Building a Paris Agreement Compatible (PAC) energy scenario

CAN Europe/EEB technical summary of key elements

June 2020

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Who we are

Climate Action Network (CAN) Europe is Europe's leading NGO coalition fighting dangerous climate change. With over 170 member organisations active in 38 European countries, representing over 1,500 NGOs and more than 47 million citizens, CAN Europe promotes sustainable climate, energy and development policies throughout Europe. www.caneurope.org

The European Environmental Bureau (EEB) is the largest network of environmental citizens' organisations in Europe. It currently consists of around 150 member organisations in more than 30 countries, including a growing number of European networks, and representing some 30 million individual members and supporters. www.eeb.org

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Legal notice

This document is the Paris storyline report as part of the final report under the PAC project deliverable 2. For more information about the PAC project, see https://www.pac-scenarios.eu.

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Introduction

This document presents the main results of the Paris Agreement Compatible (PAC) energy scenario. This scenario has been elaborated jointly by the Climate Action Network (CAN) Europe and the European Environmental Bureau (EEB) together with its member organisations and external experts.

About the PAC project

Since 2019, CAN Europe and the EEB are engaged in the PAC project, with the aim to develop a Paris Agreement Compatible scenario for energy infrastructure.[1] Under this project, both organisations have developed the key assumptions for a European-wide energy scenario that is **aligned with the Paris Agreement's objective to limit global warming to 1.5°C degree.** There is scientific evidence that this is the only acceptable goal for all policy making aimed at averting dangerous climate change**.** In view of this goal, the PAC scenario embodies the policy demands of the civil society.

As a deliverable of the PAC project, the PAC scenario is meant to be submitted to the European Network of Transmission System Operators for Electricity (ENTSO-E) and Gas (ENTSOG) in order to help improve energy infrastructure planning under the Ten Year Network Development Plan (TYNDP). In parallel, the scenario building process as such is an opportunity to elaborate a consistent civil society vision of how the EU can reach the Paris Agreement. In this view, the PAC scenario suggests a trajectory with at least **65% greenhouse gas emission reductions by the year 2030** and a **100% renewable energy supply by 2040**.

How the PAC scenario was built

The numbers presented in this document are based on desk research, comparing and adopting elements of a multitude of existing studies and models. In this regard, the PAC scenario is a bottom-up collective research exercise. EEB and CAN Europe started to gather feedback on key assumptions in spring 2019 through a series of five workshops, two webinars and an online survey. **Around 150 different stakeholders** from member organisations, science and industry were involved in the scenario building process, be it through joining these events or bilateral exchanges. This feedback helped better understand **civil society's vision of Europe's future energy system**: Which technologies are relevant for reaching a 100% renewable energy supply by 2040? Which trends are desirable in view of achieving net-zero emissions in Europe by 2040? How should trajectories evolve in order to reduce the EU's greenhouse gas emission by 65% in the year 2030?

This document summarises this **open learning process**. It reflects NGOs' priorities for an ambitious yet credible pathway towards the 1.5°C target of the Paris Agreement. The PAC scenario remains a living document. It is a first comprehensive climate and energy roadmap for European policy-makers drafted by a broad range of civil society organisations. Yet, the EEB and CAN Europe know that many questions still need to be answered through the PAC scenario modelling. We would therefore appreciate to continue this collective research exercise for Europe's energy and climate future on the basis of this document.

All data contained in the following summary refers to the EU28 Member States.

[1] For more information about the PAC project consortium and its deliverables, see www.pac-scenarios.eu.

Executive summary

The PAC scenario illustrates a pathway for the transition of the EU's energy system that is in line with EU leaders' commitment to the Paris Agreement.

The global pandemic shock shows us Europe is not resilient. The EU needs to use its answer to this as an opportunity to make sure societies recover in a manner that does not deepen but reduce the damage of the ongoing climate crisis. The time is now that the EU jointly addresses the economic and the environmental challenge through rapidly building an energy system that cuts greenhouse gas emissions by 65% in the year 2030.

The key elements of the PAC scenario are:

1. **A mobilisation of energy savings potentials** through accelerating deep renovation of buildings and a modernisation of industrial production processes. The increase of energy efficiency in transport is also a main contribution. This leads to halving the EU's energy demand between 2015 and 2050.
2. **A swift ramping up of domestic renewable energy use**, in particular of solar PV and wind energy for electricity production. Renewable electricity generation triples during the decade from 2020 to 2030. This leads to renewables covering 50% of gross final energy consumption in 2030 and 100% in 2040.
3. **An electrification of industrial processes, heating and transport**, based on renewable electricity. Heat pumps and electric vehicles are key technologies that will progressively dominate buildings and roads in the 2030s.
4. **A quick phase-out of fossil fuels**, starting with coal mostly disappearing from the mix by 2030, fossil gas by 2035 and fossil oil products by 2040. Most nuclear power plants also will be closed by 2040.
5. **A limited role for non-fossil gases and fuels** which are based exclusively on renewable hydrogen. These synthetic gases and fuels produced through electrolysis are essential for decarbonising industry and aviation, besides a smaller and declining contribution of sustainably sourced biogas and biomethane.

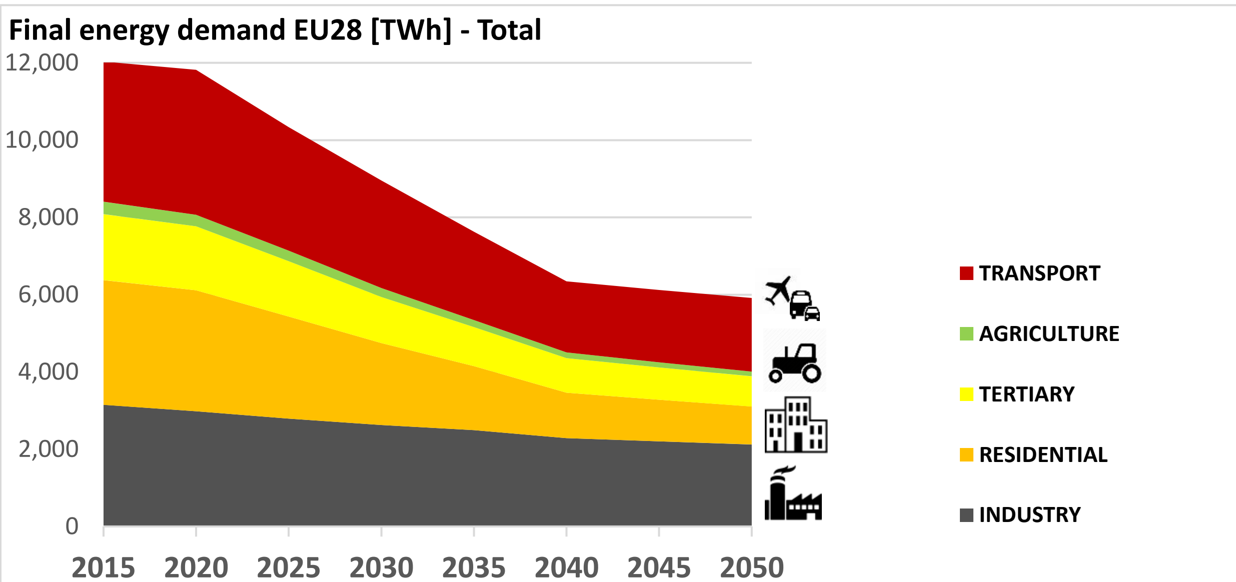
In view of the EU climate and energy targets for the year 2030, the PAC scenario shows that the current level of ambition can be raised substantially:

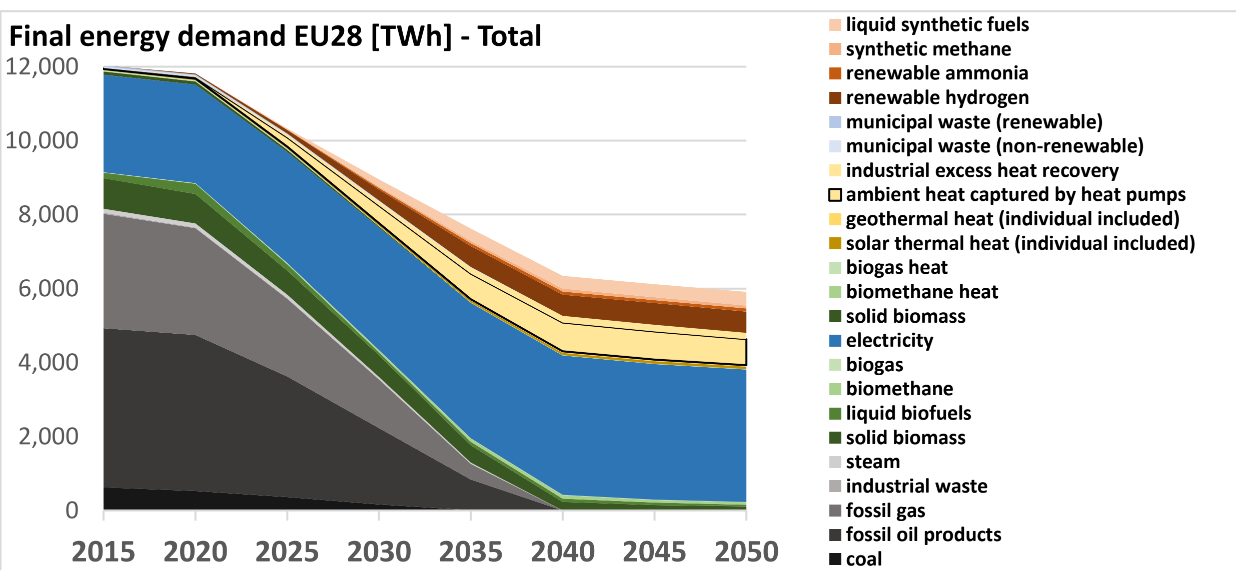
- The current EU target of reducing greenhouse gas emissions by at least 40% compared to 1990 can be updated to **65% emission reductions**.
- The current EU energy efficiency target of 32.5% also can be outperformed. The PAC scenario leads to at least **45% energy savings** as compared to PRIMES 2007 projections for both primary and final energy.
- The current EU renewable energy target of 32% share of renewable energy sources in gross final energy consumption can be increased to at least a **50% renewable energy share**.

1. Sector-specific energy demand

In a first step, the PAC scenario assesses the evolution of the final energy demand of five sectors (industry, residential, tertiary, agriculture and transport). The energy savings potentials of the sectors as well as their specific demand for different energy carriers differ strongly. Sector-specific findings are presented in the following sub-chapters. In a second step, chapter 2 will then illustrate how energy supply from fossil fuels, nuclear power and renewable energy sources could cover demand.

While the industry sector reduces its final energy demand by a third between 2015 and 2050 due to lower material demand and higher efficiencies of production processes, the transport demand is halved thanks to stabilisation of demand and electrification, and the residential sector's demand drops even by two thirds. In total, the PAC scenario projects that final energy demand halves between 2015 and 2050.





1.1 Industry

Key assumptions

Industrial transformation implies a reduction of material demand through higher reuse and recycling rates.

- Implementing circular economy approaches in the different industry sectors together with increasing energy efficiency of processes cuts the final energy demand by a third between 2015 and 2050. The PAC scenario broadly adopts the circular economy pathway of the Material Economics research project.[2]
- Wherever possible, production processes electrify with direct use of renewable electricity.
- In order to cover energy-intensive industry sectors' demand for high temperature heat, a significant increase of renewable hydrogen and to a minor extent of synthetic methane production is required. The PAC scenario assumes no carbon capture and storage/usage (CCS/CCU) technology is introduced.

Evolution of energy demand

The PAC scenario assumes a strong demand reduction of energy-intensive steel, chemicals, cement and pulp and paper industries of 39% to 48% between 2015 and 2050 due to lower material demand: Raw material is reused, recycled or substituted more often. Other industry sectors (transport and machinery equipment, non-ferrous metals, food) can realise less energy savings (11% to 28% less demand between 2015 and 2050).[3] The demand for renewable hydrogen and synthetic methane that are produced exclusively with renewable electricity rises swiftly from almost zero in 2015 to reach a level of circa 400 TWh throughout the years 2035 to 2050. Despite efficiency gains from modernisation of production processes, final electricity demand grows by 41% between 2015 and 2050 due to the electrification of processes that previously were driven by fossil fuels. The introduction of heat pumps to cover low and medium temperature demand in industries' production processes also increases the electricity demand.[4]

Integration of members' and experts' feedback

Following discussions with members and experts on how to tackle in particular the steel, chemicals and ceramics industry's demand for energy carriers with high energy density, the PAC scenario opted for a swift market introduction of renewable hydrogen that substitutes coal and fossil gas. These assumptions allow to respect limited biomass potentials which are shifted to a non-energy use as feedstock in the chemicals industry in the PAC scenario. This however requires policy framing for sustainable bioenergy use. Given the scepticism with regards to climate benefits and roll-out of CCS, preference was given to renewable hydrogen.[5]

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[2] Material Economics: Industrial Transformation 2050. Pathways to Net-Zero Emissions from EU Heavy Industry, April 2019.

[3] Taking over assumptions from Material Economics and European Commission: A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. In-Depth Analysis. COM(2018)773, Nov. 2018; European Commission: EU Reference Scenario 2016. Energy, transport and GHG emissions. Trends to 2050, July 2016; UK Department of Energy and Climate Change: Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050, March 2015.

[4] Taking over assumptions from Rehfeldt et al.: A bottom-up estimation of heating and cooling demand in the European industry. In: Energy Efficiency, Dec. 2016; Renewable Heating and Cooling European Technology and Innovation Platform: 2050 vision, Oct. 2019; Agentur für Erneuerbare Energien (AEE): Erneuerbare Energie für die Industrie, June 2017; Ecofys/Fraunhofer ISI/Greenstream/ Adelphi: Impact on the Environment and the Economy of Technological Innovations for the Innovation Fund (IF), July 2018.

[5] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops on 24 April 2019, 9 July 2019, 9 October 2019, 7 November 2019 and 31 January 2020.

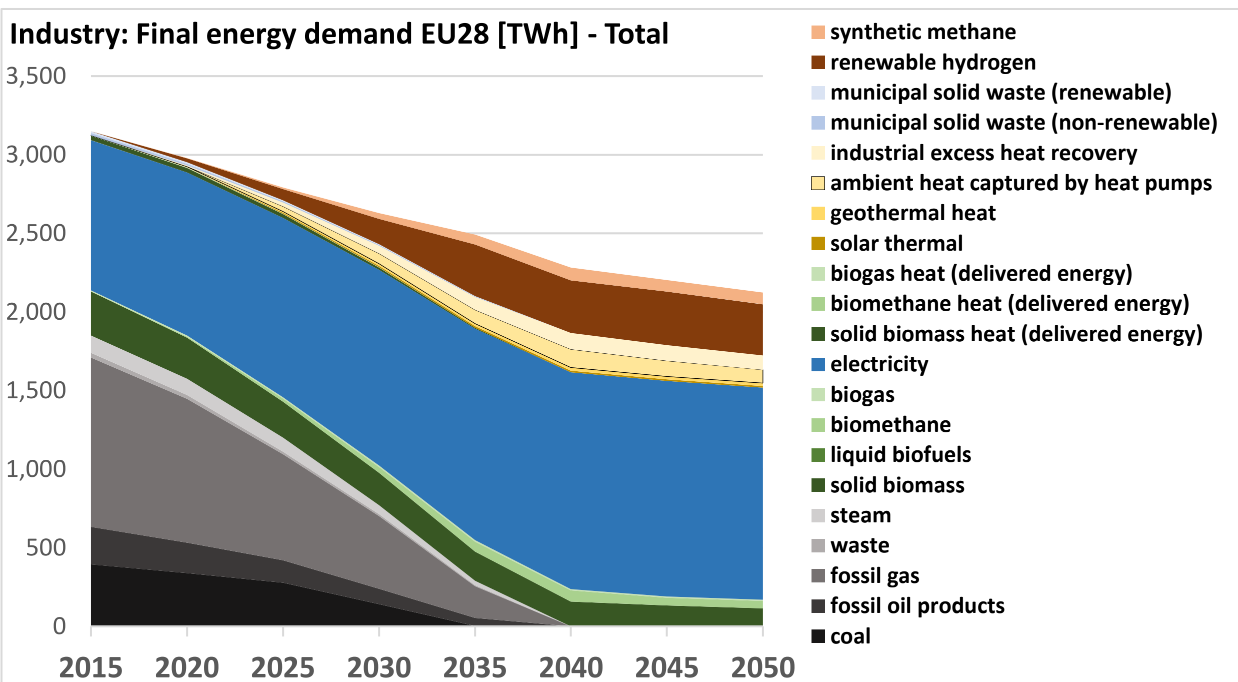
Sensitivities and limitations

The mobilisation of solid biomass in industry is in line with the sustainability criteria discussed during the PAC scenario building. Distributed biomass potentials however might be difficult to shift from decentralised individual heating to industrial production processes, even if industry sectors are willing to pay more for this energy carrier.

