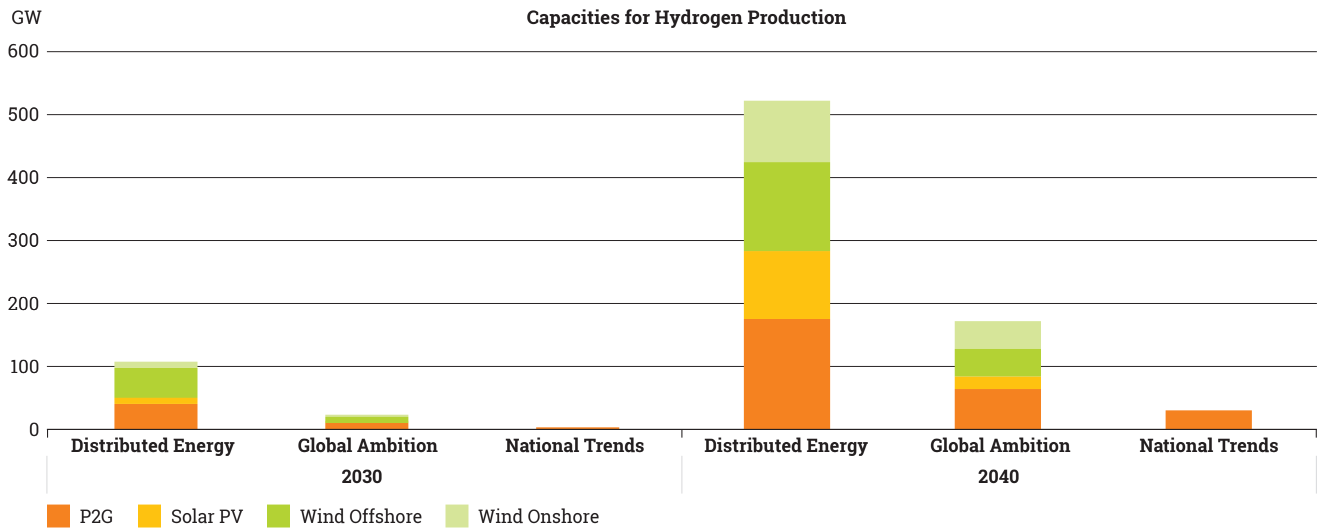


Figure 26: Capacities for Hydrogen Production

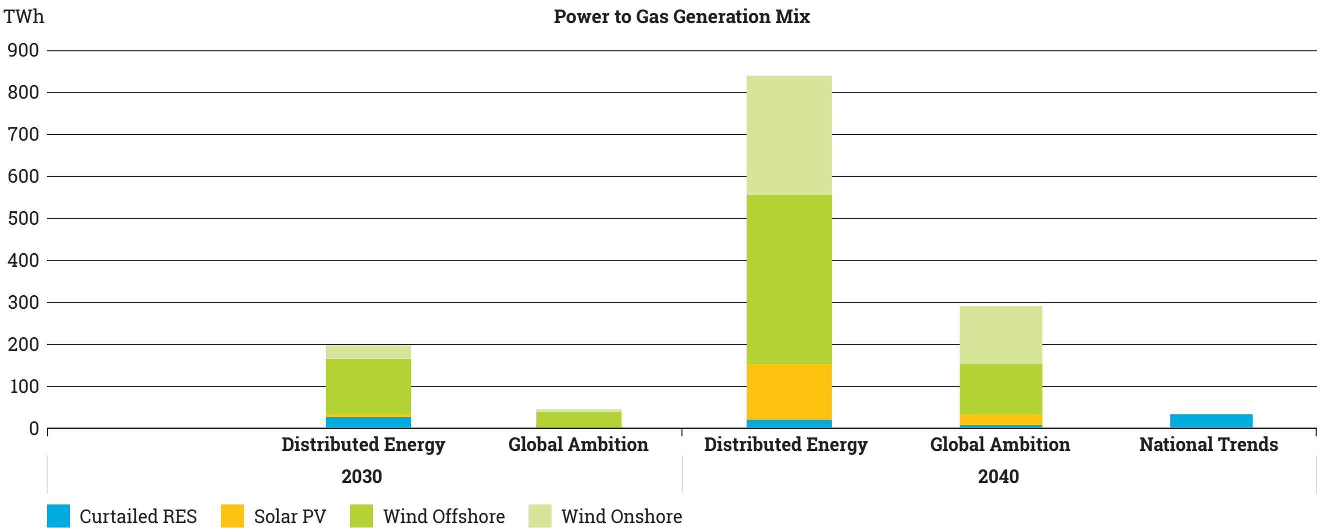


Figure 27: Power to Gas Generation Mix

5.4 Reduction in overall EU28 CO_2 emissions and necessary measures

Following the EU's long-term goal, National Trend is treated to reach 80 % to 95 % decarbonisation by 2050. Although the commonly agreed target for 2030 is 40 % GHG emission reduction, the latest adoptions to the 2030 climate and energy framework (32,5 % improvement in energy efficiency, 32 % share for renewable energy) will consequently result in higher GHG emissions reductions. This is also shown by the European Commission's Long-term Strategy Scenarios. On the other hand, the COP21 scenarios go for carbon neutrality by 2050, as suggested by the latest IPCC Special Report[11] and targeted by the European Commission.

As mentioned in Section 5.2.1, both COP21 Scenarios show a significant decrease in primary energy demand with increasing shares of renewables, mainly biomass and variable sources (both for direct use and P2G production). Whereas electricity generation has already faced some level of transition, other carriers such as gas need to follow. ENTSOs' scenario building exercise shows that to decarbonise all sectors as well as all fuel types, additional measures such as CCU/S, also in combination with bioenergy, are needed. Full decarbonisation also needs the contribution of non-energy related sectors, such as the decarbonisation of agriculture/meat production and further afforestation. It should be noted, that for GHG emissions related to non-CO_2 emissions (e. g. methane emissions) and LULUFC, ENTSOs' scenarios rely on the average given by the 1.5TECH and 1.5LIFE scenarios of the European Commission's Long-term Strategy.

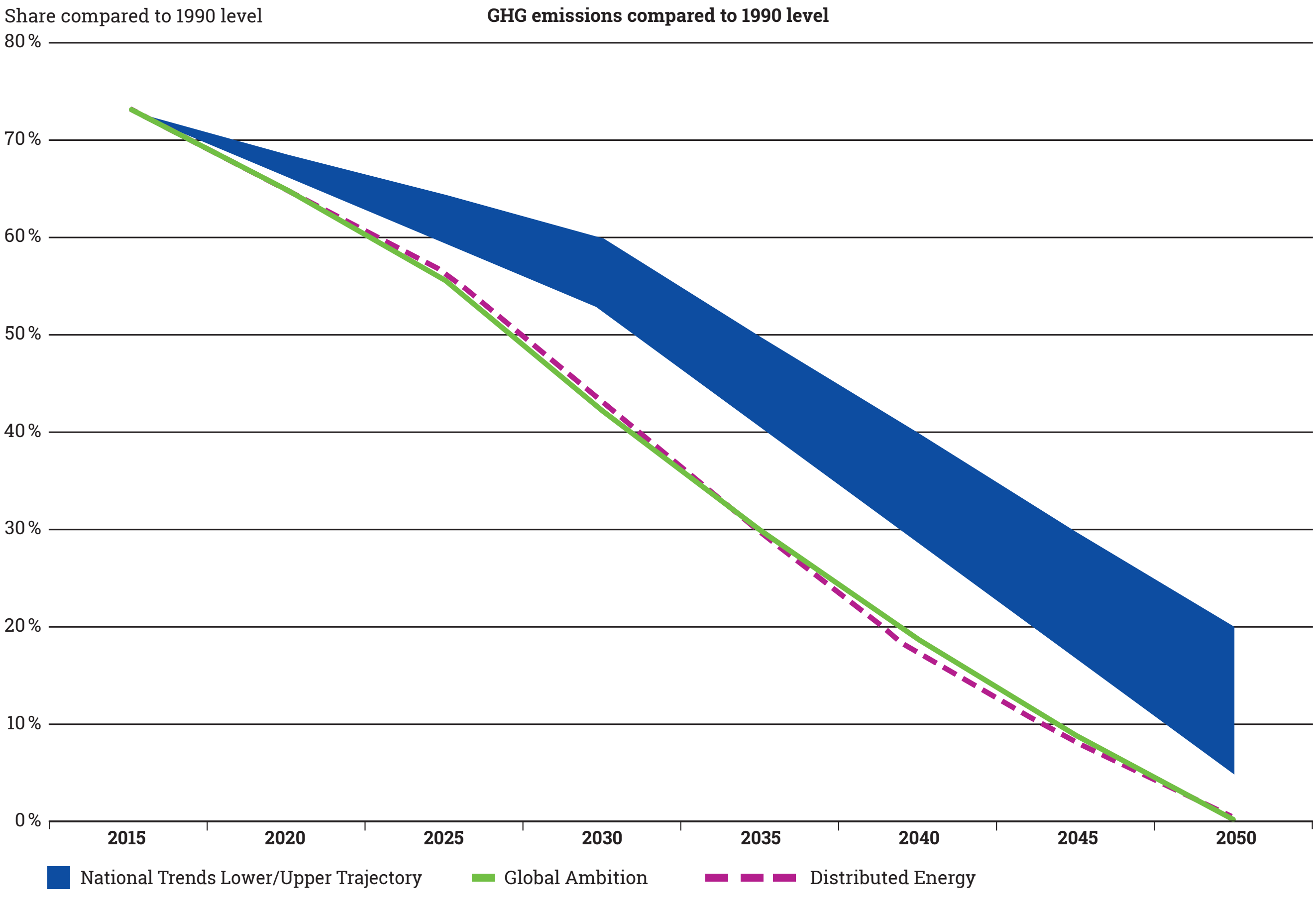


Figure 28: GHG emissions reduction pathways until 2050

11 IPCC special report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, Intergovernmental Panel on Climate Change, 2018

Electricity Generation

In 2030 the electricity sector produces emissions of between 393 and 414 $MtCO_2$, a reduction of around 75 % as compared to 1990. In the COP21 Scenarios, the electricity mix becomes carbon neutral by 2040 with emissions of 46 $MtCO_2$ in Distributed Energy and 40 $MtCO_2$ in Global Ambition. In this case both scenarios have the gas before coal merit order, but as the demand is higher in Distributed Energy, there is more consumption of both gas and coal.