While the PAC scenario integrates the electrolyser capacities and the required additional renewable electricity generation capacities, no detailed modelling was carried out with regards to the infrastructure use (electricity, gas and hydrogen grids). Following the positioning of members and experts during the PAC scenario building, renewable hydrogen is assumed to be produced domestically within the EU. Imports however might become more attractive. An in-depth comparison of costs and infrastructure is needed to analyse this sensitivity.

Key results

- Thanks to reduced demand and electrification with renewables, industry can already achieve a 100% renewable energy supply in 2040.
- Electricity constitutes more than 60% of industry's final energy demand in 2040.
- The demand for gaseous energy carriers falls to less than a quarter of final energy demand in 2040, covered by renewable hydrogen and to a minor extent by synthetic methane, biomethane and biogas.



1.2 Residential sector

Key assumptions

Technology changes and behavioural changes both bear sufficient potential to drive down the residential sector's final energy demand by more than two thirds between 2015 and 2050.

- The PAC scenario takes over assumptions of the EUCalc project[6] that the annual renovation rate of the EU building stock will increase from 1% to 3% of which 70% are deep renovations that cut the energy need of buildings by 60% and remaining renovations cutting 40% of energy needs on average.
- A high annual demolition rate of 1% is also foreseen with 70% of new constructions being highly efficient. The residential floor area per capita drops from 48 to 37 m^2 in 2050.[7]
- In addition to renovation and replacement of inefficient heating systems, new societal trends (urbanisation, building automation, behavioural changes triggered by improved awareness-raising) contribute to energy demand reduction with roughly one third, taking over Fraunhofer ISI assumptions.[8]

Evolution of energy demand

The final energy demand for space heating and hot water in residential buildings decreases by 77% from 2015 to reach 572 TWh in 2050. Primary energy will be used more efficiently because of a gradual replacement of inefficient individual fossil fuel- and solid biomass-fired heating systems by district heating networks. A strong increase of electricity demand for heating is induced by the expansion of heat pumps as the dominant technology for individual heating systems. They take over demand for gaseous energy carriers between 2030 and 2035.[9]

The remaining final demand stems from cooking, cooling, lighting and home appliances. Final energy demand for cooking decreases only slightly. Increasing electricity demand largely replaces demand for fossil fuels for cooking. The increase of final energy demand for space cooling will be offset by renovated buildings' improved protection against heat and by efficiency gains of the air conditioning installations. Final energy demand of appliances and lighting annually reduces by 2.9% to reach 139 TWh in 2050.[10]

Integration of members' and experts' feedback

Members and experts argued in favour of further mobilising energy savings through behavioural changes and societal trends. In order to mobilise these potentials and avoid rebound effects, a set of policies would need to play an important role, such as strong regulation, adequate guidance for end users and provisions to ensure no consumer is left behind. A short-term ban on gas boilers and financial incentives are considered indispensable.[11]

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[6] EUCalc: Technical documentation: WP2 –Buildings module documentation (including households and services). Preliminary version for expert review, April 2020, http://tool.european-calculator.eu.

[7] Taking over assumptions from EUCalc.

[8] Fraunhofer ISI: Study on Energy Savings Scenarios 2050. January 2019.

[9] Aalborg University: Heat Roadmap Europe 4. Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps, Oct. 2018.

[10] Taking over assumptions from Fraunhofer ISI.

[11] CAN Europe/EEB: Summaries of PAC scenario workshops.

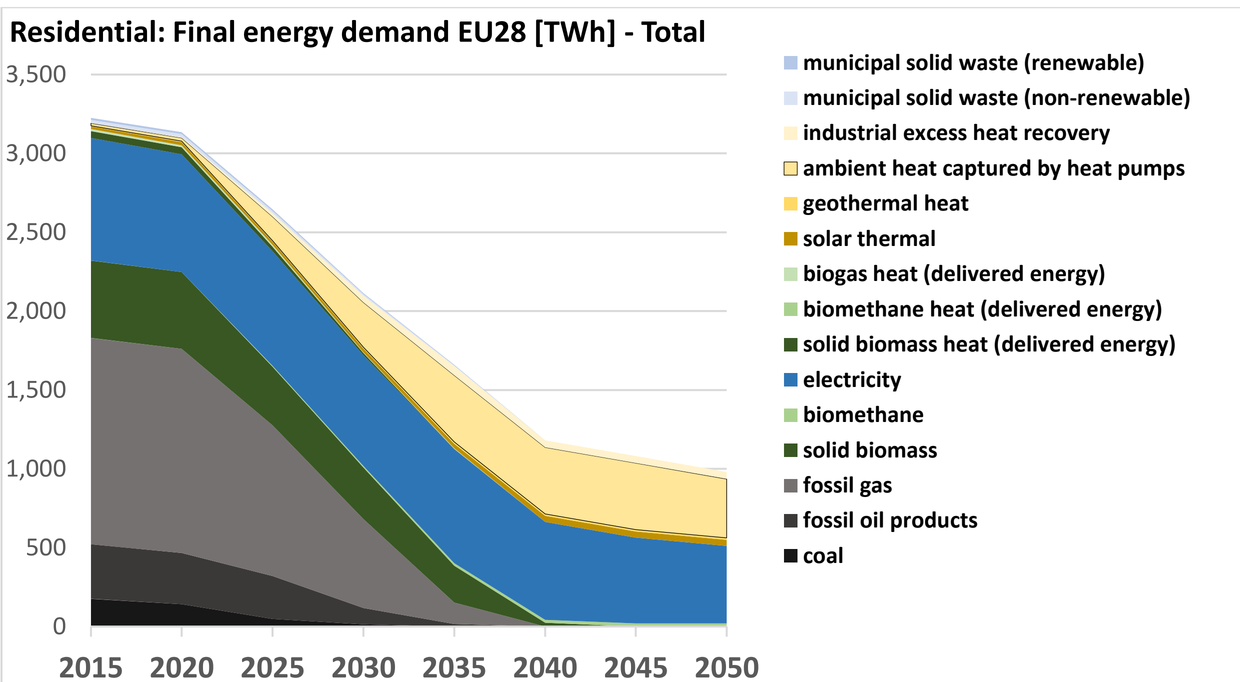
Sensitivities and limitations

Behavioural changes are difficult to predict. Their integration in scenarios necessarily leads to higher uncertainties. The potential impacts of connected appliances on households' energy demand has not been analysed.

Several studies indicate significant energy savings that can be achieved from space heating in buildings.[12] Their parameters on issues such as renovation rates, energy savings per renovation and demolition rates vary. Literature shows that the energy savings potentials from technology changes and from new societal trends do not need to be mobilised both to their full extent for realising the PAC scenario's pathways.

Key results

- Compared to other sectors, the residential sector brings about the strongest reduction in final energy demand, through deep renovation, as well as by new societal trends.
- Electricity constitutes 53% of final energy demand in 2040. Demand for fossil fuels disappears after 2035 while district heating and heat pumps take over most of the demand.
- The demand for gaseous energy carriers beyond 2035 is limited to marginal amounts of biomethane for cooking. No demand for renewable hydrogen neither for synthetic methane is expected in the residential sector.



[12] EUCalc, Fraunhofer ISI, Eurima/Climact: The key role of energy renovation in the net-zero GHG emission challenge, Oct. 2018.

1.3 Tertiary sector

Key assumptions

In accordance with the residential sector, the tertiary sector cuts its energy demand with the help of technology changes and behavioural changes. Final energy demand decreases by almost two thirds between 2015 and 2050.

- Following assumptions on buildings in the residential sector, the annual renovation rate of the EU building stock will increase from 1% to 3%. More than two thirds are deep renovations that cut the energy need of buildings by 60%. Remaining renovations cut 40% of energy need on average.
- A high annual demolition rate of 1% is also foreseen with 70% of new constructions being highly efficient. The floor area per building remains stable between 2015 and 2050.[13]
- In addition to renovation and replacement of inefficient heating systems, new societal trends (urbanisation, building automation, behavioural changes triggered by improved awareness-raising) contribute to overall energy demand reduction with roughly one third.[14]

Evolution of energy demand

The final energy demand of buildings in the tertiary sector comprises offices, wholesale and trade, hotels, gastronomy, education, health care and other building facilities for services. Like in the residential sector, deep renovation reduces massively the final energy demand, however to a slightly minor extent. In accordance with the residential sector, primary energy will be used more efficiently because of a gradual replacement of inefficient individual fossil fuel-fired heating systems by district heating networks and heat pumps.[15]

Although in the tertiary sector the share of electricity demand in final energy demand is more important than in the residential sector, it slumps by more than one third between 2015 and 2050. The strong increase of electricity demand for heat pumps is at the same time offset by reduced demand for space heating and hot water. In addition, the electricity demand for lighting and appliances (including refrigeration and ventilation) falls from 473 TWh in 2015 to 193 TWh in 2050.[16] The energy savings potential of new societal trends can unfold without rebound effects. A precondition is that building automation, digitalisation and behavioural changes go hand in hand with improved awareness-raising on energy consumption.

Integration of members' and experts' feedback

Like for buildings in the residential sector, the annual renovation rate was set at 3%, based on modelling of the EUCalc project. The feedback on mobilising energy savings through behavioural changes and societal trends in the residential sector relates also to the tertiary sector. Assumptions were taken over in accordance while reflecting again the trajectories for energy demand reduction in the tertiary sector from Fraunhofer ISI.

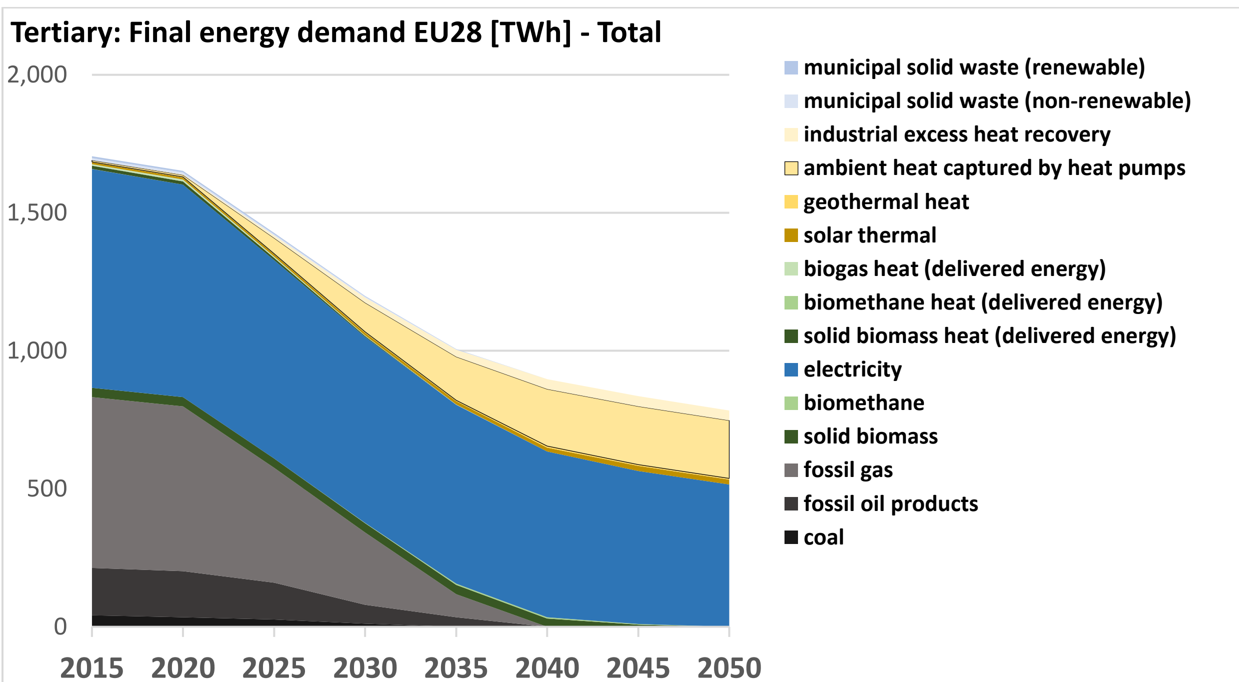
[13] Taking over assumptions from EUCalc.
[14] Taking over assumptions from Fraunhofer ISI.
[15] Aalborg University.
[16] Taking over assumptions from Fraunhofer ISI.

Sensitivities and limitations

The same limitations as in the residential sector apply. Behavioural changes are difficult to predict and imply higher uncertainties. Regarding the important share of electricity demand caused by information and communication technologies (ICT) and building technologies in the tertiary sector, future impacts of connected appliances would merit a more in-depth analysis. This would improve the first assessment that was integrated into the PAC scenario.

Key results

- With 54% less final energy demand in 2050 compared to 2015, the reduction in the tertiary sector is significant but not to the same extent as in the residential sector. It is enabled by increased deep renovation, as well as by societal trends (building automation, digitalisation and behavioural changes).
- Electricity constitutes 67% of final energy demand in 2040. Demand for fossil fuels disappears after 2035 while district heating and heat pumps take over most of the demand.
- The demand for gaseous energy carriers beyond 2035 is limited to marginal amounts for cooking. No demand for renewable hydrogen neither for synthetic methane is expected in the tertiary sector.



1.4 Agriculture

Key assumptions

Final energy demand of the agriculture sector decreases by 63% between 2015 and 2050 due to renovation of the building stock and higher energy efficiency of processes and machinery.

- Refurbishment of the building stock follows assumptions on buildings in the residential and tertiary sector.[17]
- Final energy demand for space heating, warm water and processes decreases. Electricity demand for these uses increases because of heat pumps becoming the most important technology.
- Fossil fuel demand for farming machines, motor drives and pumping devices is largely substituted by electricity and partly covered by sustainably sourced liquid biofuels.

Evolution of energy demand

The dominating fossil fuel demand for space heating, hot water and processes disappears after 2035. Electricity demand for heating increases as a consequence of the broad introduction of heat pumps. In addition, heat demand will increasingly be covered by district heating. Its contribution to agriculture's final energy demand however remains relatively small, compared to the residential and tertiary sector. Because of the lower population density in rural areas, individual heating systems remain more important.

Farming machine drives gradually phase-out the use of fossil oil products. Energy demand will be covered instead by liquid biofuels. Electrification of farming machines is not considered. Pumping devices will be electrified. Final energy demand for lighting, ventilation, motor drives and other specific electricity uses in agriculture reduces at the same pace like in the residential and tertiary sector. In addition, the direct availability of bioenergy carriers in agriculture is considered as a decisive factor. In 2040, agriculture's final energy demand is by 41% covered by self-generated biogas, by solid biomass and by liquid biofuels.

Integration of members' and experts' feedback

Following discussions with members and experts, limitations for the use of bioenergy for covering energy demand in general were defined (see also chapter 2.6). The agriculture sector mobilises only a small share of the biomass potential that is integrated into the PAC scenario.[18] The most efficient use of biogas exclusively in combined heat and power (CHP, cogeneration) is considered as a priority and as realistic.

Sensitivities and limitations

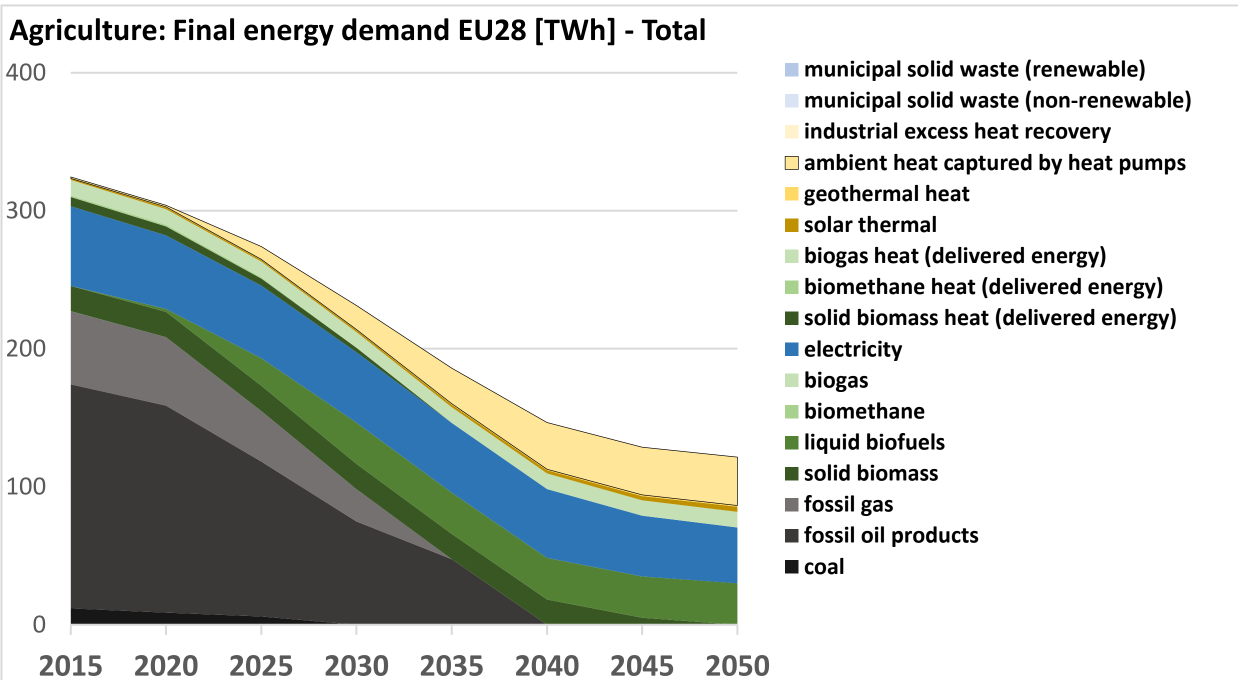
Energy demand of farming machines is important. If no electrification is assumed, it can be covered by liquid biofuels or by biomethane. Both available combustion technologies allow to fully substitute fossil oil demand. The conditions for this fuel switch however have not yet been assessed more in detail.

[17] Key assumptions are taken over from tertiary sector figures in Fraunhofer ISI.

[18] EEB: Burnable carbon. What is still burnable in a circular, cascading, low carbon economy? Position paper, June 2017; ICCT: The potential for low-carbon renewable methane in heating, power, and transport in the European Union, October 2018; CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

Key results

- The agriculture sector mobilises comparably high energy savings likewise the residential and tertiary sector. Final energy demand drops by 63% in 2050 compared to 2015.
- Overall electricity demand decreases slightly despite electrification of space heating, hot water, processes and pumping devices. The first reason is the lower heat demand, the second one is the higher energy efficiency of appliances and machinery.
- In 2040, 36% of final energy demand is electricity. Demand for fossil fuels disappears after 2035. A relatively high demand for bioenergy is preserved given the availability of sustainably sourced solid biomass and biogas for direct use on premises.



1.5 Transport

Key assumptions

Due to efficiency considerations and given the decreasing cost of renewable electricity and battery storage, in transport, fuel switching to direct electrification has been prioritised. Therefore:

- For private cars, the PAC scenario assumes a fully electrified fleet by 2040[19]. Road freight will also be covered in priority by electrification (either through batteries, highways with overhead catenary lines or switch to rail), then by renewable hydrogen for heavy duty.[20]
- Shipping will be covered by electricity for short-distance, a mix of electricity and renewable hydrogen for mid-distance (intra-EU), and a mix of renewable hydrogen and ammonia for long-distance.[21]
- Aviation will be mostly covered by liquid synthetic fuels and marginally by second-generation biofuels[22], until the progressive development of electric aircrafts post-2040.

Evolution of energy demand

In general, transport activity (i.e. the product of passengers or tons of freight*distance) will slightly increase, with annual activity growth rate ranging from 0.52% in cars to 1.67% in freight. However, the growth in travel demand will be more than compensated by efficiency gains through electrification, technical improvements, modal shift and behavioural changes. These gains will cut energy demand in half between 2015 and 2040. For private cars, this would lead to over 20% reduction in car use and a 10% increase in the number of passengers per vehicle by 2040 compared to the baseline. For aviation, most of demand reduction will stem from price incentives (with a €150/t carbon price by 2040), leading to an overall reduction in energy demand by around 26% in 2040 compared to baseline. Regarding the impact of modal shift, the PAC scenario assumes doubling[23] rail freight between 2015 and 2040[24], and a 12% shift[25] from car to bus, train, walk and bicycle combined.

Integration of members' and experts' feedback

Most of the members' and experts' feedback has been questioning transport activity growth and limited modal shift[26]. Considering these remarks, the PAC scenario has been updated to reflect behavioral changes, by applying a moderation of activity between 2020 and 2040. The PAC scenario also reflects circular economy principles, by reducing freight activity post-2040, and technological progress, by including the uptake of electric aircraft to gradually replace liquid biofuels post-2040. Since empirical evidence confirms the link between gross domestic product (GDP) growth and transport demand[27], the PAC scenario kept a moderate growth in transport activity to remain consistent with other sectors.

[19] Transport and Environment: Roadmap to decarbonising European cars, November 2018.

[20] Transport and Environment: Roadmap to climate-friendly land freight and buses in Europe, June 2017.

[21] Ammonia has a higher energy density than hydrogen and therefore allows for longer distances. Transport and Environment: Roadmap to decarbonising European shipping, November 2018.

[22] Transport and Environment: Roadmap to decarbonising European aviation, October 2018.

[23] In tons of freight*km, from around 400 billion to around 800 billion.

[24] Transport and Environment: Roadmap to climate-friendly land freight and buses in Europe, June 2017.

[25] In passenger*km.

[26] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

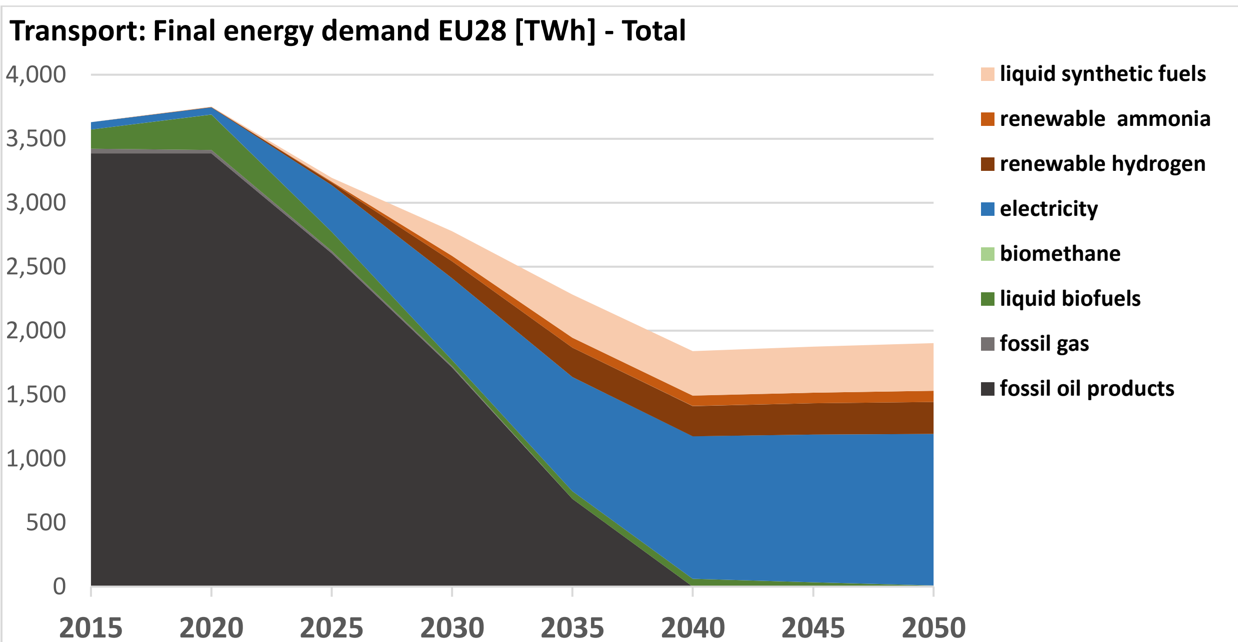
[27] OECD: Decoupling the environmental impacts of transport from economic growth, December 2016.

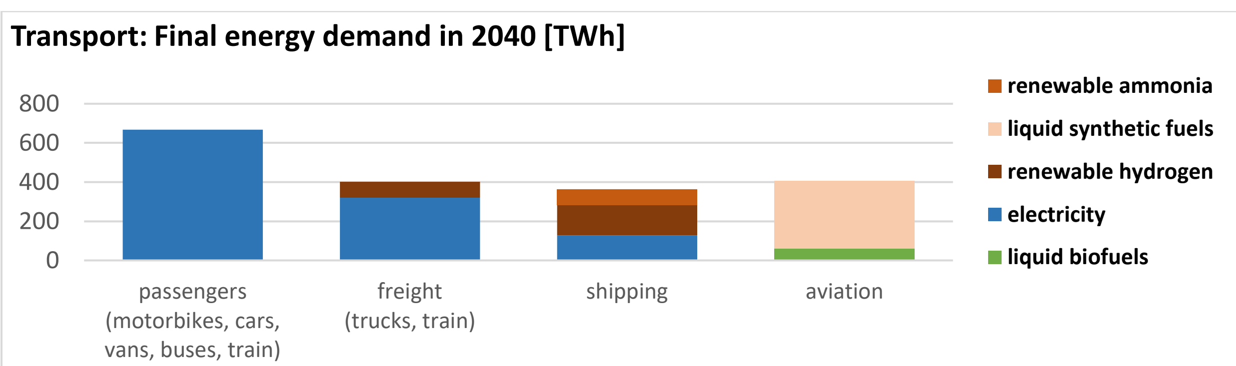
Sensitivities and limitations

Reaching net zero emissions by 2040 could be challenging for the transport sector, meaning vehicles with internal combustion engine (ICE) sold after 2020 will need to have a shorter lifetime in order to reach a fossil-free fleet by 2040. Also, the high pace of electrification requires particular attention in sustainable battery and electricity supply to remain Paris Agreement compatible.[28]

Key results

- Transport will move from a 90% fossil-based to a 100% renewable energy mix in the next 20 years.
- Biofuels demand will be halved by 2040, moved to second-generation and strictly dedicated to aviation.
- Direct use of electricity will represent around two thirds of the transport fuel mix.

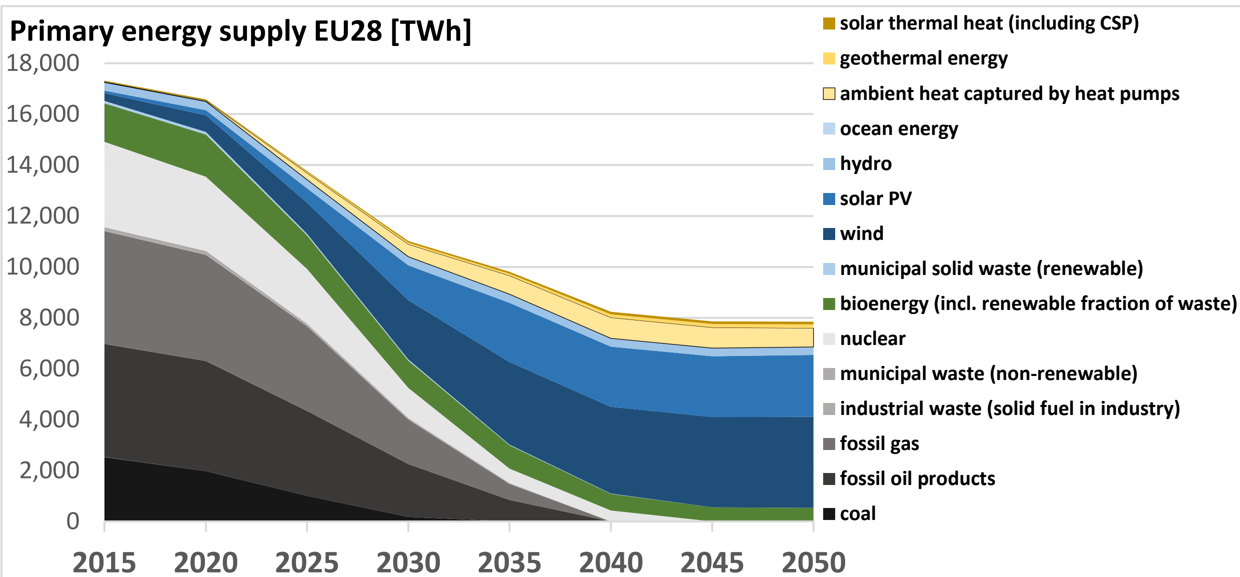


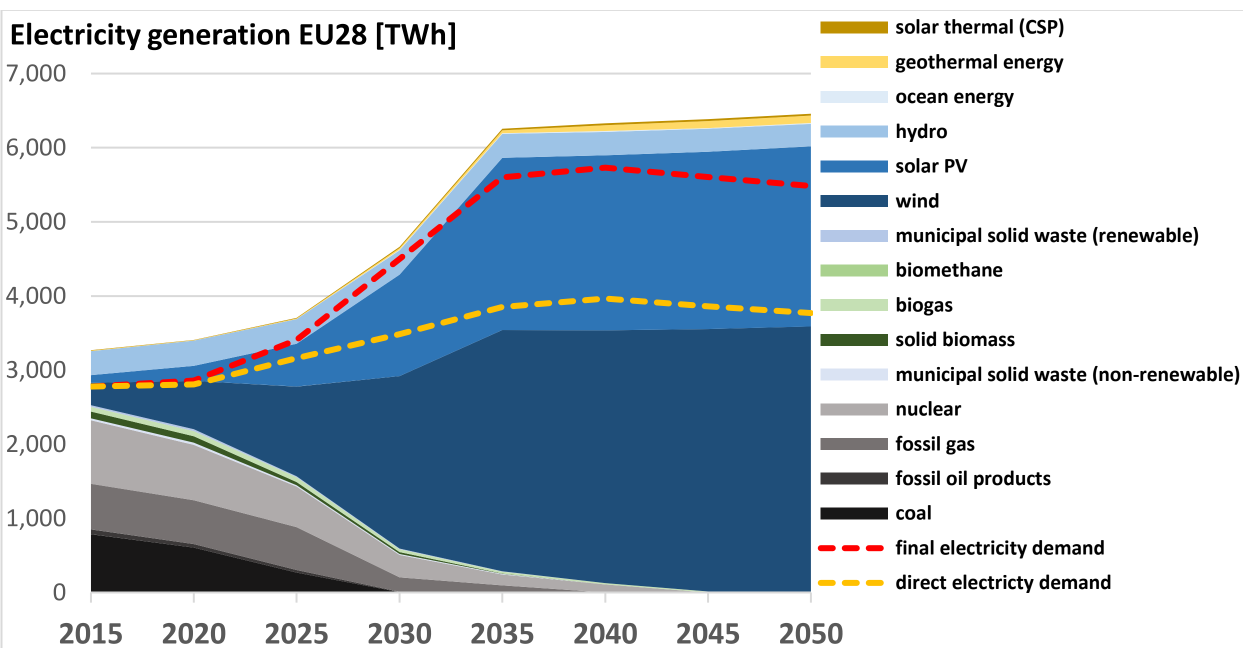


[28] Dominish, E., Florin, N. and Teske, S.: Responsible minerals sourcing for renewable energy, April 2019. The PAC scenario does not include a detailed assessment of the raw material needs for ramping up renewable generation capacities and EV batteries production. Research shows that besides increased responsible sourcing, demand for metals in a 100% renewable energy scenario can be satisfied through higher recycling rates and material efficiency. If supply chains are managed appropriately, social and environmental harms can be avoided and further expansion of unsustainable practices such as deep sea mining are not necessary.

2. Energy supply

The second chapter presents the primary energy supply that covers the sector-specific energy demand as presented in chapter 1. Primary energy covers consumption of the energy sector itself, losses during transformation (i.a. from gas into electricity) and distribution of energy, and the final consumption by end users. Losses from converting the primary energy into other energy carriers are not yet deducted, neither losses of transmission and distribution, e.g. from district heat networks or leaking gas pipelines. In the following subchapters, the specific supply and conversion of different primary energy sources is assessed. Total supply of primary energy halves from 2015 to 2050 with renewables becoming the major source by 2030. Solar PV and wind by then also supply most electricity, covering an increasing direct demand and the additional electricity demand for producing non-fossil gases through electrolysis (see "final electricity demand" below).





2.1 Phasing out coal

Key assumptions

It is as indispensable[29] as inevitable that most of the hard coal and lignite consumption will be phased-out by the year 2030.

- National coal phase-out plans for electricity generation exist in most EU Member States. These will be implemented or even anticipated by power plant operators because of high carbon prices and low economic attractiveness.[30] Coal fired power plants that supply district heat tend to be retired later.
- The increase of the carbon price and renewable capacities will strongly reduce the full load hours of the remaining coal capacities. Most of them will be retired by 2030. Very few reserve capacities remain.[31] Neither retrofitting of existing coal capacities nor new mines are considered economically viable.
- Renovation will lead to a quick replacement of individual heating based on coal. In industry, energy savings as well as electrification and renewable hydrogen will substitute the most important coal supply in the steel, cement and ceramics industries. The introduction of CCS is not considered realistic.