However, to meet the ambitious targets for electricity generation, fuel input into small scale CHP, mainly gas, needs to be 90 % decarbonised. Moreover, in Distributed Energy also CCU/S needs to be applied to CCGTs by 2040. National Trends sees emissions of 182 $MtCO_2$, on target with the 2° C scenarios shown in the Long-term Strategy from the European Commission.

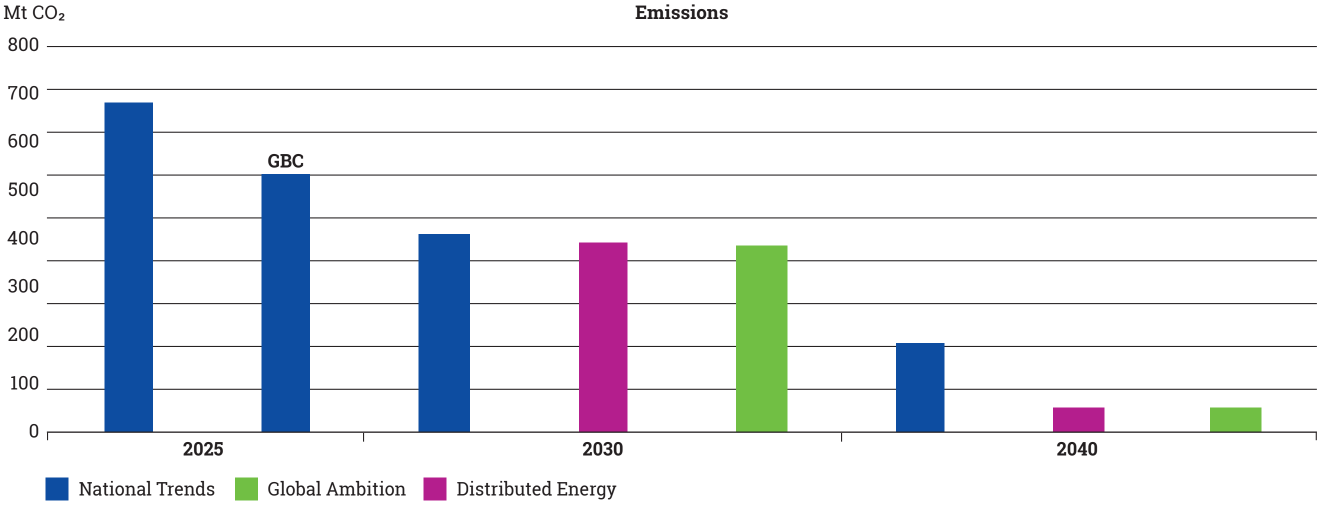


Figure 29: CO_2 emissions in the Electricity Generation

Gas supply

Gas as an energy carrier with increasing shares of renewable and decarbonised gases plays a key role in the decarbonisation of the economy. Biomethane and renewable gases produced via P2G do not have CO_2 emissions, but if CCU/S (post-combustive or during the production of biomethane) is applied their consumption can even lead to negative emissions. Apart from indigenously produced renewable gases, also the consumed natural gas needs to be decarbonised with carbon capture technologies, either pre-combustive in combination with steam methane reforming or methane pyrolysis, or post-combustive in large-scale industrial sites or power plants. However, post-combustive CCS may mostly be applied to large scale process such as industrial sites or power plants and its carbon capture rate is usually around 90 %.

In Distributed Energy in 2050, 65 % of the gas will be renewable, but for the other 35 % need to be decarbonised with carbon capture technologies: in 2050, to be carbon-neutral, 90 $MtCO_2$ need to be captured during the conversion of natural gas into hydrogen and additionally 50 $MtCO_2$ need to be removed post-combustive at industrial sites.

Figure 30 shows the emissions related to the consumption of gases and the average carbon intensity (in $kgCO_2$/kWh) of the gas mix in Distributed Energy. Due to above mentioned restrictions for post-combustive CCS, the CO_2 intensity of the gas mix decreases by 87 % in Distributed Energy by 2050 compared to conventional natural gas.

Due to higher imports, Global Ambition sees a broader need for CCU/S to decarbonise the gas mix to reach carbon neutrality. If natural gas is used as a feedstock to produce the needed hydrogen, 170 $MtCO_2$ need to be captured and stored or used. Additionally, 170 $MtCO_2$ need to be removed post-combustive. Furthermore, 150 $MtCO_2$ needs to be captured from bioenergy, which allows for negative emissions. The CO_2 intensity of gas decreases by 80 % in Global Ambition in 2050 compared to conventional natural gas.

In this context the ENTSOs' assumptions on the need and application of CCS are guided by the European Commission's Long-term Strategy and its most ambitious 1.5° C scenarios: 1.5LIFE and 1.5TECH see the necessity of 281 to 606 $MtCO_2$ captured.