Evolution of energy supply

Coal-fired power plants have become risky assets for most operators in most countries.[32] In addition, air quality legislation leads to earlier shutdowns. In 2030, only 7 TWh of electricity are produced by remaining capacities in Germany, Poland, Estonia and Czechia. These are used as back-up capacities with very low full load hours.

In the energy-intensive industry, the phase-out of coal will progress only slightly slower than in electricity generation. Coal supply falls from 394 TWh in 2015 to 140 TWh in 2030 to disappear by 2035. This development is largely due to developments in the steel industry. Firstly, the reduced steel demand cuts coal consumption. Besides this trend, a massive increase of the electric arc furnace route for steel production together with the introduction of the Direct Reduction of Iron (H-DRI) process reduces the coal supply for blast furnaces.[33]

Integration of members' and experts' feedback

The coal-phase out trajectory was developed in close collaboration with experts and members. Assumptions were discussed at the PAC scenario workshops.[34] Key figures for the electricity sector are based on the Europe Beyond Coal campaign's database of coal-fired power plants.[35] In addition to the Öko-Institut's market modelling (see page 38), several country-specific studies were considered to substantiate the phase-out trajectory.[36]

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[29] Climate Analytics: Global and regional coal phase-out requirements of the Paris Agreement, September 2019.

[30] Carbon Tracker: Powering down coal. Navigating the economic and financial risks in the last years of coal power, November 2018; Sandbag: The cash cow has stopped giving: Are Germany's lignite plants now worthless? July 2019.

[31] This was confirmed by Öko-Institut's electricity market modelling with PAC scenario assumptions and a carbon price of €84/t.

[32] Carbon Tracker: Apocoalypse now, October 2019; Carbon Tracker: Lignite of the living dead, December 2017.

[33] Material Economics.

[34] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

[35] Europe Beyond Coal: European Coal Plant Database. Status: 12 July 2019. Country-specific updates were integrated by May 2020.

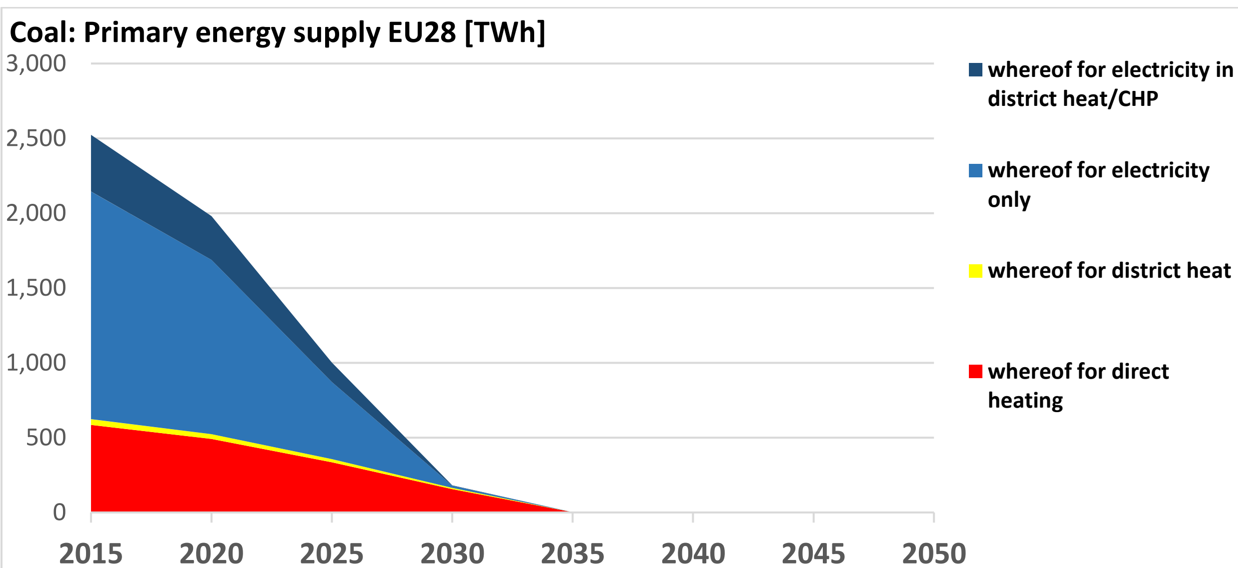
[36] Forum Energii: PEP2040 scrutinized by Forum Energii. Comments and recommendations, Nov. 2018; Energynautics: Czech power grid without electricity from coal by 2030, May 2018; REKK et al.: Accelerated lignite exit in Bulgaria, Romania and Greece, May 2020; Bartholdsen et al.: Pathways for Germany's low-carbon energy transformation towards 2050. In: Energies, 2019, 12, 2988, Aug. 2019.

Sensitivities and limitations

Depending on the short- and mid-term evolution of the EU Emission Trading System (ETS) carbon price, capacities for electricity generation could be retired even more quickly. A potential fuel switch of coal-fired power plants from coal to biomass has not been analysed in detail. Given the environmental risks associated with it, such a conversion or co-firing should be avoided.[37]

Key results[38]

- NGOs' policy demand of phasing out coal by 2030 will mostly be implemented: In electricity generation, renewables and the carbon price drive the quick phase-out in almost all Member States by 2030. Support schemes such as capacity mechanisms can delay this trend only by a few years.
- Poland and Germany are the two Member States that dominate the remaining hard coal and lignite capacities. In 2030, Poland produces 2 TWh and Germany 4 TWh of electricity from coal.
- As the use of coal in industry is mainly concentrated in a limited number of energy-intensive steel production sites, their gradual modernisation during normal investment cycles will bring about a switch from coal to renewable electricity and hydrogen (see also chapter 1.1 on industry's energy demand).



[37] Sandbag: Playing with fire. An assessment of company plans to burn biomass in EU coal power stations, Dec. 2019.

[38] Findings in this chapter also include the extraction and combustion of oil shale which statistically accounts as hard coal. In the EU, it is used for electricity generation in Estonia only. In 2030, oil shale fired capacities of 659 MW remain in Estonia with <1 TWh of electricity produced according to Öko-Institut's electricity market modelling. It is possible that these capacities will be retired earlier.

2.2 Phasing out fossil gas

Key assumptions

The continued use of fossil gas puts the EU's climate and energy goals at risk. In addition to the decreasing demand for electricity generation and in buildings, an active fossil gas phase-out by 2035 needs to be pursued.[39]

- A further increase of fossil gas supply for electricity generation to replace coal power plants is not foreseen given the availability of cheaper renewable electricity supply. Full load hours slump by 2030.[40]
- The PAC scenario assumes that fossil gas supplied for heating buildings in the residential and tertiary sector will be strongly reduced by 2035 because of the high rate and depth of renovation that trigger the replacement of fossil gas boilers. Any uptake of fossil gas supply in transport is not realistic.
- The impact of methane leakage from fossil gas infrastructure on global warming increases pressure to rapidly cut fossil gas supply.[41] The introduction of CCS is not considered realistic.

Evolution of energy supply

Together with fossil oil products, fossil gas in 2015 was the most important source of primary energy supply of the EU. In industry, fossil gas dominates with 1,077 TWh supplied in 2015 (34% of industry's final energy demand). As a consequence of reduced material demand, increased energy efficiency, electrification and introduction of non-fossil gases (renewable hydrogen, synthetic methane), supply goes down to 203 TWh in 2035 (8% of final demand) and will be entirely phased out by 2040.

While 41% of the residential sector's and 36% of the tertiary sector's final energy demand in 2015 was covered by fossil gas, the share drops to 9% in 2035. The remaining 136 TWh in the residential sector and 84 TWh in the tertiary sector will eventually disappear from the mix by 2040 because of the high rate and depth of renovation that trigger the replacement of fossil gas boilers for individual heating. Cooking will be largely electrified or switched to biomethane.

The share of fossil gas in electricity generation falls from 22% (616 TWh) in 2015 to 2% (96 TWh) in 2035. Remaining capacities however will not always immediately be mothballed. They might still be used to burn non-fossil gases (renewable hydrogen, synthetic methane) to offset variable renewable electricity generation during very few hours of peak demand.

Integration of members' and experts' feedback

During the collective PAC scenario building process, members and experts highlighted the need for proactive fossil gas phase-out policies of Member States in order to achieve the ambitious trajectory. Instruments such as a ban on gas boilers and financial incentives for transitioning cities to fossil-free heating are a prerequisite.[42]

[39] E3G: Pathway to a climate neutral 2050: Financial risks for gas investments in Europe, February 2020; E3G: Deep decarbonisation and the future of gas in the EU, March 2019; Global Witness: Overexposed: How the IPCC's 1.5°C report demonstrates the risks of overinvestment in oil and gas, April 2019; FoEE: Can the climate afford Europe's gas addiction? November 2017.

[40] This was confirmed by Öko-Institut's electricity market modelling with PAC scenario assumptions and a carbon price of €84/t.

[41] Energy Watch Group: Natural gas makes no contribution to climate protection, September 2019.

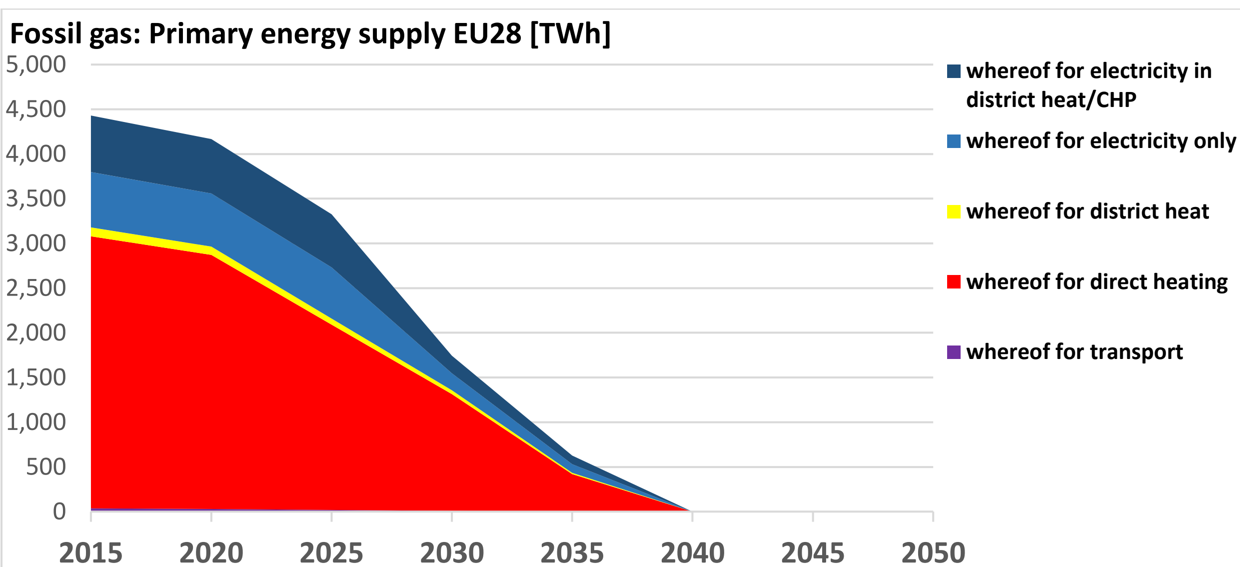
[42] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

Sensitivities and limitations

Uncertainties remain with regards to the pace of fossil gas phase-out. The oversupply of cheap fossil gas streaming to Europe makes a quick shift to its alternatives challenging in the residential and tertiary sectors. Households' investment decisions tend to favour continued use of the heating technology that they already are familiar with, in particular if Member States subsidise installing new gas boilers in households. Existing fossil gas infrastructure exerts inertia, meaning that established operators and gas suppliers successfully keep their consumers tied to incumbent distribution chains. Alternatives such as new and efficient district heating networks often would need to be anticipated and facilitated first in lengthy spatial planning processes. Against this backdrop, policies and measures are a decisive element for the role of fossil gas.

Key results

- Electricity generation from fossil gas decreases by 84% from 2015 to 2035. Fossil gas is not needed as a "bridge fuel". Immediate leap-frogging from coal to renewable electricity generation is possible.
- Renovation pushes fossil gas out of buildings' energy supply. Final energy demand for fossil gas in the residential sector drops by 90% from 2015 to 2035 (-86% in tertiary). Electrification and non-fossil gases fully substitute fossil gas in industry between 2035 and 2040.
- High carbon prices and EU and Member States' commitment to phasing out fossil gas is crucial for the trajectories shown in the PAC scenario.



2.3 Phasing out fossil oil

Key assumptions

The absolute domination of fossil oil products in the transport sector is not compatible neither with the Paris Agreement's 1.5°C objective nor with the EU climate and energy targets,[43] therefore:

- Fossil oil disappears from the transport sector's energy supply by 2040 thanks to massive electrification combined with fuel-switching.[44]
- Ongoing modernisation of production processes and higher energy efficiency lead to a gradual phase out of oil in industry and agriculture. Circular economy principles accompany the phase out in the chemicals industry, also with regard to its role as a raw material.[45]
- Fossil oil will be phased out for space heating and hot water in buildings with the gradual replacement of old and inefficient heating oil boilers due to renovations.

Evolution of energy supply

Fossil oil products in 2015 were the most important source of primary energy supply. By 2030, fossil oil will remain by far the dominating energy supply in transport. In 2015, it covered 93% of final energy demand (3,385 TWh). Even after a steep market introduction of electric vehicles, 60% of final demand is still covered by fossil oil in 2030. With a further massive upscaling of renewable electricity, of renewable hydrogen and liquid synthetic fuels, its share decreases to 28% in 2035. Fossil oil products then are phased out by 2040.

In agriculture, fossil oil covered 50% of final energy demand in 2015 (162 TWh), falling to 47 TWh in 2035. It will be partly substituted by renewable electricity and by liquid biofuels for farming machinery, leading to an entire phase-out between 2035 and 2040. Fossil oil supply for heating in buildings has a less important role. Similar to the phase out of fossil gas boilers, the renovation of buildings leads to a fast switch to renewable heating such as heat pumps and renewable district heating. Fossil oil supply will reduce by 95% between 2015 and 2035 in the residential sector (-80% in tertiary).

Fossil oil supply in industry is often limited to processes that can be electrified or that can switch to biomass or non-fossil gases.[46] In electricity generation, fossil oil loses its marginal role as reserve capacity and for islands.

Integration of members' and experts' feedback

Based on a comparison of cost factors and technology readiness, members and experts attending the PAC scenario workshops and providing feedback suggested a very quick ramping up of electric vehicles and thus an advanced phase-out of fossil oil in road transport.[47]

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[43] Global Witness: Overexposed: How the IPCC's 1.5°C report demonstrates the risks of overinvestment in oil and gas, April 2019.

[44] Transport and Environment: How to decarbonise European transport by 2050, November 2018.

[45] Material Economics.

[46] In 2015, the non-energy use of fossil oil products in the chemicals industry (707 TWh) is 25 times higher than the direct use for energy supply. In contrast with the latter, fossil oil will remain in non-energy use for the production of raw materials. Circular economy approaches however allow for a phase-out by 2050. In energy statistics, the non-energy use of fossil fuels in the chemicals industry is not accounted with regards to emissions or shares of energy carriers.

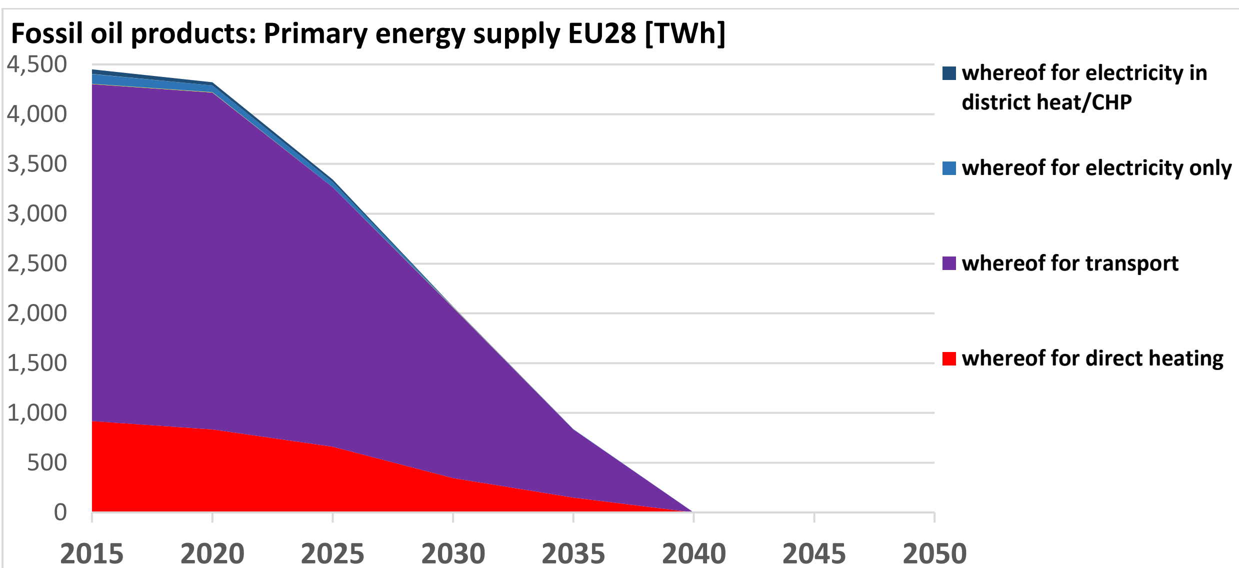
[47] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

Sensitivities and limitations

The availability of alternatives to fossil oil in aviation is limited to second generation liquid biofuels and liquid synthetic fuels. Their competitiveness has not been assessed in detail. The analysis of economic and regulatory conditions for phasing out the fossil oil product kerosene by 2040 lies beyond the exercise of this first PAC scenario.

Key results

- Fossil oil quickly loses its dominating role in the transport sector by 2035, shrinking to 28% of final energy demand. This is followed by a full phase out by 2040, provided liquid synthetic fuels are scaled-up from the beginning of the 2030s to substitute kerosene in aviation.
- Like in the case of fossil gas, deep renovations quickly squeeze fossil oil out of the supply mix for heating and hot water in buildings. Final energy demand for fossil oil in the residential sector drops by 95% from 2015 to 2035 (-80% in tertiary).
- Phasing out fossil oil in industry is less challenging than leaving fossil gas. It slumps from a share of 8% in final energy demand in 2015 to 2% in 2035.



2.4 Phasing out waste incineration

Key assumptions

- Waste incineration will be phased out by 2040, assuming a 20-year lifetime of incinerators and taking into account a gradual implementation of the circular economy approach and shrinking waste volumes.

Evolution of energy supply

Burning solid municipal waste in waste incinerators for electricity and heat production only plays a minor role in the EU's energy mix.[48] In light of the implementation of the circular economy legislation in the EU, the available residual waste will decline while the biomass share of waste will partly be redirected towards biogas generation or solid biomass CHP at lower investment and operating costs. Electricity generation falls from 48 TWh and gross final heat consumption from 96 TWh in 2015 to zero in 2040. Waste as a solid fuel in industry disappears by 2040.

Integration of members' and experts' feedback

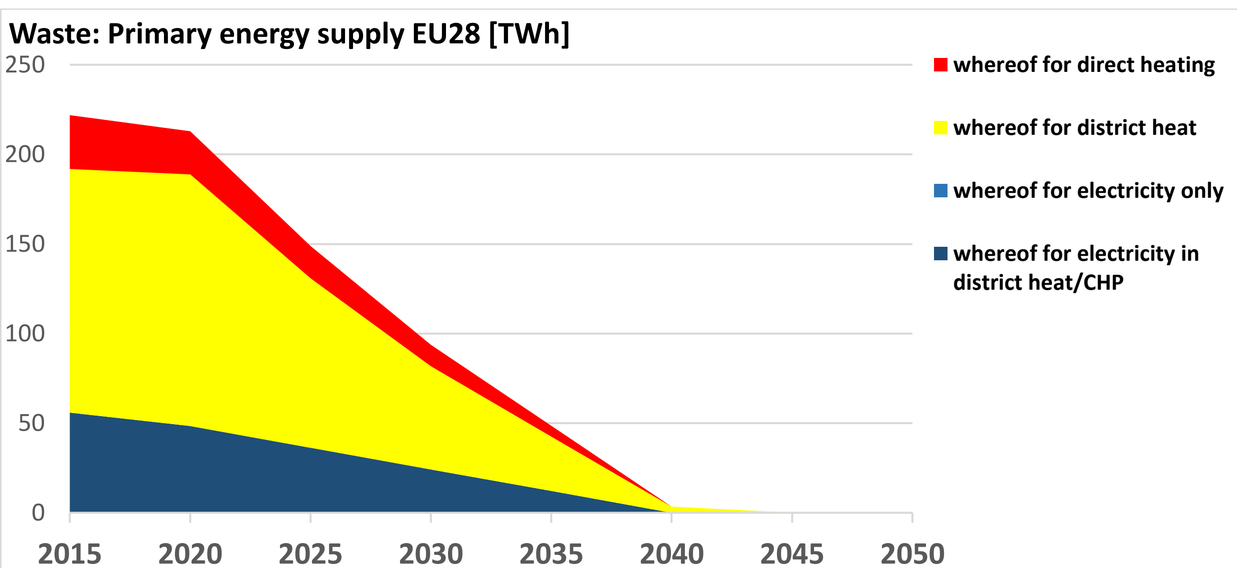
Members and participants of the scenario workshops confirmed the phase-out trajectory for waste incinerators. Keeping a continuously high level of waste demand would undermine targets for higher recycling rates.

Sensitivities and limitations

Poor data quality of installed capacities and operating parameters of waste incinerators need to be improved.

Key results

- The EU continues its circular economy approach, reduces waste and leaves waste incineration by 2040.



[48] Eurobserver: Renewable municipal waste barometer, November 2014; ENTSO-E: Transparency platform, November 2019. Given the average biomass share in solid municipal waste, 43% of energy supplied is renewable energy.

2.5 Phasing out nuclear power

Key assumptions

- Newly added capacities are not realistic due to high investment costs and competition of renewables.
- Lifetime is limited to 40 years unless governments and/or operators explicitly announce schedules.
- Increasing costs of maintenance, of the fuel chain and decommissioning incentivise earlier retirements.

Evolution of energy supply

National phase-out plans will be implemented. In countries without such plans, the expected retirement of capacities is based on the country profiles published by the World Nuclear Association.[49] For economic and security reasons, lifetimes are not extended anymore. After 40 years of operation, most capacities are retired as investment in modernisation and maintenance costs are higher than expected income from wholesale markets.[50] Only capacities at an advanced stage of construction will be completed.

Installed capacities in France alone in 2015 exceeded the sum of installed capacities in all other EU Member States. Provisions of the *Programmation pluriannuelle de l'énergie* 2018 (PPE) apply: at least 12 reactors from defined sites will have to be retired between 2027 and 2035 to reduce the share of nuclear power to the legally fixed maximum threshold of 50% of French electricity consumption. Following an option under the PPE, two additional reactors will be retired between 2025 and 2026 as foreseen by PPE in case of oversupply on the European wholesale electricity market. The lifetime of remaining capacities will be mostly limited to 40 years, because after the fourth decennial inspection, further modernisation is economically not viable for the operator EDF.[51]

Electricity generation decreases from 857 TWh in 2015 to 109 TWh in 2040 and disappears by 2045. Only very few capacities built after 2000 remain in the electricity mix between 2040 and 2045, mainly in France and UK.

Integration of members' and experts' feedback

Retirement trajectories were discussed and slightly adapted in exchange with members' national experts.

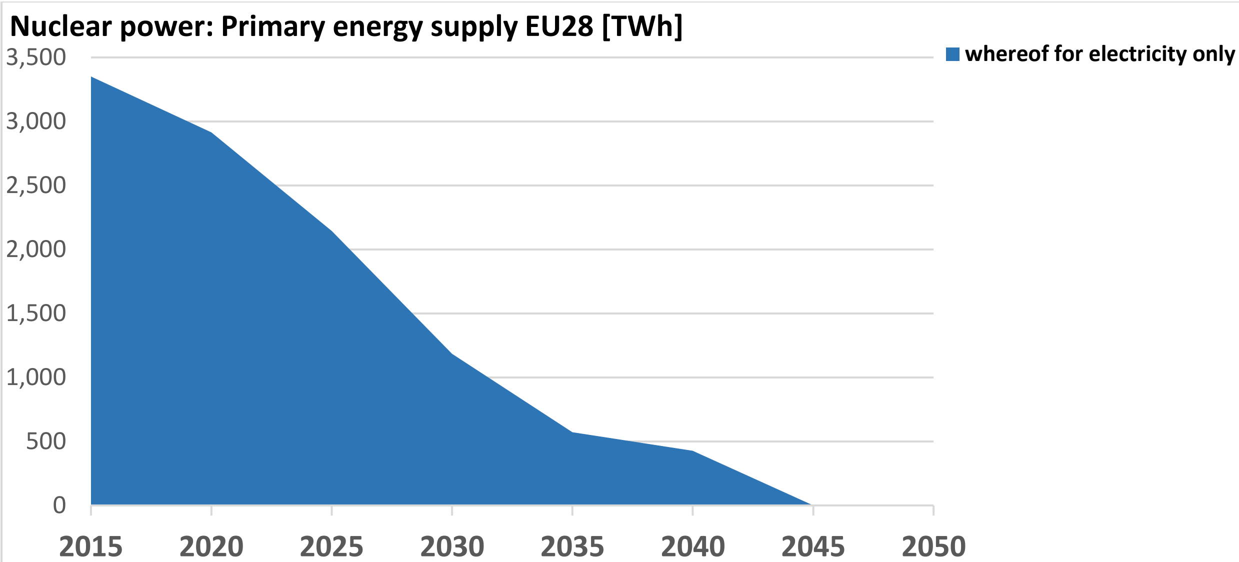
Sensitivities and limitations

Nuclear power is strongly dependent on national policy frameworks and still enjoys direct and indirect subsidies. For countries without clear phase-out plans, governments' commitment to support this technology is crucial.

Key results

- A minority of EU Member States keeps nuclear power in the mix. Except for the few reactors added after 2000, all capacities will be retired by the year 2040.
- Its share in electricity generation drops from 26% in 2015 to 6% in 2030 and remains marginal in 2040.

[49] World Nuclear Association: Country profiles, Sept. 2019; https://www.world-nuclear.org/information-library/country-profiles.aspx
[50] Öko-Institut: The Vision Scenario for the European Union. 2017 Update for the EU-28, February 2018; Négawatt: Scénario négaWatt 2017-2050. Dossier de synthèse, January 2017.
[51] Négawatt.


Nuclear power: Primary energy supply EU28 [TWh]
whereof for electricity only
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2015
2020
2025
2030
2035
2040
2045
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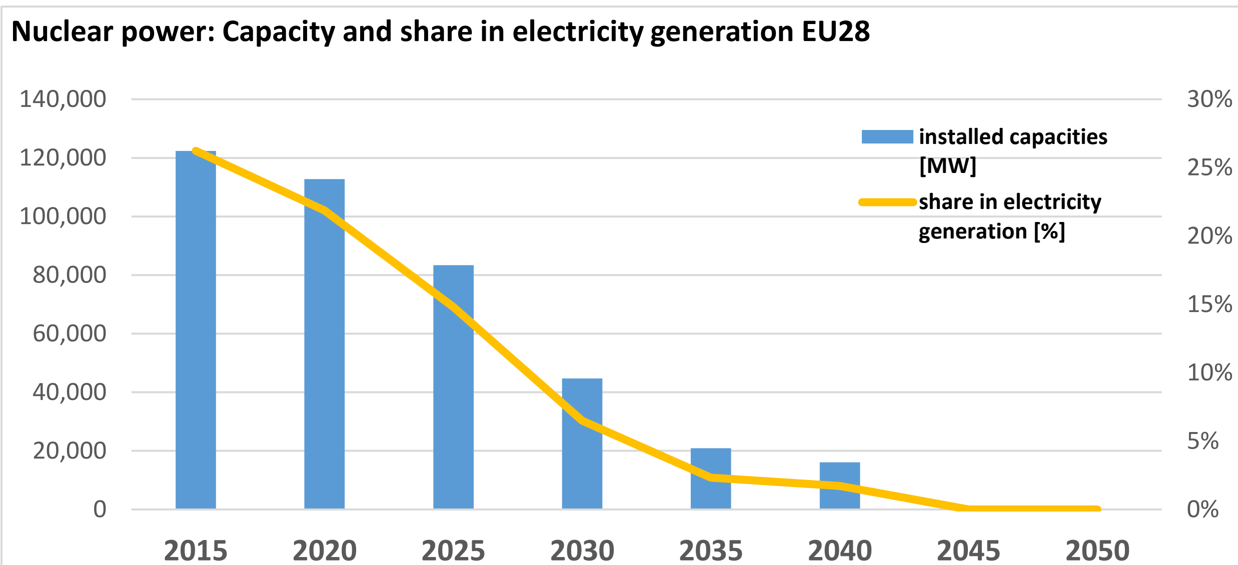
Nuclear power: Capacity and share in electricity generation EU28
installed capacities [MW]
share in electricity generation [%]
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
30%
25%
20%
15%
10%
5%
0%
2015
2020
2025
2030
2035
2040
2045
2050

2.6 Mobilising bioenergy

Key assumptions

Biomass is an abundant resource with a very limited sustainable potential for energy. Therefore, the PAC scenario implies clear boundaries for bioenergy use:

- In line with EEB's and CAN Europe's principles on sustainable bioenergy use, an increase of forest harvests is excluded. For reasons of forest ecology, areas left out of harvesting increase and a maximum of 70% of residues is available for energy needs. Co-firing and electricity-only use is replaced by cogeneration.[52]
- Only waste and residues with climate benefits and no alternative use feed the biogas production.[53] Due to reduction of waste streams, no substantial increase of available fermentable waste is expected.
- So-called first generation biofuels are phased-out by 2030. Second generation biofuels are limited to aviation and self-consumption in agriculture, with low land footprint and stringent sustainability criteria.

Evolution of energy supply

In order to phase out coal and fossil gas during the 2030s, bioenergy carriers are kept or redirected towards hard to decarbonise industry sectors such as steel, ceramics, cement and glass. Bioenergy steadily covers around 10% of industry's reducing final energy demand between 2015 and 2050. While biomethane supply increases, solid biomass for direct heating in industry is more than cut in half between 2015 (280 TWh) and 2050 (114 TWh). Solid biomass is however shifted towards a non-energy use as raw material input in the chemicals industry (270 TWh in 2050). This allows to substitute fossil oil products in a circular economy approach.[54] In the residential sector, individual heating with solid biomass (15% of final energy demand in 2015) decreases due to energy savings and switching to other more efficient individual renewable heating systems or connection to district heating.

Biogas is mostly used in small CHP units. As a relatively costly but dispatchable energy carrier, they can turn into "gap fillers" to produce more flexibly and offset variable solar and wind. In the 2030s, most biogas is upgraded to biomethane in order to substitute fossil gas in distinct industry sectors' processes that require methane.

Supply of liquid biofuels reaches a peak in 2020 with 278 TWh to strongly slump to 39 TWh in 2050. The dominant use for blending of first generation biofuels in road transport ends with the quick market introduction of electric vehicles. Biofuel use is reoriented towards hard to decarbonise aviation. In addition, by 2030, 30 TWh are self-consumed in agriculture to substitute fossil oil products in farming machinery.

Integration of members' and experts' feedback

Priorities for bioenergy use in different sectors were substantiated and adapted in exchange with members and PAC scenario workshops. This included a gradual phasing out of bioenergy from individual and district heating.[55]

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[52] CAN Europe, EEB et al.: Pitfalls and potentials. The role of bioenergy in the EU climate and energy policy post 2020. NGO recommendations, April 2015; EEB: Burnable carbon. What is still burnable in a circular, cascading, low carbon economy? June 2017.

[53] ICCT: The potential for low-carbon renewable methane in heating, power, and transport in the European Union, October 2018. Sequential crops could be a valuable feedstock for biogas production provided they do not drive unsustainable farming practices.

[54] Material Economics.