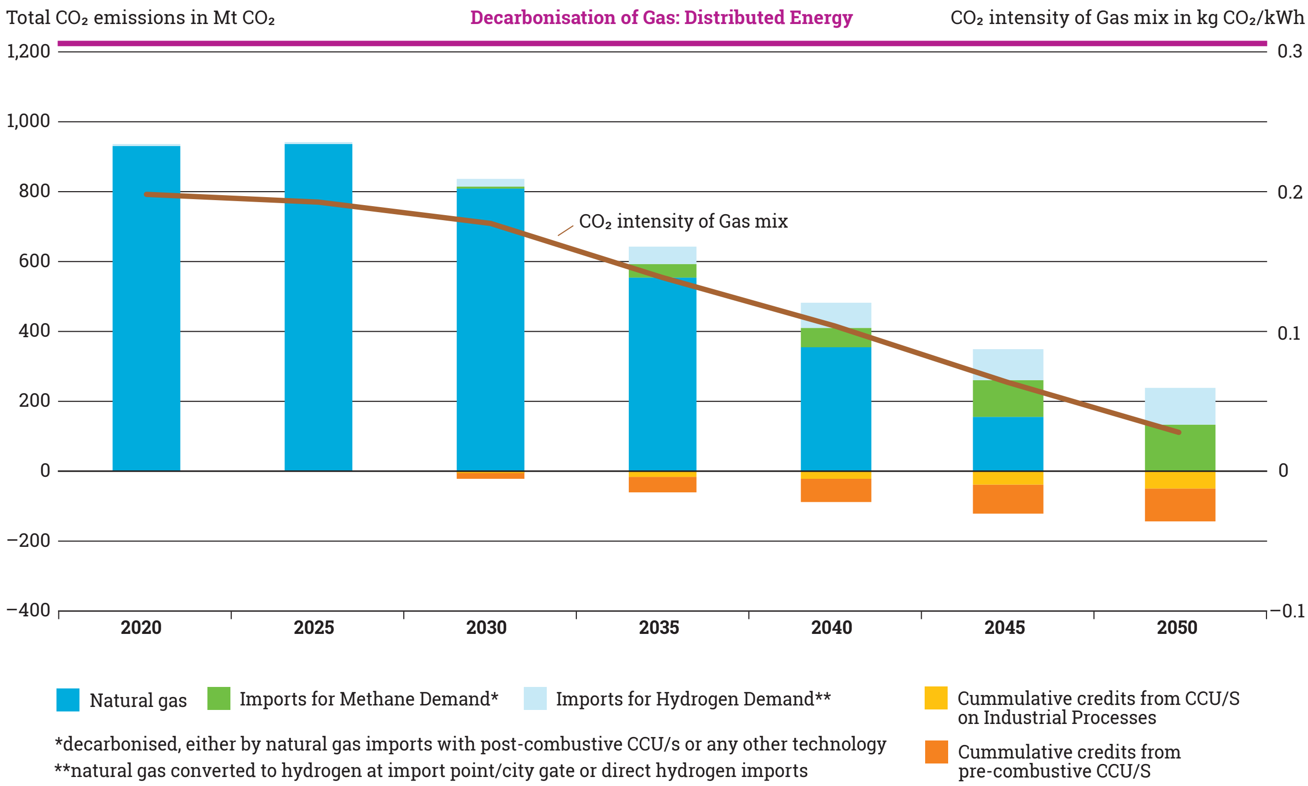


Figure 30: Decarbonisation path of gas in Distributed Energy

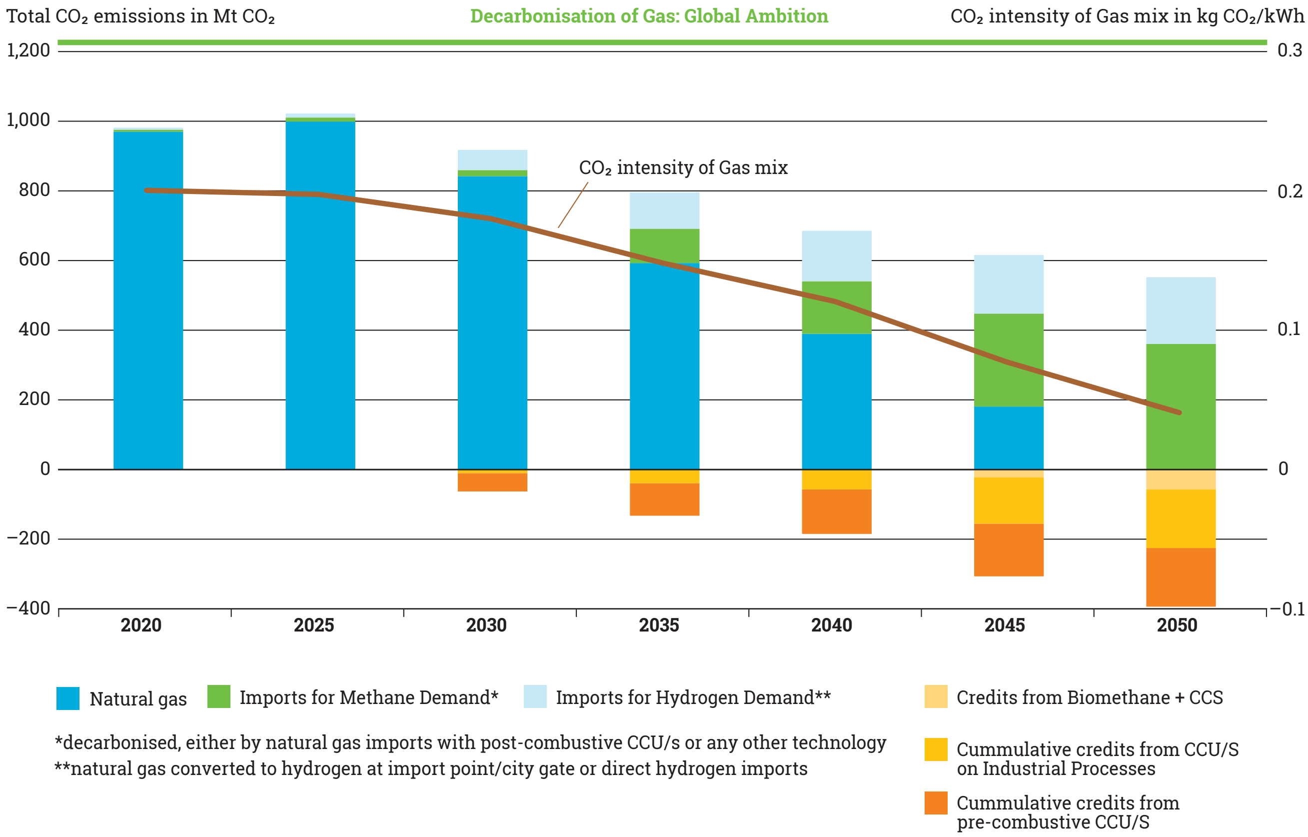


Figure 31: Decarbonisation path of gas in Global Ambition

6 Electricity Costs

The CO_2 price and electricity demand directly affect the marginal cost of the scenarios. Distributed Energy has the highest CO_2 price and electricity demand in both time-frames, therefore the marginal cost is the highest. The cost assumptions of wind and solar also influence the CO_2 price having an effect on the Levelized cost of electricity in each market node, and the electricity marginal costs of the scenarios.

Levelised cost of electricity

Across all the scenarios new capacity for electricity generation comes mainly from wind and solar power. Global trends show that incentives, innovation, and investment have matured the solar and wind industry; their levelised costs of electricity (LCOE) is significantly lower compared to other low carbon generation technologies, such as tidal or CCGTs with CCS.

Decisions on what technology to build in an electricity market investment modelling exercise are driven by the achieved electricity market price, i.e. the weighted average price from hours when the wind/solar generator is producing, which is impacted by general supply/demand situations and the amount of previously installed capacity of the same technology. Furthermore, the cost and availability of flexibilities such as interconnection or storage, such as P2X and batteries, impact the investment decisions, since higher amounts of storage may improve the achieved price for variable renewable technologies.

Global Ambition assumes very strong cost reductions for offshore wind, with offshore wind economically competitive to onshore wind and solar PV. Distributed Energy assumes strong reduction in solar PV costs. Wind onshore is generally competitive in both scenarios. Solar PV is generally most competitive in Southern Europe, whereas onshore wind is particularly competitive in Northern and Western Europe. For offshore wind, the lowest costs take place in North Sea and southern Baltic Sea regions.

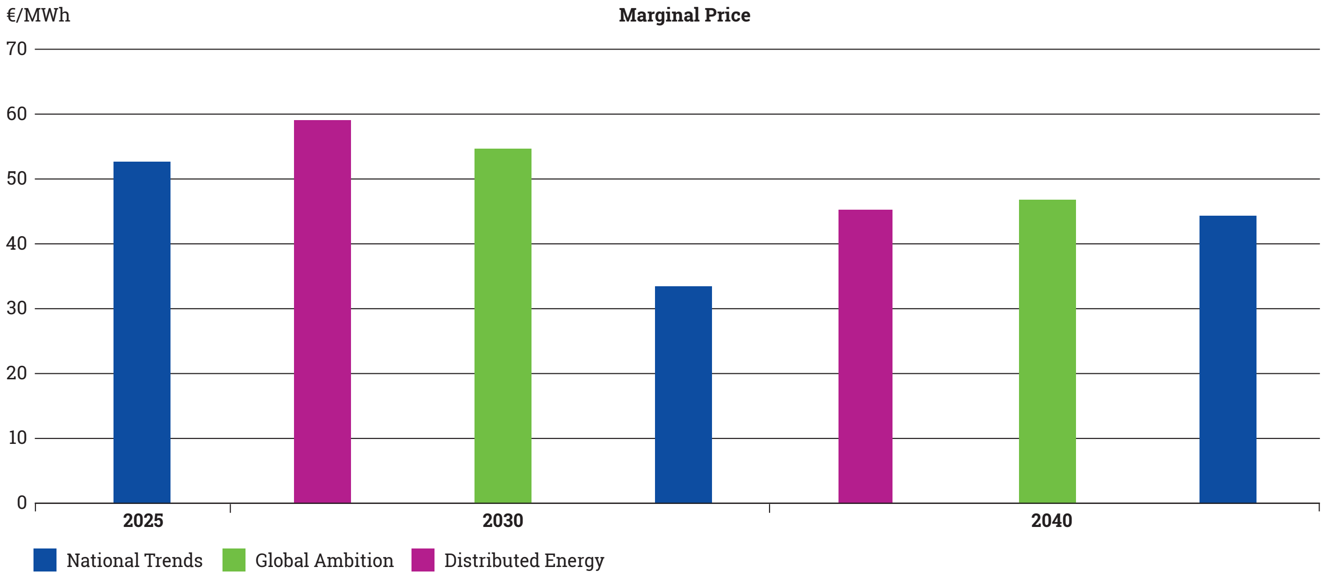


Figure 32: Marginal costs

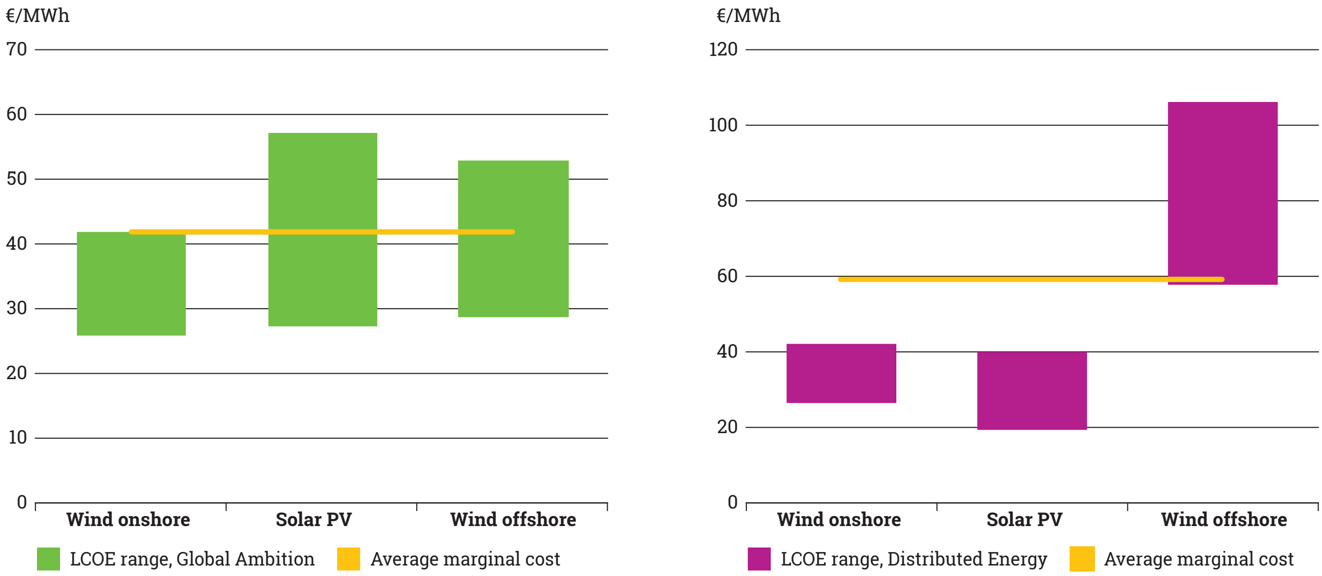


Figure 33: LCOE: Global Ambition 2040 and Distributed Energy 2040

7 Benchmarking

A literary review of relevant external studies is a best practice approach when undertaking a complex task such as developing scenario for the ENTSOs and EU28 perimeter. The purpose of the exercise is to understand whether or not the input assumptions and methodologies that ENTSOs employ result in credible and plausible outcomes compare to other expert opinions and methods.

As part of our internal quality process for scenario building, the ENTSOs have compared its TYNDP 2020 scenarios to the following relevant studies (but not limited to):

1. **TYNDP 2018 Scenarios (ENTSOs, 2018).**
2. **EU Reference Scenario: Energy, transport and GHG emissions – Trends to 2050 (EC, 2016).**
3. **EUCO3232.5 scenario (EC, 2019).**
4. **A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy (EC, 2018).**
5. **Decarbonization pathways (Eurelectric, 2018).**
6. **e-Highway2050 – Modular Development Plan of the Pan-European Transmission System 2050 / Europe's future secure and sustainable electricity infrastructure (eHighway, 2015).**
7. **World Energy Outlook 2018 (IEA, 2018).**
8. **Gas for Climate (Navigant, 2018).**

It is acknowledged that there are different approaches and purposes for each of the listed studies. The studies each have a view on the EU28 electricity and gas sectors. It is possible to create plausible ranges for scenario parameters such as, low to high ranges for demand; EV uptake, Heat Pump uptake; installed capacity for generation, low to high range gas for imports etc. In the following sections ENTSOs have focused their benchmarking on the overall electricity and gas demand, electrification and gas supply.