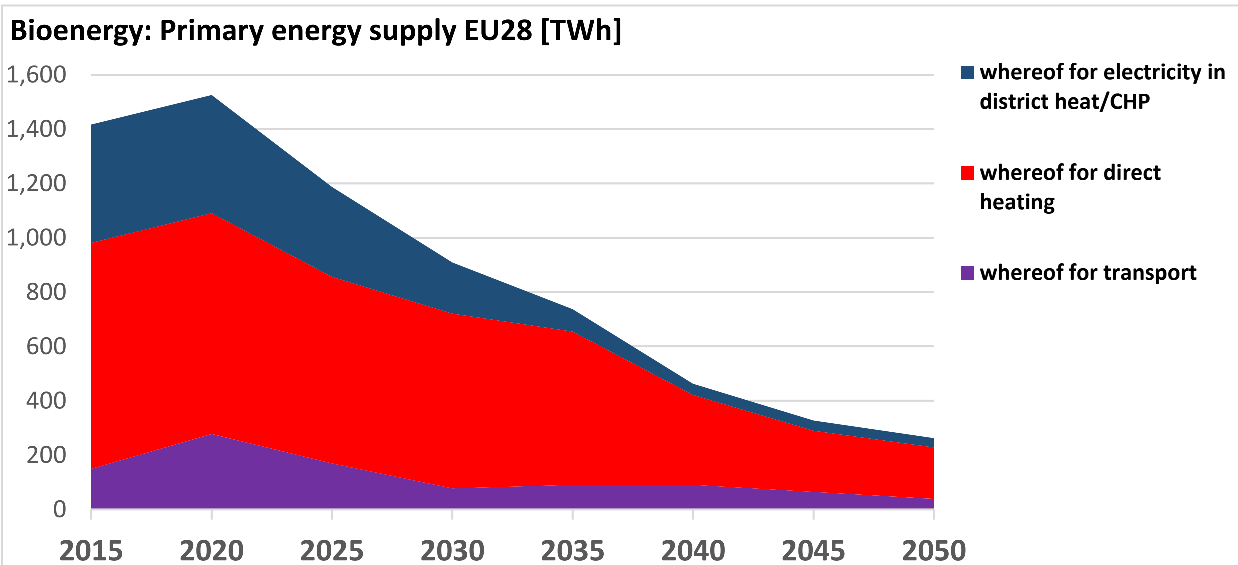
[55] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

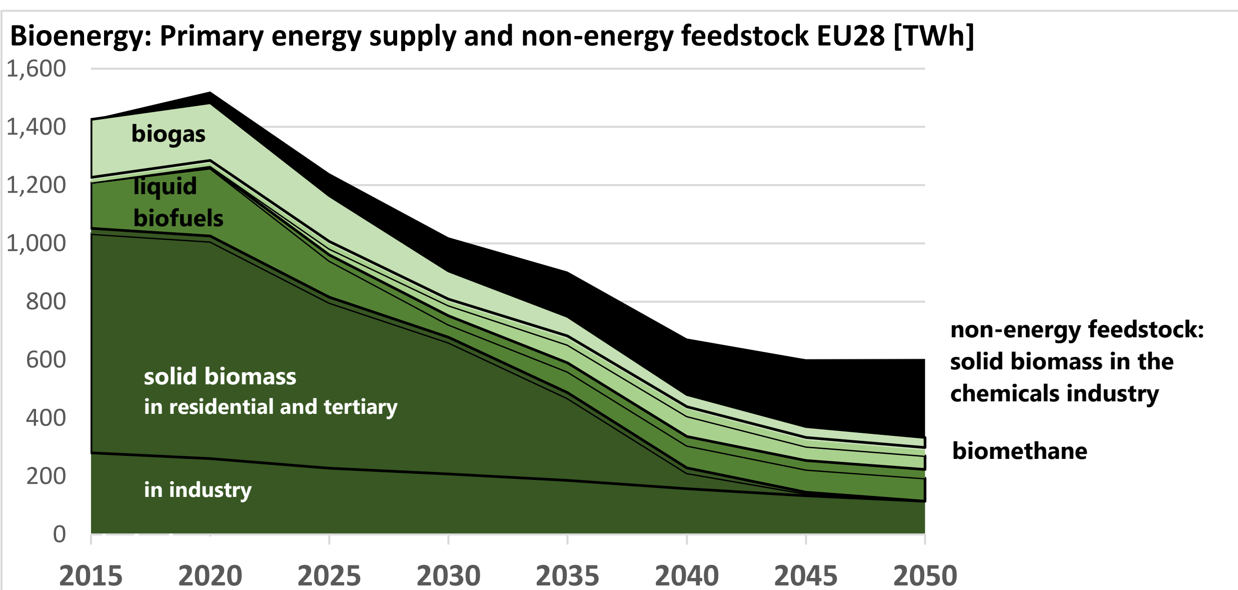
Sensitivities and limitations

The decrease of bioenergy in heating depends on future costs and flexibility needs that are difficult to assess. Deep renovation could offer an opportunity to shift away solid biomass from inefficient individual heating.

Key results

- Primary energy supply of bioenergy decreases by almost two thirds between 2015 and 2050. Its share in primary energy supply falls from 9% to 6% in 2050. If the use of solid biomass as non-energy feedstock in the chemical industry is included, supply still more than halves.
- Bioenergy plays an important qualitative role thanks to its flexible and versatile energy carriers that respond to specific demands of sectors and processes where no renewable alternative is accessible.
- Sustainable bioenergy quantitatively loses in importance but respects the boundaries of its potentials.





2.7 Mobilising solar energy

Key assumptions

- Solar photovoltaic (PV) is the cheapest and easiest to scale up renewable technology. Further decreases in installation costs turn solar self-consumption into a major driver for electrification. The PAC scenario largely takes over assumptions on solar PV potentials from the Energy Watch Group (EWG)/LUT model.[56]
- Solar thermal heat grows less strongly than solar PV. Its shares in district heating play an increasing role. The PAC scenario takes over assumptions on solar thermal potentials from the Heat Roadmap Europe.[57]
- Concentrated solar thermal power (CSP) remains limited to a few southern European countries with sufficient solar irradiation and suitable locations.

Evolution of energy supply

The solar PV electricity generation increases more than ten-fold from 103 TWh equalling a 3% share in electricity generation in 2015 to 1,368 TWh (30%) in 2030. Just after wind energy, it becomes the EU's second electricity source with 2,360 TWh representing 37% of electricity generation in 2040.

Solar thermal heat remains an energy source used for individual heating in the residential and tertiary sector. Building renovation and replacement of inefficient fossil heating systems triggers a switch to solar thermal installations. They double their supply from 25 TWh in 2015 to 58 TWh in 2050. In addition, solar thermal heat is increasingly supplied through expanding district heat networks with a maximum of 21 TWh reached in 2040.

Electricity generation from CSP increases from 5 TWh in 2015 to 17 TWh in 2030 and 24 TWh in 2040. Its contribution to European electricity generation however is marginal and does not exceed 0.5%.

Integration of members' and experts' feedback

In a number of countries short-term market forecasts indicate a slower uptake than projected by the EWG/LUT model.[58] Solar PV growth rates during the 2020s consequently were reduced and further uptake was delayed.

Sensitivities and limitations

Neither the share of ground-mounted solar PV nor its space demand have been assessed more in detail. While environmental risks are negligible, potential synergies and conflicts with agriculture's needs have to be clarified.

Key results

- Solar PV makes solar energy the second most important electricity source of the PAC scenario by 2030. After a quick ramp-up until 2030, it covers up to 38% of electricity generation in 2050.
- Solar thermal heat supply more than doubles until 2050. It reaches new consumers in the tertiary sector and in industries with low temperature demand thanks to the expansion of district heat networks.

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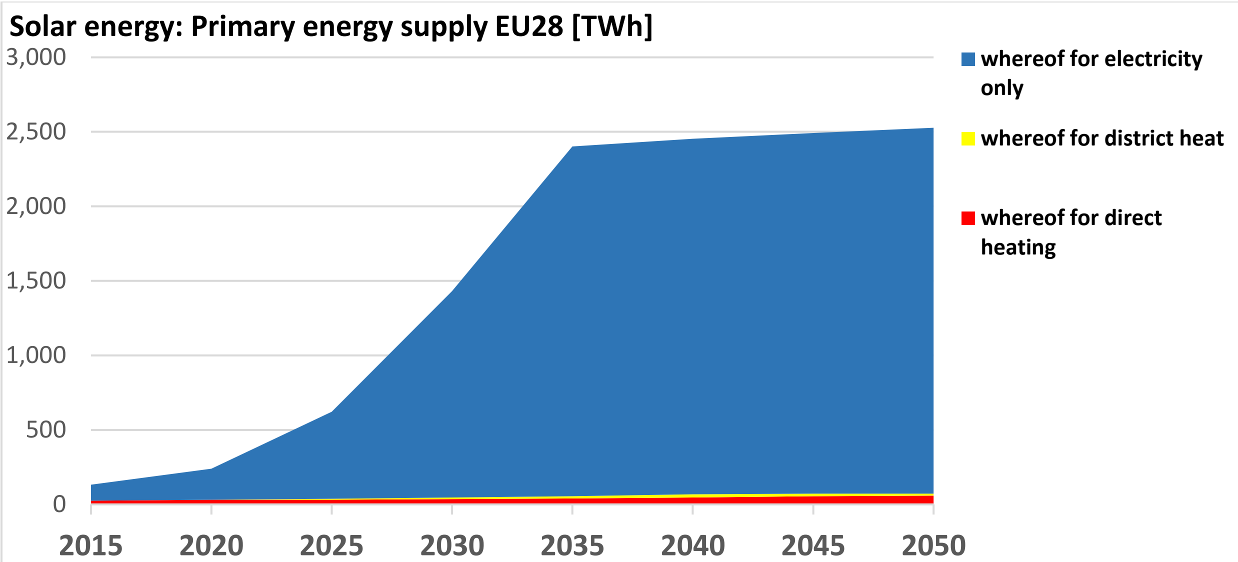
[56] EWG/LUT: Global Energy System based on 100% Renewable Energy. Energy Transition in Europe across Power, Heat, Transport and Desalination Sectors, December 2018.

[57] Aalborg University: Heat Roadmap Europe 4.

[58] Solar Power Europe: Global Market Outlook for Solar Power 2019-2023, July 2019; Eurobserver: PV barometer 2020, April 2020.


Solar energy: Primary energy supply EU28 [TWh]
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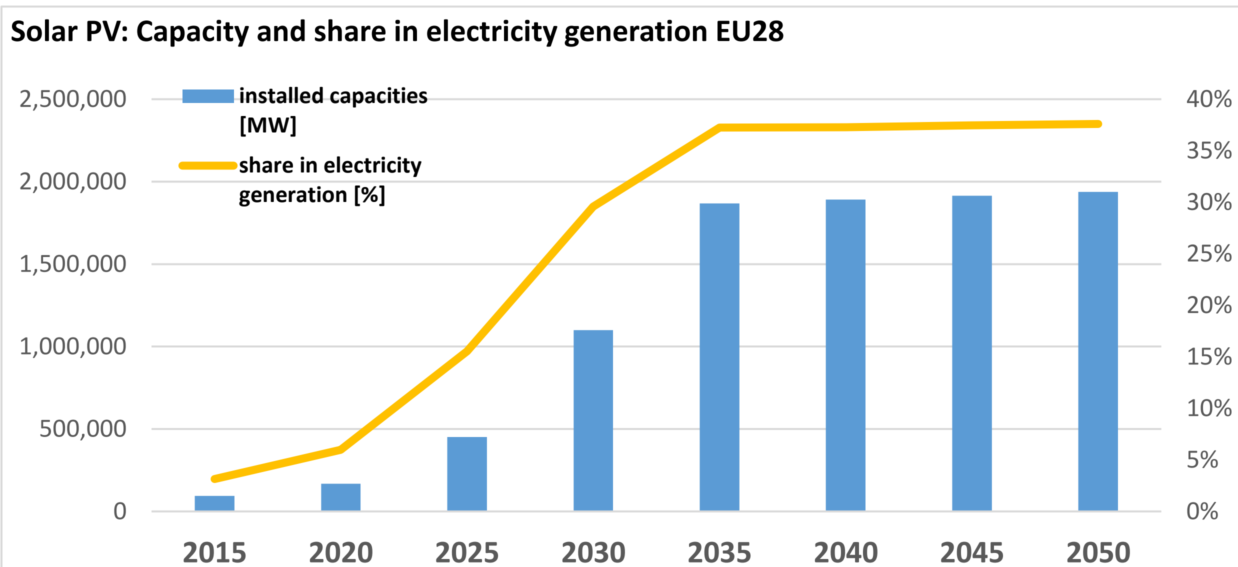
Solar PV: Capacity and share in electricity generation EU28
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installed capacities [MW]
share in electricity generation [%]
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30%
25%
20%
15%
10%
5%
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2.8 Mobilising wind energy

Key assumptions

- Electricity generated by wind turbines onshore and offshore is one of the cheapest renewable technologies. Further decreases in installation costs make it a driver for electrification. The PAC scenario largely takes over assumptions on onshore wind potentials and capacity factors from EWG/LUT.[59]
- Offshore wind potentials and capacity factors are taken over from BVG Associates and the International Energy Agency (IEA), following the European Commission's estimation of up to 450,000 MW of capacity. The PAC scenario assumes that this potential will partly be mobilised.[60]

Evolution of energy supply

The quick upscaling of onshore wind electricity generation leads to a more than six-fold increase from 267 TWh to 1,829 TWh between 2015 and 2030. The share of onshore wind in electricity generation increases from 8% to 40%. Onshore wind then is the EU's most important electricity source, reaching 2,591 TWh in 2040 (41% of electricity generation).

Offshore wind electricity generation rises even faster from 35 TWh in 2015 to 497 TWh in 2030, equalling an increase from 1% to 11% of electricity generation. Every fifth kilowatt-hour of wind power comes from an offshore turbine in 2030. Offshore wind farms contribute 818 TWh in 2040 (13% of electricity generation).

Integration of members' and experts' feedback

In a number of countries short-term market forecasts indicate a slower uptake of onshore wind capacities than projected by the EWG/LUT model.[61] Growth rates during the 2020s were reduced and further uptake delayed.

Sensitivities and limitations

Novel floating foundation technologies that are not yet introduced in the market allow installations in deeper waters (>70 m) and in areas with sea ice. Such technology innovations could further advance offshore wind shares.

Key results

- Due to a speedy multiplication of capacities both onshore and offshore, wind energy becomes the EU's most important source of primary energy supply in 2030 with 2,326 TWh, just before fossil gas and oil.
- If onshore wind capacities are scaled-up according to the PAC scenario trajectory, only a third of the 450,000 MW offshore wind capacity potential needs to be mobilised to make wind energy the most important source of primary energy supply in 2030. A higher offshore wind share is however possible.

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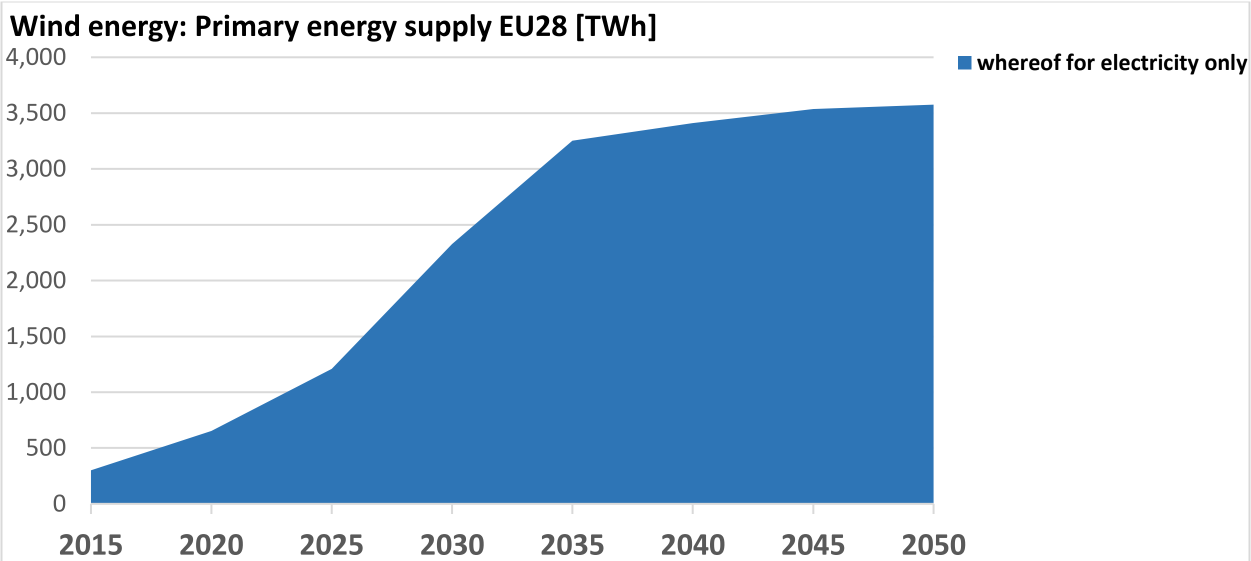
[59] EWG/LUT.

[60] Wind Europe/BVG Associates: Our energy, our future. How offshore wind will help Europe go carbon-neutral, November 2019; European Commission: A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. In-Depth Analysis. COM(2018)773, November 2018.

[61] Wind Europe: Wind energy in Europe in 2018. Trends and statistics, February 2019; Eurobserver: Wind energy barometer 2020, March 2020.


Wind energy: Primary energy supply EU28 [TWh]
whereof for electricity only
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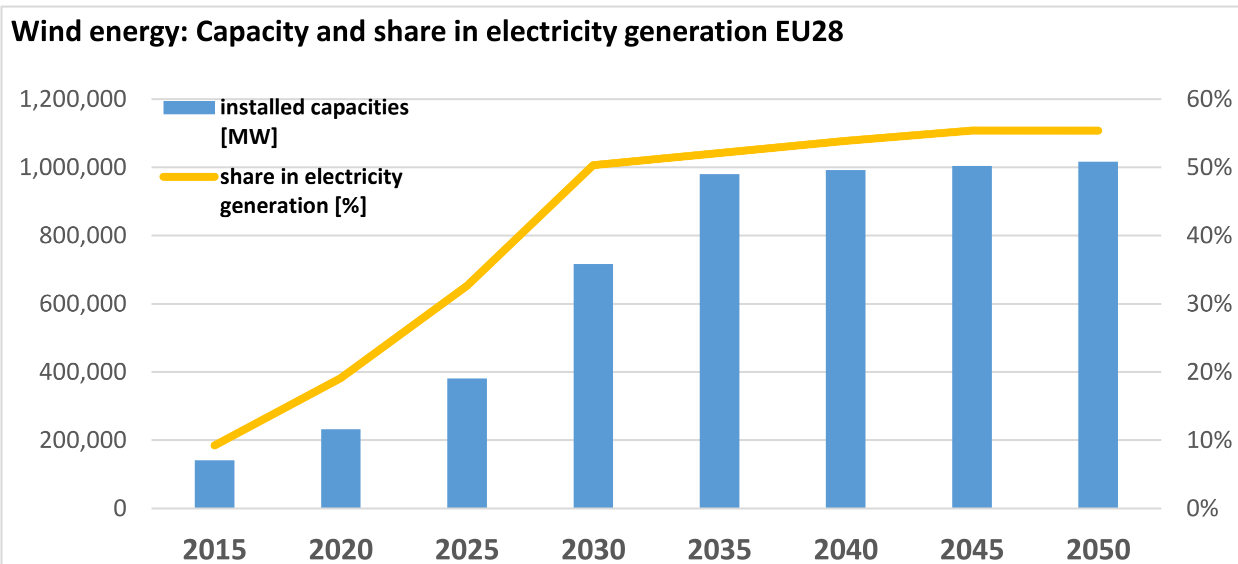

Wind energy: Capacity and share in electricity generation EU28
installed capacities [MW]
share in electricity generation [%]
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
60%
50%
40%
30%
20%
10%
0%
2015
2020
2025
2030
2035
2040
2045
2050

2.9 Mobilising hydropower

Key assumptions

- Capacities of run-of-river, reservoir or mixed hydro[62] power will not increase from 2020 onwards.
- A slight linear increase for all hydro power capacities from 2015 to 2020 is integrated into the PAC scenario to mirror power plants already in construction.
- The PAC scenario assumes a 10% loss in electricity production due to environmental requirements and climate change. Capacity factors are taken over from the EWG/LUT model.[63]

Evolution of energy supply

Even under keeping a constant level of hydropower capacity, its electricity generation decreases. Climate change will affect water availability for hydropower. Depending on the temperature increase, hydropower production in Europe could go down by around 6% under a moderate warming scenario and by 13% under high warming scenarios[64]. Additionally, the implementation of the Water Framework Directive (WFD) through minimum flow requirements and other mitigation measures might affect the overall hydropower production by around 3%[65]. Therefore, the PAC project shows a slight decrease in hydropower production, even with constant capacities.

Integration of members' and experts' feedback

In general, feedback from members and experts has been supportive on PAC scenario's assumption not to increase hydropower capacity beyond 2020. Some EU28 countries have already increased their installed capacity between 2010 and 2015 and are planning additional increase by 2020[66]. Therefore, when possible, figures have been updated with most recent data from Eurostat, and installation rates have been extrapolated until 2020.

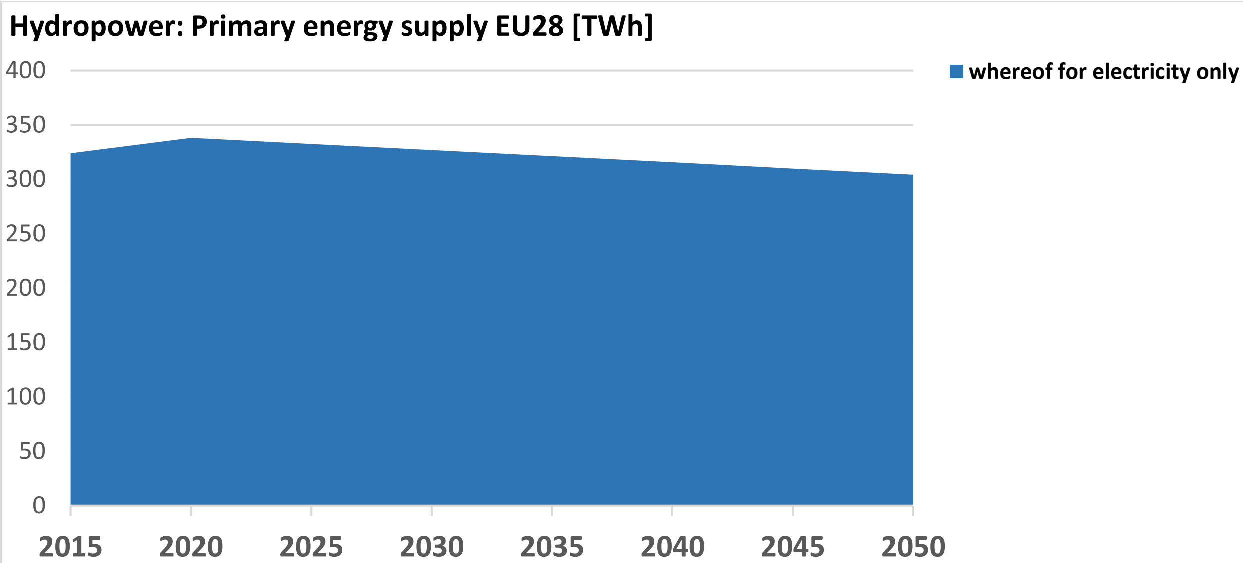
Sensitivities and limitations

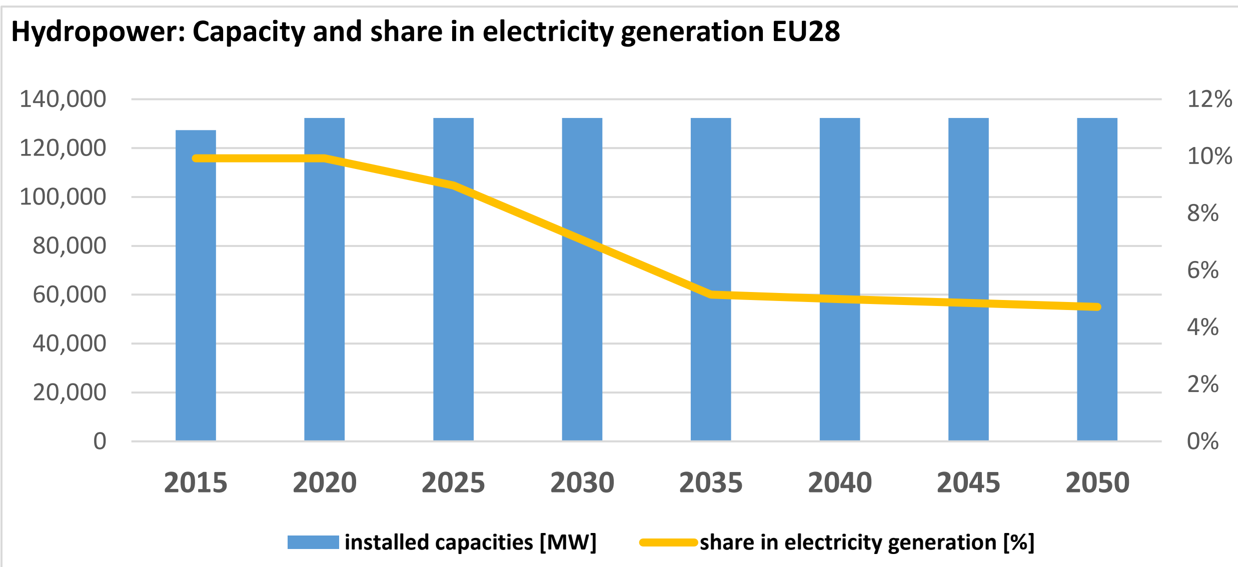
The PAC scenario has chosen deliberately conservative assumptions on new hydropower projects. Actual post-2020 installed capacity might be higher.

Key results

- Unless upgrade of existing facility, no further hydropower expansion happens beyond 2020.
- Hydropower production will drop by 10% due to climate change and environmental requirements.

[62] Hydro plants with natural water inflow into an upper reservoir where part or all equipment can be used for pumping water uphill
[63] EWG/LUT.
[64] COACCH: The economic cost of climate change in Europe: Synthesis report on COACCH interim results, November 2019.
[65] Arcadis/Ingenieurbüro Floecksmühle: Hydropower generation in the context of the EU water framework directive, May 2011.
[66] ECN: NREAP database, https://ecn.nl/collaboration/nreap/2010/data/index.html.


Hydropower: Primary energy supply EU28 [TWh]
400
350
300
250
200
150
100
50
0
2015
2020
2025
2030
2035
2040
2045
2050
whereof for electricity only


Hydropower: Capacity and share in electricity generation EU28
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
12%
10%
8%
6%
4%
2%
0%
2015
2020
2025
2030
2035
2040
2045
2050
installed capacities [MW]
share in electricity generation [%]

2.10 Mobilising ocean energy

Key assumptions

- Although tidal, wave, ocean thermal and salinity gradient energy are still in their infancy, conditions for market introduction are good. Assumptions are mainly taken over from the European Commission and short-term market analysis.[67]

Evolution of energy supply

The accessible ocean energy potential of 3,360 MW installed capacities is mainly mobilised between 2025 and 2030. Electricity generation reaches 2 TWh in 2025 and multiplies five-fold to reach 10 TWh in 2030. The share of ocean energy in final electricity demand remains marginal with a maximum of not more than 0.2%.

Integration of members' and experts' feedback

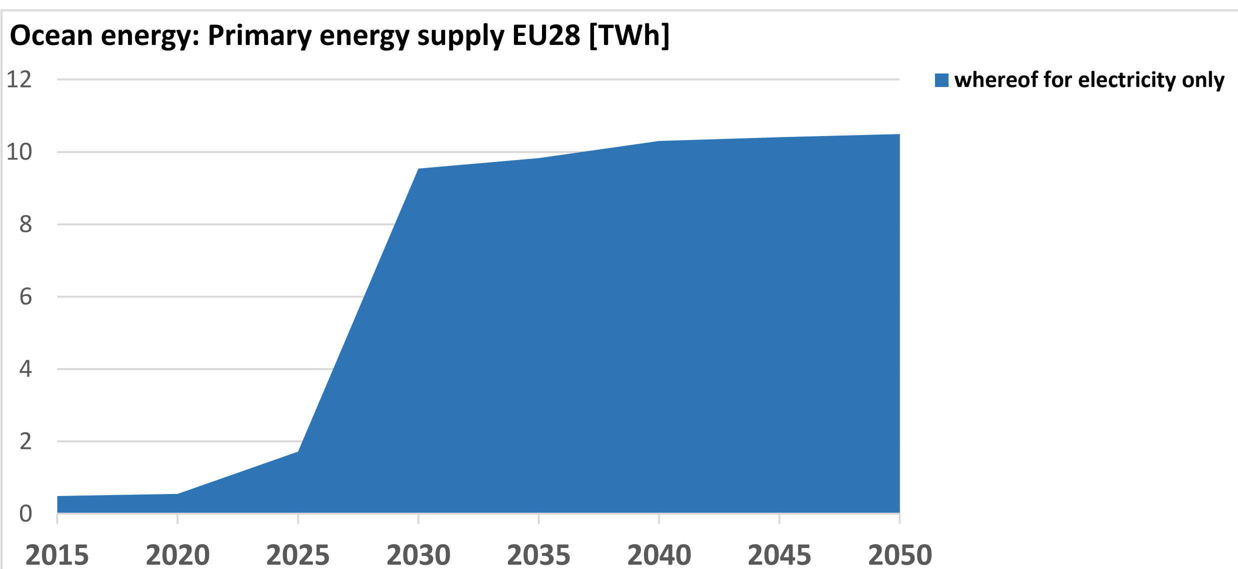
Members and experts from the ocean energy industry confirmed key assumptions of the PAC scenario.

Sensitivities and limitations

Research and industry currently cannot provide robust trajectories for the development of ocean energy capacities beyond the year 2030. In a simplified approach, the PAC scenario assumes that ocean energy technologies until 2050 will continue electricity generation at least on the same level as in 2030.

Key results

- Ocean energy is at the brink of market introduction with a positive outlook. It complements Europe's offshore energy portfolio in the coastal regions but plays a marginal role in European energy mix.



[67] European Commission/Wavec: Market Study on Ocean Energy, May 2018; Eurobserver: Ocean energy barometer, November 2018.

2.11 Mobilising ambient and geothermal energy

Key assumptions

- Ambient heat captured by heat pumps is the key driver for electrification of heating mainly in residential and tertiary sectors. Technology developments also allow an increased share for industries' low temperature processes. Heat pump potentials are based on Heat Roadmap Europe.[68]
- The PAC scenario assumes that 1 kWh of gross heat production from heat pumps entails 0.7 kWh of ambient (aero- or geothermal) heat captured by heat pumps and 0.3 kWh of direct electricity demand.[69]
- In contrast to ambient energy captured by heat pumps, deep geothermal energy potentials are primarily mobilised through cogeneration. The PAC scenario is based on assumptions from the European Technology & Innovation Platform Deep Geothermal (ETIP DG) and the EWG/LUT model.[70]

Evolution of energy supply

Heat pumps that capture ambient (aerothermal and shallow geothermal) energy quickly ramp up their energy supply from 25 TWh in 2015 to 497 TWh in 2030. They become the most important renewable energy supply for heating buildings in the residential and tertiary sectors after 2030, leaving solid biomass behind them.

Deep building renovation induces a steady switch from individual fossil heating systems to heat pumps. They are the first choice for individual heating. However, starting from the middle of the 2020s, a quarter of energy supplied by heat pumps is also distributed through the growing district heat networks. Up to 117 TWh are consumed in industry in 2040, covering 5% of industry's final energy demand.

Deep geothermal energy projects are more difficult and take more time to be mobilised than individual heat pumps. Primary energy supply in 2030 (81 TWh) nevertheless is four times higher than in 2015. Until 2050, supply triples to reach 247 TWh, mainly due to a stronger uptake of geothermal CHP feeding also into district heat networks. Electricity from geothermal CHP plants however only covers a maximum of 2% of final electricity demand by 2050.

Integration of members' and experts' feedback

In a number of countries short-term market forecasts indicate a slower uptake of geothermal electricity generation capacities than projected by the EWG/LUT model. Growth rates during the 2020s were adopted and further uptake delayed.[71]

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[68] Aalborg University: Heat Roadmap Europe 4.

[69] The electricity demand of heat pumps is already included in final electricity demand and not a renewable energy source as such. It is thus not included in the aforementioned numbers. The electricity consumed by heat pumps to harvest the renewable energy source of ambient (aerothermal and geothermal) energy however will have a 100% renewable electricity mix by the year 2040.

[70] ETIP DG: Implementation Roadmap for Deep Geothermal, April 2019; EWG/LUT.