7.1 Final Electricity Demand

The highest final electricity demand corresponds to Distributed Energy, with the actual growth being due to the very strong increase in electric vehicles and heat pumps. The Global Ambition scenario has the lowest final electricity demand, due to the higher gas share. In the EU-28, total electricity generated from renewable energy sources covers about 61–64 % of electricity demand in 2030 and about 81–83 % in 2040. Variable renewable energies (wind and solar) play a key role in renewables expansion as their share of the electricity mix increases to 43-45 % by 2030 and to 62–65 % by 2040. Wind is the most important driver and generates about one third of the final electricity demand in 2030 and 45–50 % in 2040. Solar covers 10–15 % of the demand in 2030 and 13–20 % in 2040. The remaining share of renewable energies consists of biomass and hydropower.

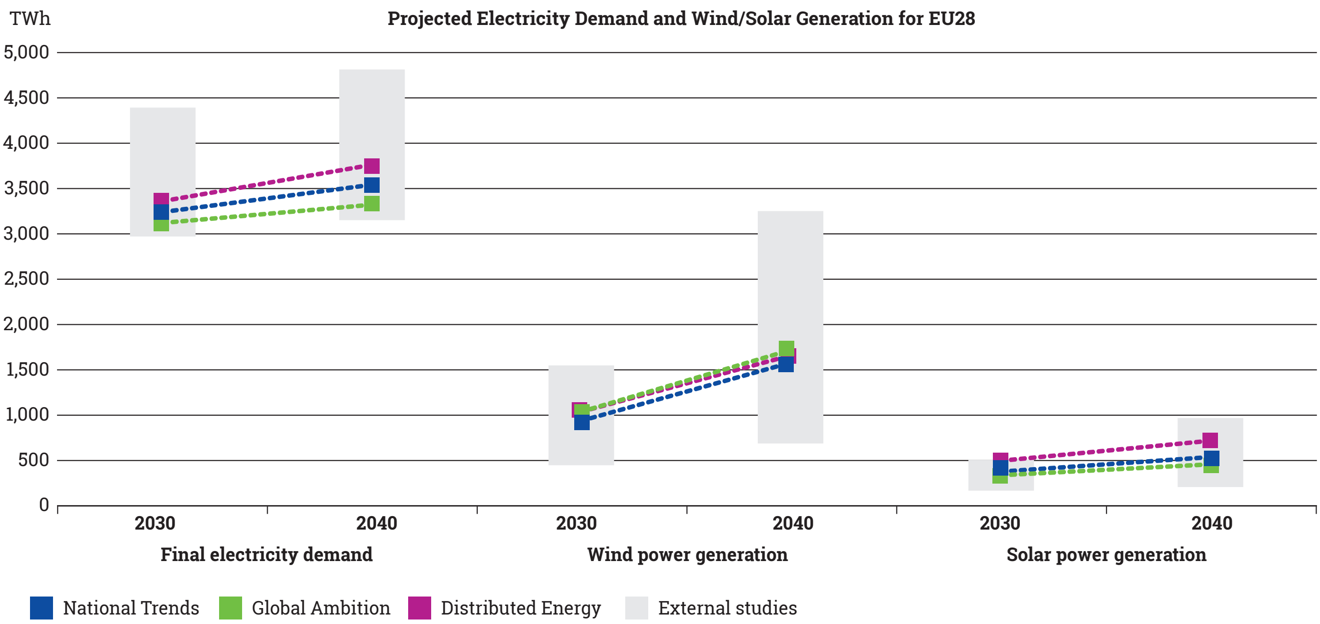


Figure 34: Benchmarking of projected electricity demand and wind/solar generation for EU28

Electrification rates

The final electricity energy demand divided by final energy demand indicates the direct electrification of different scenarios. The general increase in share illustrates that electrification is one key driver trying to achieve a sufficient decarbonization up to 2050. The electrification trajectories of the TYNDP 2020 scenarios are in between the upper and respectively lower benchmarking limits which are set by the of Eureletric Scenario 3 on the one hand and the EC reference case 2016 scenario on the other hand. As displayed for the year 2050, the Distributed Energy scenarios achieves roughly the same electrification rate as the EC 1.5 TECH scenario, which is close to 50 %. The Global Ambition scenario follows approximately the same electrification path as the EU LTS Baseline scenario and additionally Eurelectric Scenario 1, which accomplishes the goal of 80 % emission reduction up to 2050.

The sectorial breakdowns of the industry, residential and commercial sectors illustrate that the COP 21 scenarios are, with regard to electrification, in the order of magnitude compared to other external scenarios.

A similar statement can also be made to the transport sector for the mid-term horizon (2030 and 2040), where the electrification is in the ballpark of other external scenarios. For 2050, the transport electrification in the ENTSOs' COP 21 scenarios matches the EC's 1,5TECH scenario, but is lower compared to Eurelectric's scenarios.

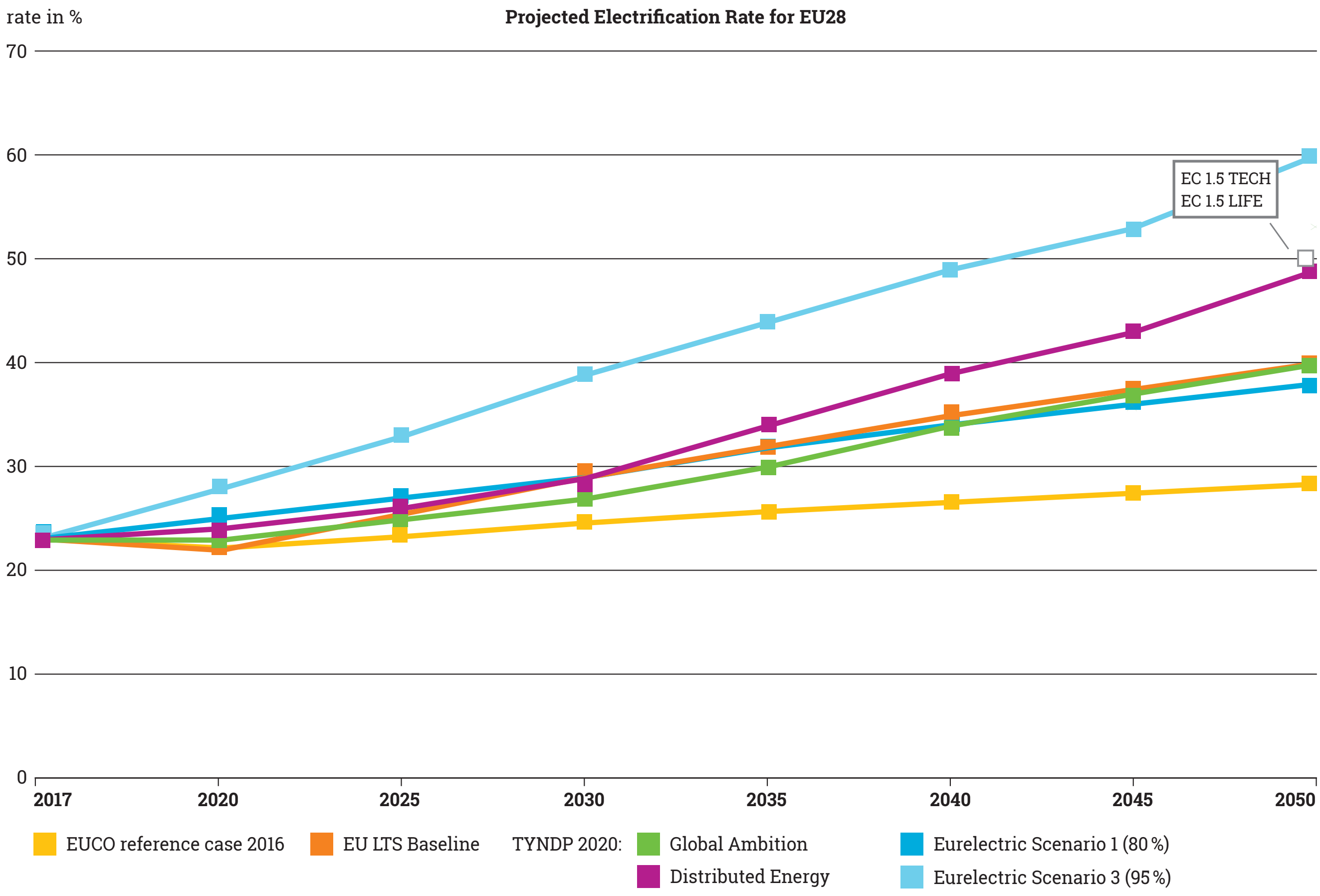


Figure 35: Benchmarking of projected electrification rate for EU28

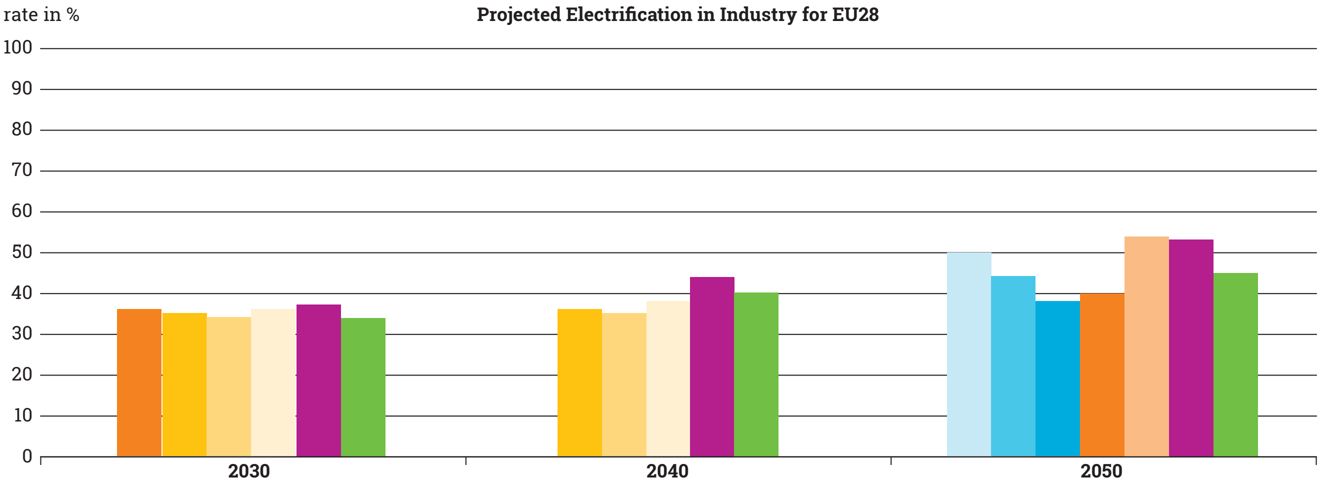


Figure 36: Benchmarking of projected electrification rate for EU28

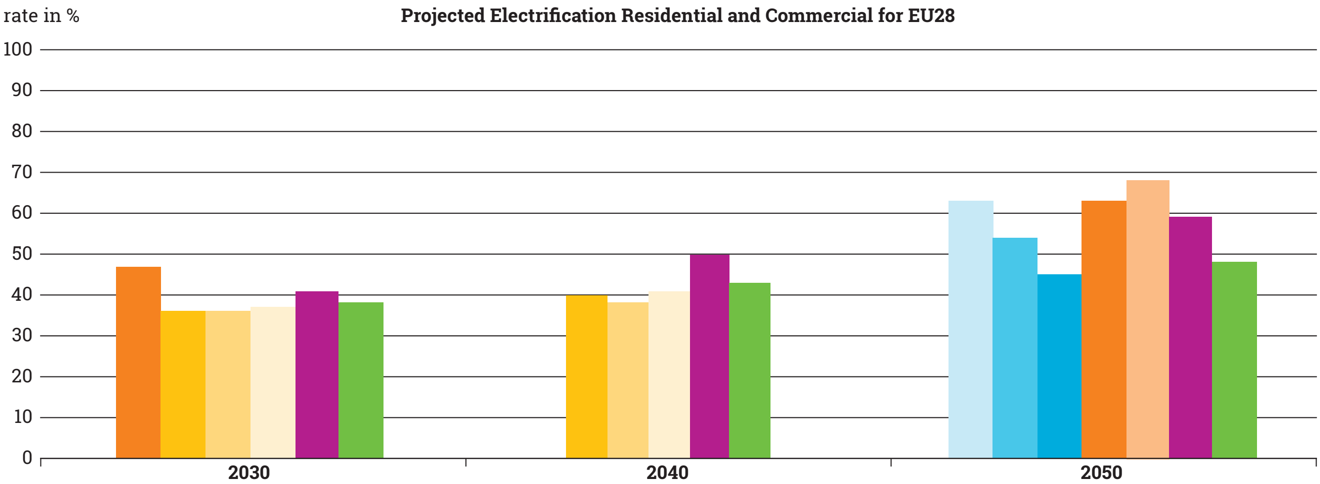


Figure 37: Benchmarking of projected electrification residential and commercial for EU28

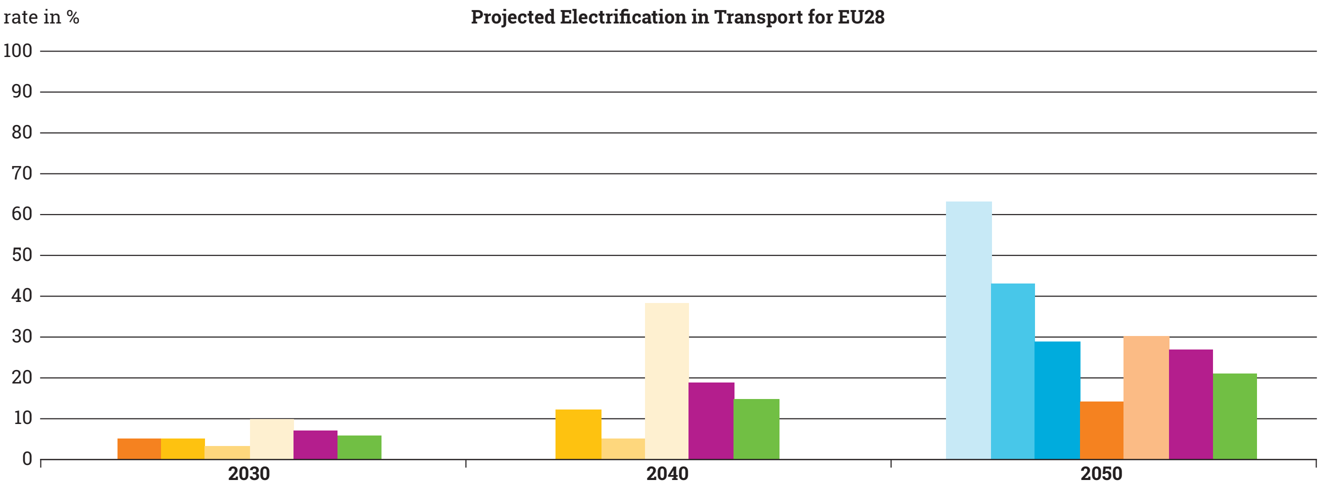


Figure 38: Benchmarking of projected electrification in transport for EU28

IEA WEO 2018_New Policies
IEA WEO 2018_Current Policies
IEA WEO 2019_Sustainable Development
EU LTS Baseline
EC LTS Baseline
TYNDP 2020: Global Ambition
Distributed Energy
Eurelectric Scenario 1 (80 %)
Eurelectric Scenario 2 (90 %)
Eurelectric Scenario 3 (95 %)

7.2 Gas demand

Although ENTSOs scenarios follow their specific assumptions and methodologies , they are designed to meet the same EU climate objectives as other external scenarios.

ENTSOs scenarios in the range of IEA and EC scenarios

The total gas demand considered in the COP21 scenarios is in the range of the New Policies Scenario and the Sustainable Development Scenario published by the IEA in the World Energy Outlook 2018. Additionally, Distributed Energy reaches the EU climate targets in 2050 with a similar gas demand to the "1.5 TECH scenario" of EC's Long-Term Strategy, and Global Ambition reaches the same objectives with a gas demand in 2050 in the range of EC's P2X and 1.5 TECH scenarios.

In the timeframe 2020–2040, National Trends, based on current draft NECPs, shows a lower gas demand in 2030 than any of the IEA scenarios, including Sustainable Development, and ca. 10% higher than the EUCO32/32.5 scenario. As shown in Figure 39, part of the difference with EUCO32/32.5 comes from the consideration of some national coal to gas switch policy objectives in the respective draft NECPs and therefore translated into National Trends.

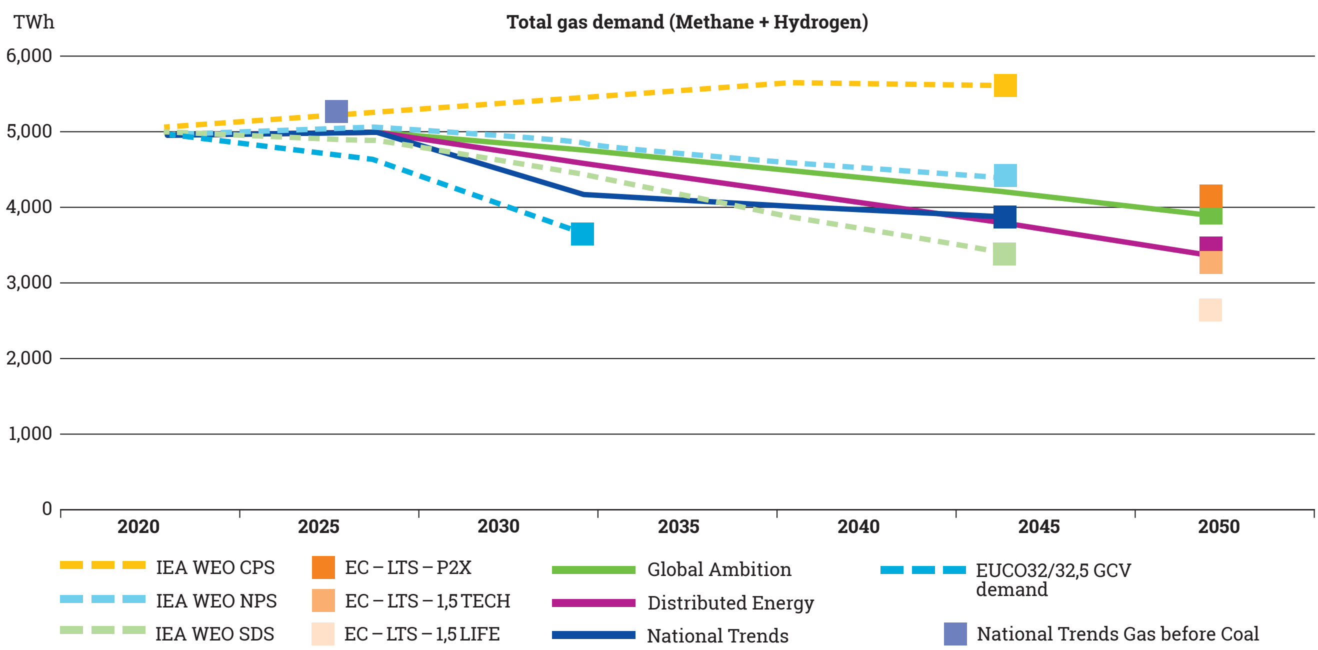


Figure 39: Total gas demand – benchmark vs IEA WEO 2018 and EC LTS

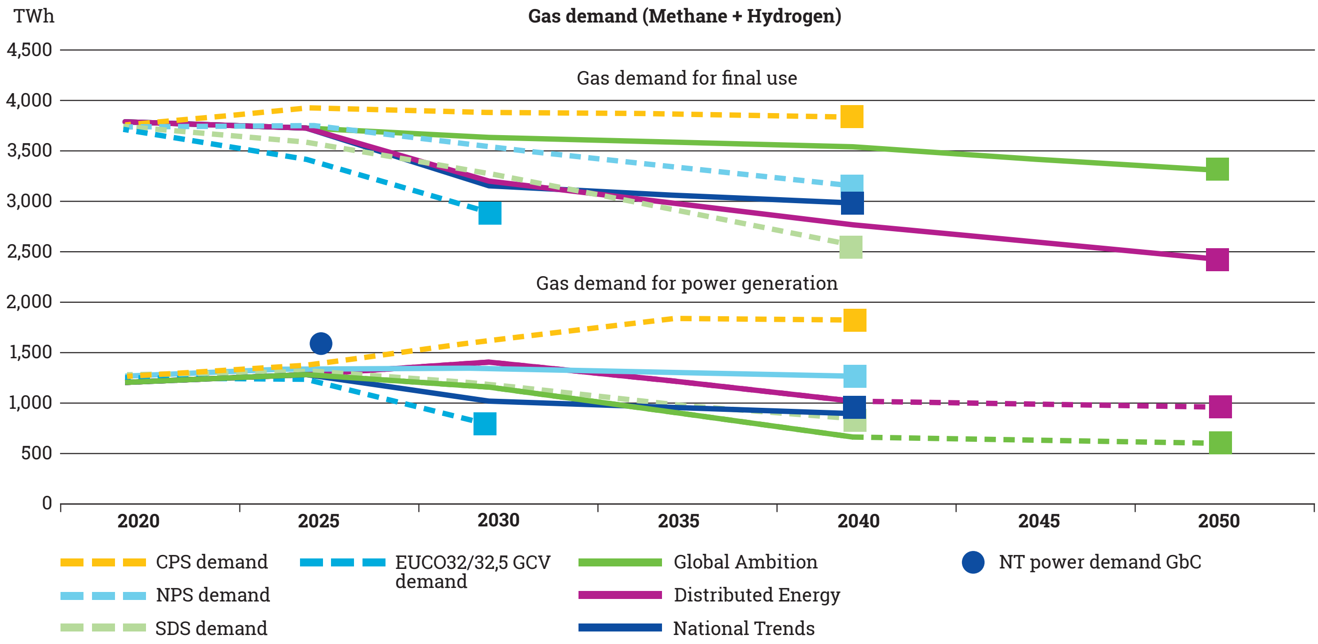


Figure 40: Gas demand for final use and for power generation – benchmark vs IEA WEO 2018 and EC LTS

Gas demand for final use and for power generation follow different evolutions

When looking into the gas demand more in detail, the total gas demand (methane and hydrogen) can be divided in the gas demand for final use, where gas is directly used as energy or feedstock (Residential, Tertiary, Industry and Transport demand) and the gas demand for power generation, where the energy is converted into electricity.

Gas demand for final use in National Trends is very close to the Sustainable Development scenario of IEA and to Global Ambition up to 2030. In 2040, the gas demand for final use of National Trends is around 3,000 TWh, between Distributed Energy and Global Ambition. Regarding the gas demand for power, until 2030, NT shows the lowest of all ENTSOs and IEA scenarios, close to EUCO32/32.5. in 2040, the gas demand for power is close to IEA SDS and between Distributed Energy and Global Ambition.

Gas demands for Global Ambition and Distributed Energy show opposite trends: as a consequence of its centralised approach, Global Ambition has the highest gas demand for final use, close to IEA NPS in 2030, and between IEA NPS and CPS in 2040, whereas Distributed Energy indicates an evolution of the final demand close to IEA SDS until 2040. However, regarding the gas demand for power, the decentralised scenario Distributed Energy has the highest demand close to IEA NPS in 2030 and decreasing to reach IEA SDS levels in 2040, whereas Global Ambition and National Trends show a lower demand further below the IEA SD scenario in 2030.

7.3 Renewable gas supply

The gas production in the next thirty years can be divided in three different categories: production of biomethane, Power-to-Methane ($P2CH_4$) and Power-to-Hydrogen ($P2H_2$).

Biomethane in the range of EC LTS scenarios and Gas for Climate study

Biomethane generation in Global Ambition is comparable to 1.5 TECH and 1.5 LIFE scenarios of EC LTS, whereas Distributed Energy considers a higher generation of biomethane within the EU comparable to the P2X scenario. with National Trends having the most limited penetration of biomethane, all scenarios are therefore in the range of the EC Long-Term Strategy. Additionally, Distributed Energy shows comparable generation to the Gas for Climate study by Navigant (1,200 TWh in gross calorific value).

Power-to-gas sees a limited development compared to EC LTS

As a result of the assumptions on the generation potential as well as the development rate of P2G technologies, the ENTSOs scenarios all look more conservative than EC LTS, explaining the limited gap between the overall indigenous generation considered in EC LTS and ENTSOs scenarios.

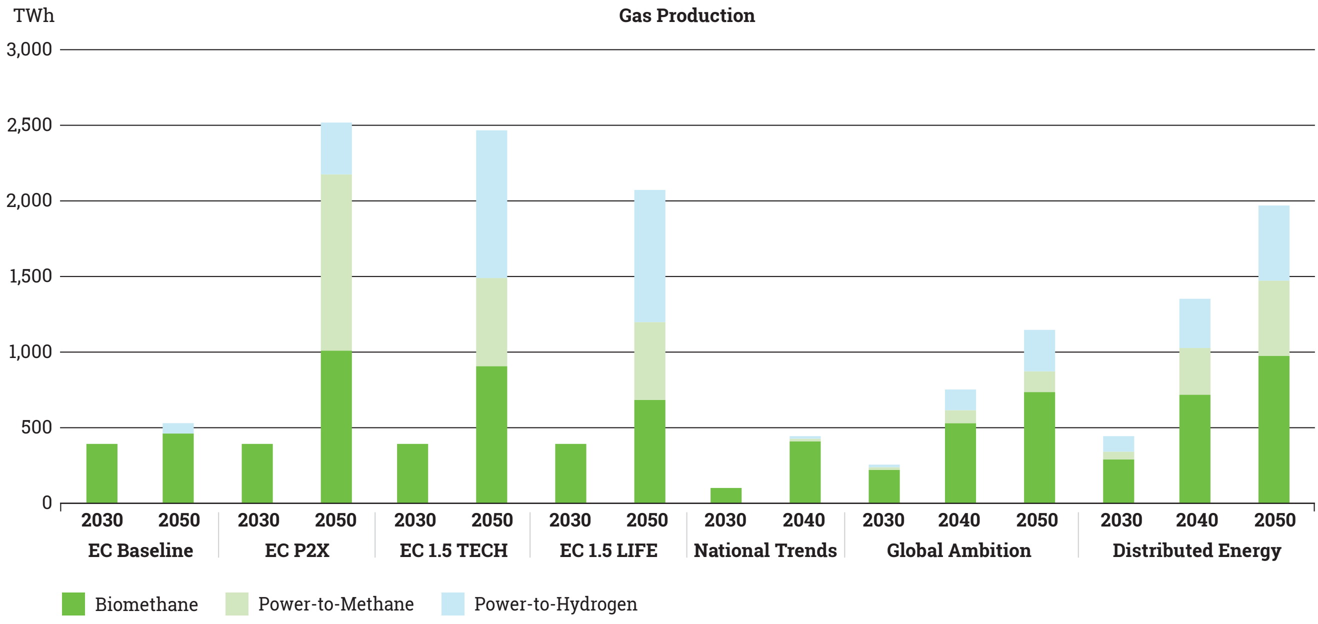


Figure 41: Renewable gas production – ENTSOs vs EC LTS (P2X, 1.5TECH, 1.5LIFE)

7.4 Gas imports

All scenarios show an increasing import demand for the timeframe until 2030, which is similar to the IEA WEO scenarios – only EUCO32,5/32 shows decreasing import shares, which can be partly explained by out-dated data for indigenous natural gas production. In contrast to National Trends, both Global Ambition and Distributed Energy have declining import shares after 2025. With high shares of indigenously produced renewable gases, Distributed Energy shows alignment with EC's most ambitious 1.5 Tech scenario, where Global Ambition shows a balanced development of gas imports being in between levels given by the two more ambitious IEA scenarios NPS and SDS. The difference in imports for 2020 reflects the recent reduction of Groningen field production decided by the Netherlands, which is not considered in the other external scenarios.

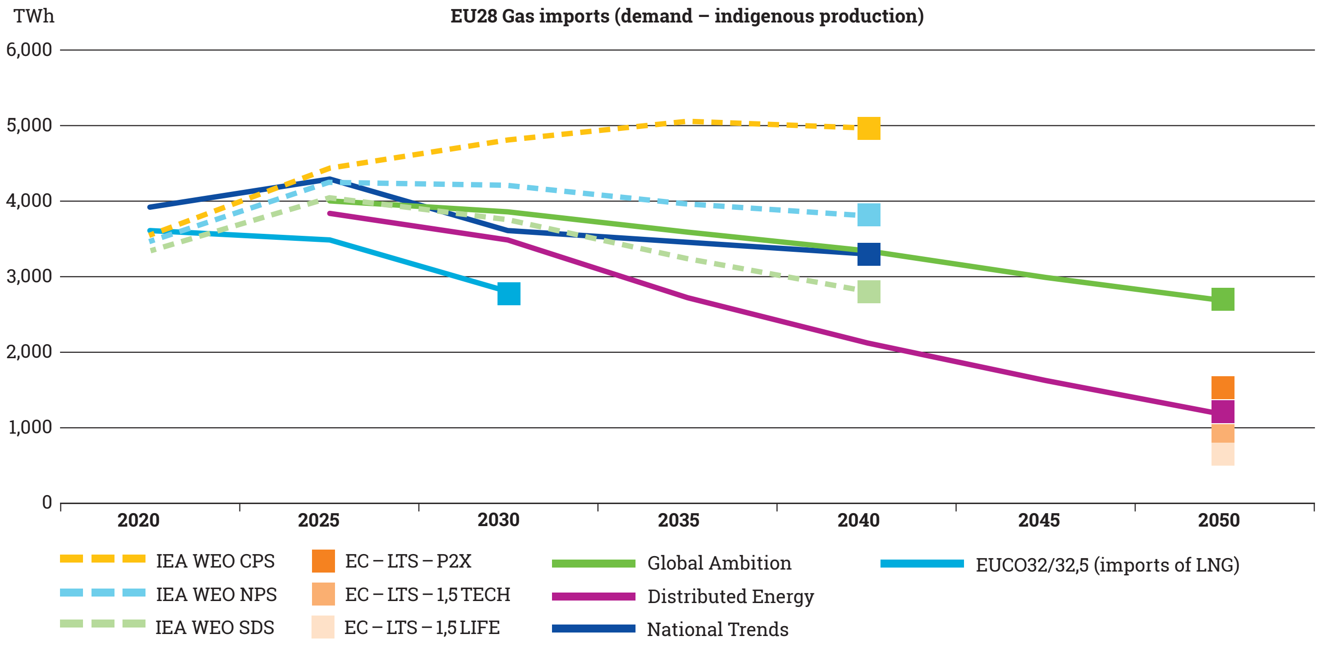


Figure 42: Gas imports per scenario and per year

7.5 Conclusion

Benchmarking the demand, renewable generation and electrification with peer studies and former TYNDPs illustrates the reasoning behind the 2020-scenarios in their assumptions and methodologies. National Trends is based on the national policies towards meeting the EU's climate targets for 2050. However, the benchmark confirms both Global Ambition and Distributed Energy scenarios to be plausible pathways towards meeting the COP21 targets considering contrasted evolutions of the energy system.

ENTSOs scenarios robust and fit for purpose

The contrasts in demand and production technologies as well as the centralised/de-centralised approach to the development of renewable technologies and its impact on the energy imports make the ENTSOs scenarios the best support for assessing the infrastructure needs of the energy system for the next decades.

8 Fuel Commodities and Carbon Prices

Fuel prices are key assumptions for the power market modelling as they determine the merit order of the electricity generation units, and thus the electricity dispatch and resulting electricity prices.

The ENTSOs have used several sources to benchmark the different price forecasts and projections in order to conclude on the reference source to be used for the scenarios (IEA, Primes, Bloomberg, IHS). This assessment shows that the prices provided by the PRIMES, which considers the global context and development that influences commodity prices, in-line with the EC targets, is robust enough to be used as a reference for gas, oil and coal prices as well for the CO_2 price. Prices for nuclear, lignite and biofuels are kept the same as considered for TYNDP 2018. Figure 43 summarises the source for each fuel type and CO_2.

Starting from the PRIMES reference price for National Trends 2030, the CO_2 price will be increased in order to achieve a specific carbon budget as defined for each specific storyline and year. Table 5 summarises all the resulting prices per scenario.

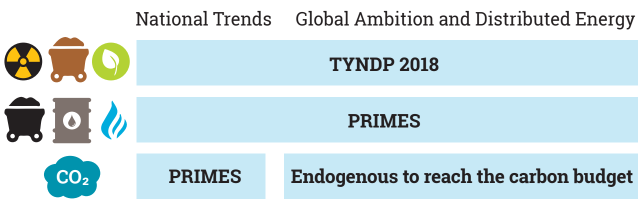


Figure 43: Summary of fuel price references

		2020	2021	2023	2025		2030			2040		
					BE	G2C	NT	DE	GA	NT	DE	GA
€/GJ	Nuclear	0.47	0.47	0.47	0.47		0.47			0.47		
	Lignite	1.1	1.1	1.1	1.1		1.1			1.1		
	Oil shale	2.3	2.3	2.3	2.3		2.3			2.3		
	Hard Coal	3.0	3.12	3.4	3.79		4.3			6.91		
	Natural Gas	5.6	5.8	6.1	6.46		6.91			7.31		
	Light Oil	12.9	14.1	16.4	18.8		20.5			22.2		
	Heavy Oil	10.6	11.1	12.2	13.3		14.6			17.2		
€/tCO_2	CO_2 price	19.7	20.4	21.7	23	56	27	53	35	75	100	80

Table 5: Fuel prices in TYNDP 2020 scenarios

9 Stakeholder feedback and how it shaped the Storylines

External stakeholders representing the gas and electricity industries, customers and environmental NGOs, regulators, EU Members States and the European Commissions were key in building an ambitious, yet technically sound, set of scenarios.

The Scenario Building team has worked jointly with stakeholders through interactive workshops, webinars and web-consultations. Dozens of stakeholders provided input to formulate, with the ENTSOs, the new scenarios storylines.

As a result, the ENTSOs scenarios uniquely represent generally accepted, yet highly ambitious, views of what the future could look like, rather than a view of the future desired or promoted by any organisation. They will allow the testing of Europe's future energy infrastructures under varied and stressing situations.

The development process is covered in detail by the material released prior to the publication of this report, the high-level process for these storylines followed the steps as shown:

1. **Public workshop: "TYNDP 2020 Scenario Development Workshop", 29 May 2018 (link)**
2. **Publication of first draft of five storylines describing potential relevant futures for the electricity and gas system in Europe developed by ENTSO-E and ENTSOG, 2 July 2018 (link)**
3. **Public consultation of storylines: "2020 Scenario Storylines ", 2 July to 14 September 2018 (link)**
4. **Public Webinar on "Scenario Development Process Update", 21 November 2018 (presentation send to participants via email)**
5. **Public Webinar on Final Storyline Release, 18 April 2019 (link)**
6. **Publication of Final Storylines, 29 May 2019 (link)**
7. **ENTSOG's Public Workshop on the Supply Potentials and Market Related Assumptions for TYNPD 2020, 10 July 2019 (link)**
8. **TYNDP Cooperation Platform (with EC and ACER) and High-Level Meetings throughout the whole process with main focus on National Trends as the central policy scenario.**

10 Improvements in 2020 Scenarios

Since TYNDP 2018 the ENTSOs have aligned their TYNDP timelines and processes leading to the same TYNDP publication timeframes. Before that time, each organisation had its own individual process with the ENTSO-E TYNDP 2016 and ENTSOG TYNDP 2017 respectively. The joint development of the TYNDP Scenarios, introduced at the TYNDP2018 project start, must be highlighted as one of the most significant process improvement steps, as ENTSO-E and ENTSOG pooled their Scenario Building efforts and expertise in the frame of the interlinked model.

The focus study on the interlinkage between gas and electricity[12], performed by Artelys and presented to Copenhagen Infrastructure Forum 2019, concludes that most of the interlinkage is captured in the scenarios and the level of direct interaction mainly depends on the assumptions made on the different technologies for gas to power and power to gas conversion, as well as on the hybrid technologies. These interactions define the interlinkage between gas and electricity thus directly derive from the storylines defined and selected with the stakeholders.

Both ENTSOs consistently work to modernise their data, tools and methodologies between each release of the scenarios. Some of the key improvements for the Scenarios 2020 are presented below. The methodologies used by both ENTSOs to produce the scenarios are presented in detail in the Annex of this report.

12 https://www.entsog.eu/methodologies-and-modelling#consistent-and-interlinked-electricity-and-gas-model

10.1 More sustainability-oriented Scenarios (carbon budget)

With the introduction of a carbon budget as an input to the COP 21 scenarios, the ENTSOs can assess what the targets set by the COP 21 require from the energy system beyond 2025 and hence, support the policy decision-making process.

The development of the carbon budget and the input assumptions to the scenarios have involved a wide range of stakeholders including environmental organisations, participating to the credibility of the two very different pathways the energy system could take towards reaching the European Union climate ambitions. Building on the previous exercise, the ENTSOs have kept the centralised and decentralised approach of, respectively, Global Ambition and Distributed Energy scenarios. Even if these scenarios should not be considered more likely than others, they will allow the ENTSOs to consider the electricity and the gas system under the most contrasted situations, thus delivering the most comprehensive assessment.

10.2 Total Energy Scenarios (Top-down)

Whereas ENTSOs' TYNDP 2018 Scenarios were mainly based on bottom-up collected data for the gas and electricity sectors, for the first time, they have developed top-down Scenarios capturing the full energy system (all sectors, all fuels). In this sense, the joint Working Group Scenario Building developed an in-house energy model tool called the "Ambition Tool".

The main objectives were:

1) to better map the sectoral coupling and the associated interdependence between the gas and electricity sectors
2) to improve the methodologies to capture all GHG emissions and their development within a time period and thus ensure that the scenarios are in compliance with the Paris Agreement targets (carbon budget method as stated by the IPCC Special Report).

It is a policy driven top-down energy model, as no cost elements are considered and is linked to the Eurostat 2015 data as projection starting point. Working Group Scenario Building is looking at the European ambition level with levers sectoral technology split, fuel types, supply sources etc. and is working out the future energy carrier content (focusing on the gas and electricity system).

10.3 Electricity Demand

TRAPUNTA (**T**emperature **R**egression and lo**A**d **P**rojection with **UN**certainty **A**nalysis) is the next step in electricity load forecasting after one year of development. This tool is a software that allows electric load prediction starting from data analysis of the historical time series (electric load, temperature, other climatic variables) and evaluation of the future evolution of the market (e. g., penetration of heat pump, electric vehicles, batteries, population and industrial growth). It has been developed by Milano Multiphysics for ENTSO-E. TRAPUNTA is based on an innovative methodology for the electric load projection analysis based on regression, model order reduction and uncertainty propagation.

10.4 Gas Demand

Quality Split

Taking into account recent technologic and political trends, ENTSOs have decided to investigate the demand for methane and hydrogen separately. The term gas therefore stands for the sum of both gas types.

Daily gas peak demand computation

As for TYNDP2018 Scenarios, the daily gas peak demand figures for gas have been collected from the TSOs for the bottom-up scenario National Trends. For the top-down scenarios, as the annual demand values were determined with the Ambition Tool, ENTSOs have developed a methodology to compute daily gas peak demand figures using sectoral full load hours and temperature-demand regression curves.

Dunkelflaute climatic case

Considering the level of development of renewable generation capacities in the COP21 scenarios, especially in 2040, the ENTSOs have developed for the first time a Dunkelflaute climatic case (DF) to assess the possible impact of additional gas demand for power generation when minimum variable renewable generation is available for two weeks.

10.5 Electricity Generation

Co-optimisation

Following the exchange with internal and external stakeholders a co-optimization of generation capacity and grid was performed. This new method includes following key improvements:

- Endogenous and simultaneous optimisation of generation capacity and interconnectors
- Utilisation of scenario dependent CAPEX costs, OPEX costs and fuel prices with endogenous CO_2 level adjustment
- Endogenous CO_2 price setting as a function of carbon budget as main investment lever
- Consideration of household solar battery storage systems, vehicle to grid and industry demand side response
- Implementation of RES technology evolution by the usage of time horizon (2025, 2030 and 2040) related RES infeed time series

Trajectories collection

The Scenario Building process is developing "top-down" scenario data sets that are quantified using a number of optimisation loops according to the stakeholder agreed storylines. In order to improve the scenario quantification by setting plausible boundaries, the Working Group Scenario Building established a Trajectory data collection for various core supply and demand elements based on up to three national scenarios (with low, medium and high development trajectories). The main aim of this complementary information is to help better integrate uncertainties on national political decisions like coal phase-outs, nuclear fleet developments, RES support schemes but also to elaborate on upcoming technologies like electric vehicles, battery storages or P2G.

Based on those data, it is possible to:

- Ensure coherency with national studies
- Take into account national policies and political decisions/plans
- Set boundaries for technology developments
- Compare the outcomes of the ENTSOs scenarios with national perspectives

10.6 Gas supply

In TYNDP 2018, gas supply assumptions consisted of mainly bottom-up data for domestic production of natural gas, biomethane and P2G without a quality split in methane and hydrogen.

Import share

As done in external studies (e.g. EC's "Clean Planet for all") ENTSOs' developed generic assumptions on the import share for gas supply. This enables the ENTSOs to test the gas infrastructure under different conditions (high import shares, low import shares). ENTSOs are convinced that centralisation and de-centralisation will have a major impact on future infrastructure needs.

Biomethane

To further improve the data quality and capture latest trends, ENTSOG in collaboration with the consultancy Navigant (previously Ecofys) has developed a "Biomethane Production tool", which is based on the assumptions of the "Gas for Climate" study. The tool considers anaerobic digestion and thermal gasification as technologies to produce biomethane. To capture the potential of both technologies it differentiates between several feedstock types and growing regions within Europe.

Hydrogen supply

For the first time, ENTSOs have identified the need for hydrogen supply considering three major technologies: P2G, Steam Methane Reforming plus CCU/S and Methane Pyrolysis. They have developed methodologies to identify the indigenous production of hydrogen by aforementioned technologies and, following their assumptions on the import share, the need for direct hydrogen imports and/or natural gas imports to convert it into hydrogen in Europe, respectively.

10.7 P2G

For the top-down scenarios, the quantification of the production of synthetic hydrogen and methane via P2G was extended to a two-step approach for the top-down scenarios. In a first step, curtailed electricity from the electricity market model is considered a source of renewable electricity for to produce renewable gases (hydrogen, methane). In a second step, additional renewable electricity production is assumed and modelled to meet the demand for renewable gases. This is done via a dedicated model, which quantifies the needed RES and P2G capacities for the purpose of supplying synthetic gas.

10.8 Data Visualisation Platform

An online data visualisation platform was set up to engage with internal and external stakeholders and improve the transparency with regard to the scenario outcome. Stakeholders have simplified as well as extended data access with online analysis functions.

11 Next Steps

The ENTSOs are currently working on the further development of their Interlinked Model and on the integration of the focus study recommendations for the identification of projects worth a dual assessment on both gas and electricity systems.

ENTSOG completed its project collection phase in July 2019. For the first time ENTSOG opened its TYNDP to Energy Transition Related projects including biomethane, P2G and ccs/u projects. ENTSO-E is collecting submissions in October – November 2019 and will run a second submission window for future projects after the release of its Identification of System Needs 2040 study in April 2020.

Over the coming months, the ENTSOs will pursue their respective TYNDP 2020 development process, in a close timeline:

- The electricity and gas draft TYNDPs will be published in Q3 2020 for public consultation.
- Further to receiving the public consultation feedback as well as ACER's opinion, the ENTSOs will publish the final TYNDPs, by end 2020 for gas and in spring 2021 for electricity.
- Both TYNDPs will support the 5th PCI selection process.

National Trends will serve as basis for ENTSO-E's Identification of System Needs study, which assesses pan-European network needs, their impact in regions, where grid projects should be considered, potential needed policy adjustments and technical challenges.

A cost-benefit analysis (CBA) of electricity transmission and storage projects will be performed for National Trends (2025 and 2030 time horizons). Additionally, to illustrate the robustness of the proposed infrastructure projects, a subset of CBA parameters will be determined for Distributed Energy and Global Ambition (2030 time horizon). Projects will also be assessed in a 'Current Trends' scenario, as requested by ACER. This is an ENTSO-E scenario not included in this report which describes a future where the energy transition is slower than planned.

The scenarios will also feed into projects within ENTSO-E's Markets and System Operations committee, such as looking at market design and system operability in 2030.

ENTSOG TYNDP 2020 will include the Project-Specific CBAs (PS-CBAs) for those projects having declared their intention to apply for the 5th PCI list. Full PS-CBAs will be performed for transmission, storage and LNG terminal gas projects, and will consider all scenarios and the whole time-horizon of the TYNDP (from 2020 to 2040). Energy Transition Related (ETR) projects will be assessed with a reduced and sustainability-oriented CBA, to assess how they can deliver in terms of decarbonisation of the energy system and support the European climate ambitions.

12 Glossary

ACER: Agency for the Cooperation of Energy Regulators.

BECCS: Bio-Energy Carbon Capture and Storage. CCS applied to Bio-Energy, thus resulting in a net negative emission of carbon dioxide.

Biomethane: Gaseous renewable energy source derived from agricultural biomass (dedicated crops, by-products and agricultural waste and animal waste), agro-industrial (waste from the food processing chain) and the Organic Fraction Municipal Solid Waste (OFMSW).

Bottom-Up: This approach of the scenario building process collects supply and demand data from Gas and Electricity TSOs.

Blue Hydrogen: Hydrogen obtained from natural gas or industrial residual gases by splitting them into hydrogen and CO_2. The CO_2 is then captured and stored/used.

CAGR: Compound annual growth rate.

CAPEX: Capital expenditure.

Carbon budget: This is the amount of carbon dioxide the world can emit while still having a likely chance of limiting average global temperature rise to 1,5 °C above pre-industrial levels, an internationally agreed-upon target.

Carbon price: cost applied to carbon pollution to encourage polluters to reduce the amount of greenhouse gases they emit into the atmosphere.

CBA: Cost Benefit Analysis carried out to define to what extent a project is worthwhile from a social perspective.

CCS: Carbon Capture and Storage. Process of sequestrating CO_2 and storing it in such a way that it won't enter the atmosphere.

CCU: Carbon Capture and Usage. The captured CO_2, instead of being stored in geological formations, is used to create other products, such as plastic.

CHP: Combined heat and power.

COP 21: 2015 United Nations Climate Chance Conference.

Curtailed Electricity: Curtailment is a reduction in the output of a generator from otherwise available resources (e.g. wind or sunlight), typically on an unintentional basis. Curtailments can result when operators or utilities control wind and solar generators to reduce output to minimize congestion of transmission or otherwise manage the system or achieve the optimum mix of resources.

Coal phase-out: Coal is the most carbon intensive fossil fuel and phasing it out is a key step to achieve the emissions reductions needed to limit global warming to 1.5 °C, as enshrined in the Paris Agreement.

DSR: Demand Side Response. Consumers have an active role in softening peaks in energy demand by changing their energy consumption according to the energy price and availability.

(Kalte) Dunkelflaute: German for „(cold) dark doldrums" expresses a climate case, where in addition to a 2-week cold spell, variable RES electricity generation is low due to the lack of wind and sunlight.

EC: European Commission.

EV: Electric vehicle.

GDP: Gross domestic product.

GHG: Greenhouse gas.

Hybrid Heat Pump: heating system that combines an electric heat pump with a gas condensing boiler to optimize energy efficiency.

IEA: World Energy Outlook.

Indirect electricity demand: Indirect electrification means that electricity is not used as a direct replacement for fossil fuels, but as an input in industrial processes.

LCOE: Levelised costs of electricity. It represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle.

LNG: Liquefied natural gas.

LULUCF: Land Use, Land Use Change and Forestry. Sink of CO_2 made possible by the fact that atmospheric CO_2 can accumulate as carbon in vegetation and soils in terrestrial ecosystems.

NECPs: National Energy and Climate Plans are the new framework within which EU Member States have to plan, in an integrated manner, their climate and energy objectives, targets, policies and measures to the European Commission. Countries will have to develop NECPs on a ten-year rolling basis, with an update halfway through the implementation period. The NECPs covering the first period from 2021 to 2030 will have to ensure that the Union's 2030 targets for greenhouse gas emission reductions, renewable energy, energy efficiency and electricity interconnection are met.

NGO: Non-governmental Organisation.

OPEX: Operational expenditure.

P2G: Power to gas. Technology that uses electricity to produce hydrogen (Power to Hydrogen – P2H2) by splitting water into oxygen and hydrogen (electrolysis). The hydrogen produced can then be combined with CO_2 to obtain synthetic methane (Power to Methane – $P2CH_4$).

P2L: Power to liquids. Combination of hydrogen from electrolysis and Fischer-Tropsch process to obtain synthetic liquid fuels.

PCI: Project of Common Interest.

Power-to-Hydrogen/P2Hydrogen: Hydrogen obtained from $P2H_2$.

Power-to-Methane/P2Methane: Renewable methane, could be biomethane or synthetic methane produced by renewable energy sources only.

PRIMES: The PRIMES energy model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model provides projections of detailed energy balances, both for demand and supply, CO_2 emissions, investment in demand and supply, energy technology penetration, prices and costs.

RES: Renewable energy source.

Shale gas: Shale gas is natural gas that is found trapped within shale formations (e.g. via fracking).

Synthetic methane: fuel gas that can be produced from fossil fuels such as lignite coal, oil shale, or from biofuels (when it is named bio-SNG) or from renewable electrical energy.

Top-Down: The "Top-Down Carbon Budget" scenario building process is an approach that uses the "bottom-up" model information gathered from the Gas and Electricity TSOs. The methodologies are developed in line with the Carbon Budget approach.

TRAPUNTA: Temperature REgression and loAd Projection with UNcertainty Analysis. Software that allows to perform electric load prediction starting from data analysis of the historical time series (electric load, temperature, other climatic variables) and evaluation of the future evolution of the market (e.g., penetration of heat pump, electric vehicles, batteries, population and industrial growth). It has been developed by Milano Multiphysics for ENTSO-E.

TSO: Transmission System Operator.

TYNDP: Ten-Year Network Development Plan.

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