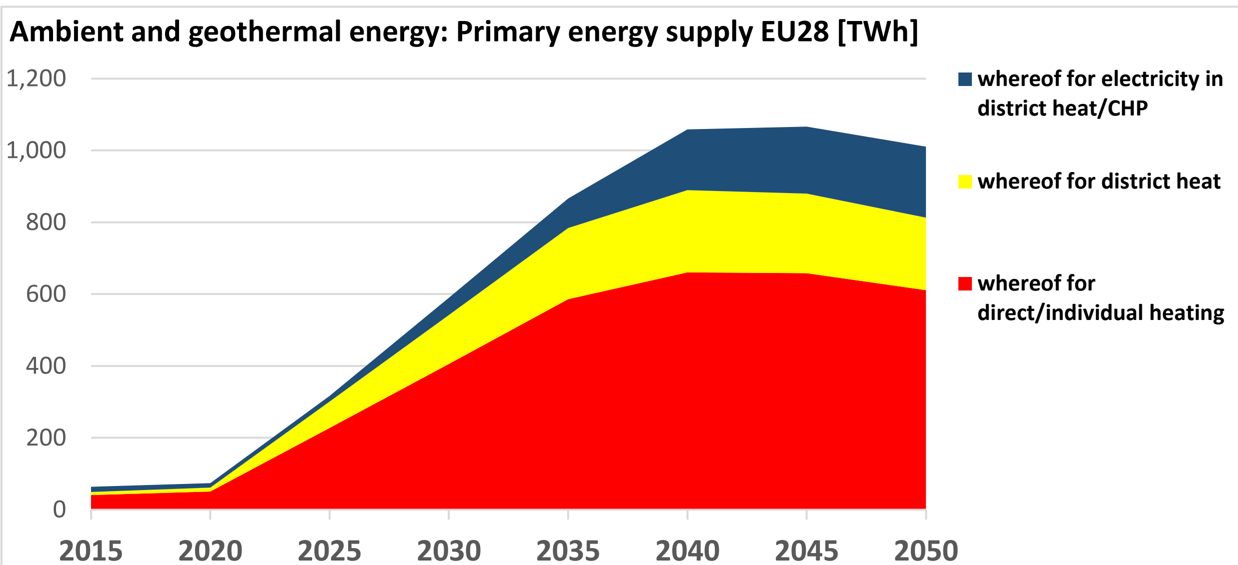
[71] Eurobserver: Heat pumps Barometer, Nov. 2018; European Geothermal Energy Council: Geothermal market report, June 2019.

Sensitivities and limitations

Implementing deep geothermal electricity projects in many Member States is still economically relatively risky. Only half of the expected growth of capacities that was projected in the previous 2020 National Renewable Energy Action Plans (NREAPs) has been achieved. Stable support schemes are crucial for the deployment of the trajectories described in the PAC scenario.

Key results

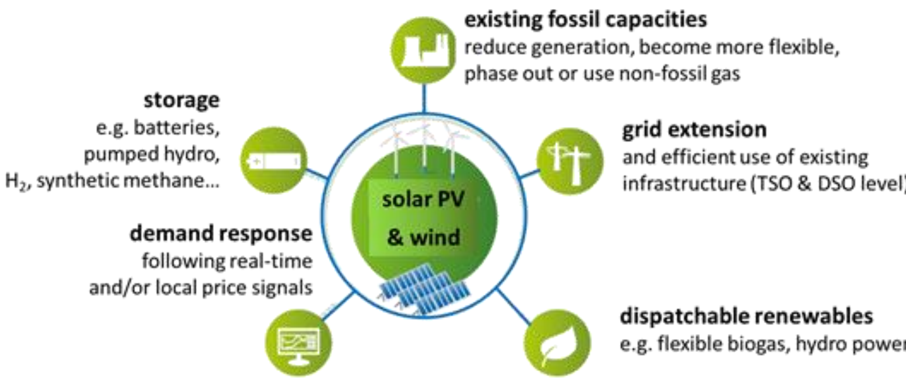
- The deep renovation of buildings presents an opportunity for installing heat pumps as an easy to deploy heating technology. Heat pumps efficiently increase the use of renewable electricity for heating. They cover 15% of gross final heat consumption in 2030 and 54% in 2040.
- It is more challenging to scale up CHP plants and heating stations using deep geothermal potentials. In the PAC scenario, primary energy supply of geothermal energy increases more than ten-fold from 21 TWh in 2015 to 247 TWh in 2050.



Electricity market modelling with different flexibility options

The PAC scenario projects an energy system that largely relies on the variable renewable energy sources solar PV and wind. The higher their share in the energy mix, the more relevant is the assessment of adequacy: Electricity supply needs to meet demand at every moment in time. The interplay of different flexibility options needs to interact smoothly to always guarantee a stable grid and security of supply.

Flexibility options mobilised in the PAC scenario



Graphic: AEE

On an annual base, electricity generation perfectly matches demand. Solar PV installations and wind turbines naturally cannot be dispatched. Their output often varies strongly on seasonal and daily base. Therefore, an hourly modelling is required. For this purpose, PAC scenario data is fed into the PowerFlex electricity market model run by Öko-Institut. It simulates cross-European wholesale electricity markets. In this modelling exercise, the swift expansion of the net transmission capacities of cross-border electricity grids is taken over from the TYNDP 2018 Global Climate Ambition 2040 scenario. The increased cross-border exchange of electricity helps prevent shortages or curtailment. In the year 2030, 63.5 TWh of renewable electricity however cannot be delivered to end consumers. Most excess renewable electricity is used by flexible electrolysers to produce renewable hydrogen (see chapter 2.12).

In addition, other flexibility options help to balance demand and supply in 2030:

- Pumped hydro storage (54 TWh stored and 39 TWh reinjected into the grid in 2030)
- A broad market introduction of ever cheaper solar PV batteries (76 TWh stored in 2030 with 343,108 MW of installed generation capacity) allows to shave peak load and ease the grids through self-consumption. Batteries of electric vehicles were not considered as a flexibility option in this model run.
- Demand side flexibility schemes will incentivise consumers as in industry to shift their demand to those time periods when there is an oversupply. In this PowerFlex model run it was assumed that 5% of any national peak demand could be shifted for one hour.
- A flexible operation of fossil gas fired power plants also contributes to balancing demand and supply. Fossil gas capacities for electricity generation will however continue to decrease and eventually be phased out by 2035. Flexible biogas cogeneration also could contribute as a flexibility option but was not part of this model run.
- Heat networks and flexible power-to-heat could offer additional flexibility but were neither considered in this model run.

2.12 Producing non-fossil gases and fuels

Key assumptions

- Non-fossil gases and fuels are based on hydrogen that is exclusively produced with renewable electricity. In order to respond to specific demands of industry and transport sectors, renewable hydrogen can be converted into renewable ammonia, synthetic methane and liquid synthetic fuels.[72]
- All non-fossil gases are linked with important losses of primary energy input. Efficiencies of electrolysers and conversion processes gradually improve. Levelised costs of renewable hydrogen production however remain relatively high compared to direct electrification and constrain market introduction.[73]
- Against the background of limited potentials and low efficiencies, the PAC scenario restricts the use of non-fossil gases to sectors and processes that cannot use renewable electricity directly and that do not have any alternative to substitute fossil fuels, i.e. to energy-intensive industries and parts of transport.

Evolution of energy supply

Demand for renewable hydrogen firstly occurs in the energy-intensive industry processes that require an energy carrier with high energy density such as steel, chemicals, non-ferrous metals and pulp, paper and printing. By 2030, 6% of industry's final energy demand is covered by 161 TWh of renewable hydrogen. Between 2035 and 2050, renewable hydrogen demand remains stable in these sectors with 320 to 340 TWh, covering 15% of demand. In addition, synthetic methane is introduced to a minor extent to replace fossil gas in certain industry processes such as in cement, ceramics, glass, non-ferrous metals and pulp, paper and printing.[74] In 2030, 37 TWh of synthetic methane are consumed in the industry. Demand doubles to reach 63 TWh to 81 TWh between 2035 and 2050, covering up to 4% of industry's final energy demand.

In the transport sector, renewable hydrogen is scaled up at comparable pace to cover 131 TWh of demand in 2030 (5% of transport's final energy demand), increasing to 250 TWh in 2050 (13% of demand). It is mainly used to substitute fossil oil products in heavy freight where electric drives are not fully deployed, and in fuel cells in mid-distance shipping. In parallel, renewable hydrogen is converted to renewable ammonia for long-distance shipping (maximum of 86 TWh in 2050, 4% of the transport sector's final energy demand).

For aviation, liquid synthetic fuels are the only short-term renewable alternative besides liquid biofuels to phase-out the fossil oil product kerosene. Aeroplanes become the most important consumer of renewable gases and fuels with 192 TWh of liquid synthetic fuels consumed in 2030 (7% of transport's final energy demand), rising to 374 TWh (20% of demand) in 2050, while electric aircraft are firstly used to substitute the use of biofuels.

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[72] CAN Europe: Position on the use of gas in the future energy system, January 2020. Sustainably sourced biogas and biomethane also are non-fossil gases but covered in chapter 3.6. Hydrogen produced through steam methane reformation with fossil gas currently dominates European hydrogen consumption in industry. In the PAC scenario data, the current fossil hydrogen demand is not disclosed as such explicitly but included in the industry's primary energy demand.

[73] ICCT; International Energy Agency: The future of hydrogen, June 2019; Cambridge Econometrics/Element Energy/European Climate Foundation: Towards fossil-free energy in 2050, March 2019; Agentur für Erneuerbare Energien (AEE, German Renewable Energies Agency): Metaanalyse Erneuerbare Gase in der Energiewende, March 2018; Agora Energiewende/Enervis: Power to gas/Power to liquid calculator, February 2018.

[74] Material Economics; European Commission: A clean planet for all; AEE: Erneuerbare Energie für die Industrie. Renews Kompakt, June 2017; UK Department of Energy and Climate Change/Department for Business, Innovation and Skills: Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050. Glass, Ceramic sector, Food and Drink, March 2015.

Integration of members' and experts' feedback

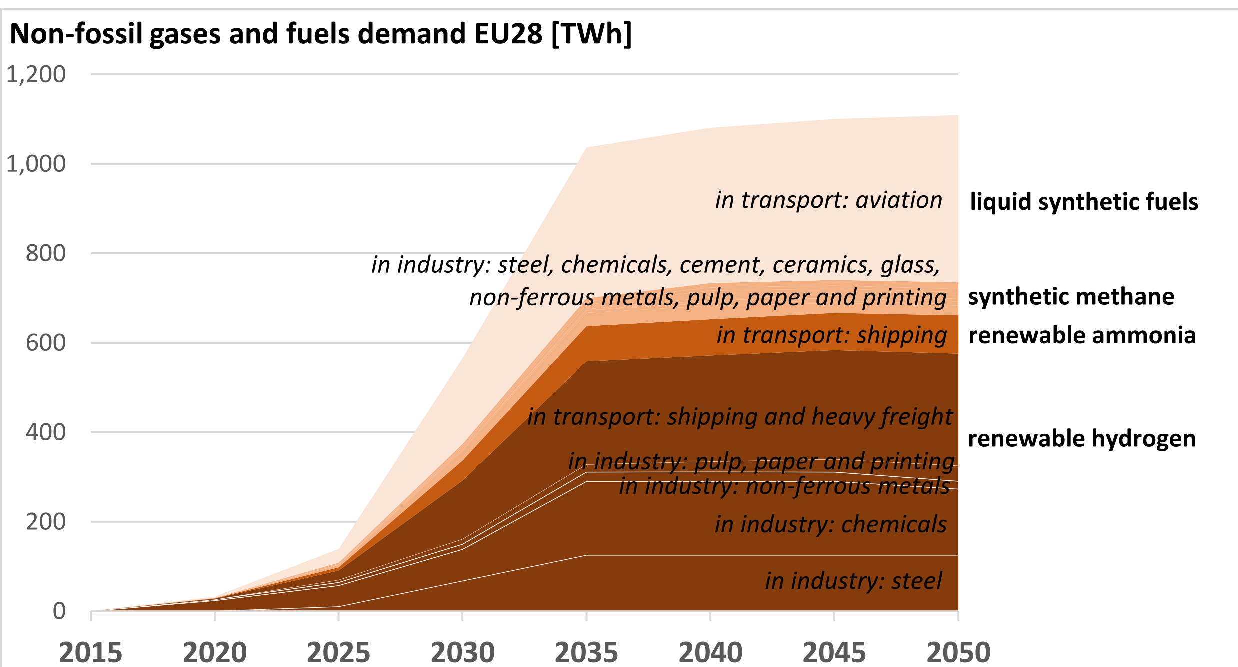
Members and participants of the PAC scenario workshops agreed that, given the availability of more efficient and easier to deploy solutions, non-fossil gases and fuels would not play any role in the residential and tertiary sectors, neither in agriculture. Additional electricity needed for producing renewable hydrogen should come from domestic EU potentials. Imports of renewable hydrogen from beyond the EU should be avoided.[75]

Sensitivities and limitations

Potential imports of renewable hydrogen are not included in the PAC scenario. Depending on costs, infrastructure and policy frameworks, such imports might play a role in the future. A complex set of economic and environmental parameters still would need to be assessed in order to explore its feasibility and desirability.

Key results

- Non-fossil gases have climate benefits only if they are exclusively produced with renewable electricity and replace fossil fuels in distinct demand sectors where there is no other sustainable alternative such as renewable heat or direct electrification with renewable electricity.
- Already during the 2020s, first relevant shares of renewable hydrogen have to be introduced to accompany the phase-out of coal and fossil gas in energy-intensive industries. In view of their poor efficiency, non-fossil gases however will only play a limited role compared to direct electrification.
- Compared to industry, renewable hydrogen, renewable ammonia and in particular liquid synthetic fuels cover a higher share of transport's final energy demand (up to 37% in 2050). Only a very swift and broad scaling up of renewable hydrogen generation allows for the ambitious fossil oil phase out in transport.

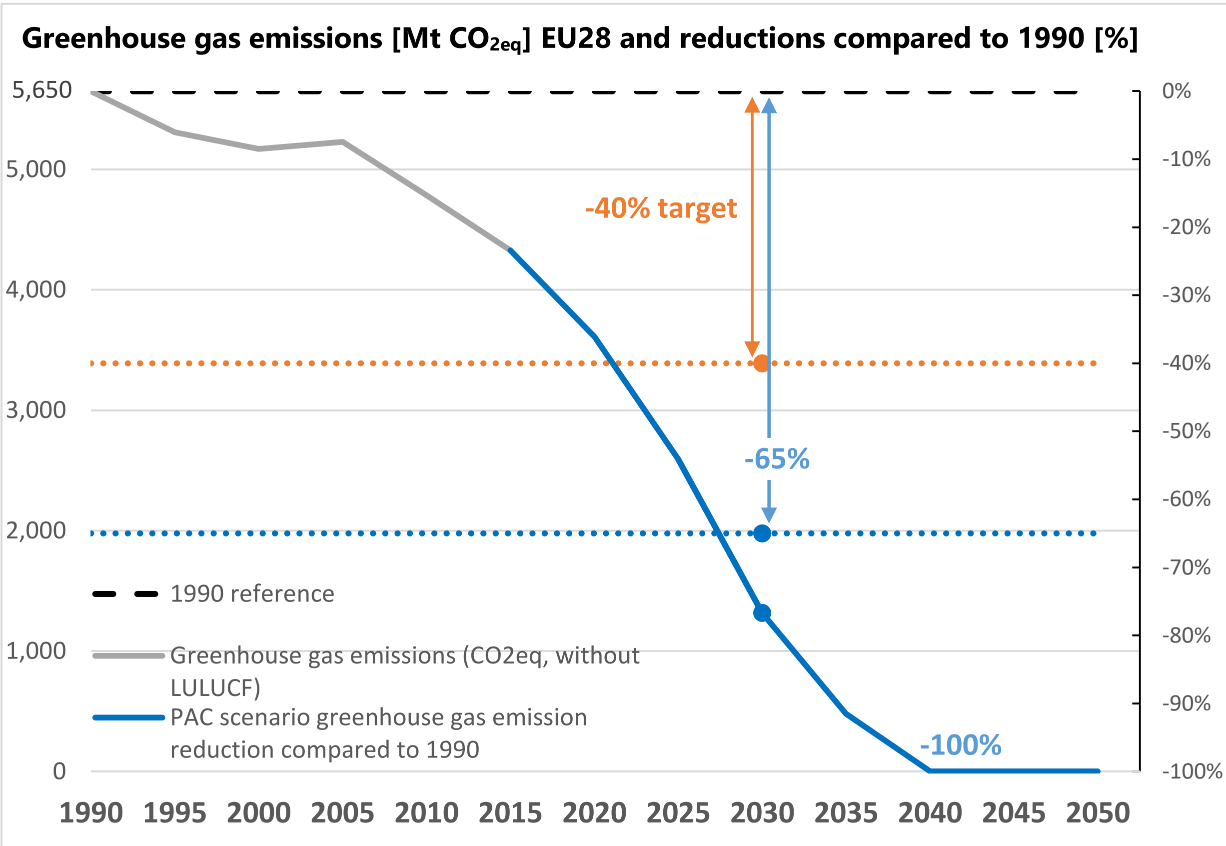


75 CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.

3. Reaching the Paris Agreement 1.5°C target

3.1 Greenhouse gas emissions reductions

The PAC scenario's overarching aim is to illustrate a robust pathway that ensures the EU limits global warming to not more than 1.5°C as endorsed in the Paris Agreement. The deployment of energy savings and renewable energy potentials as described in chapters 1 and 2 ensure a quick reduction of greenhouse gas emissions.

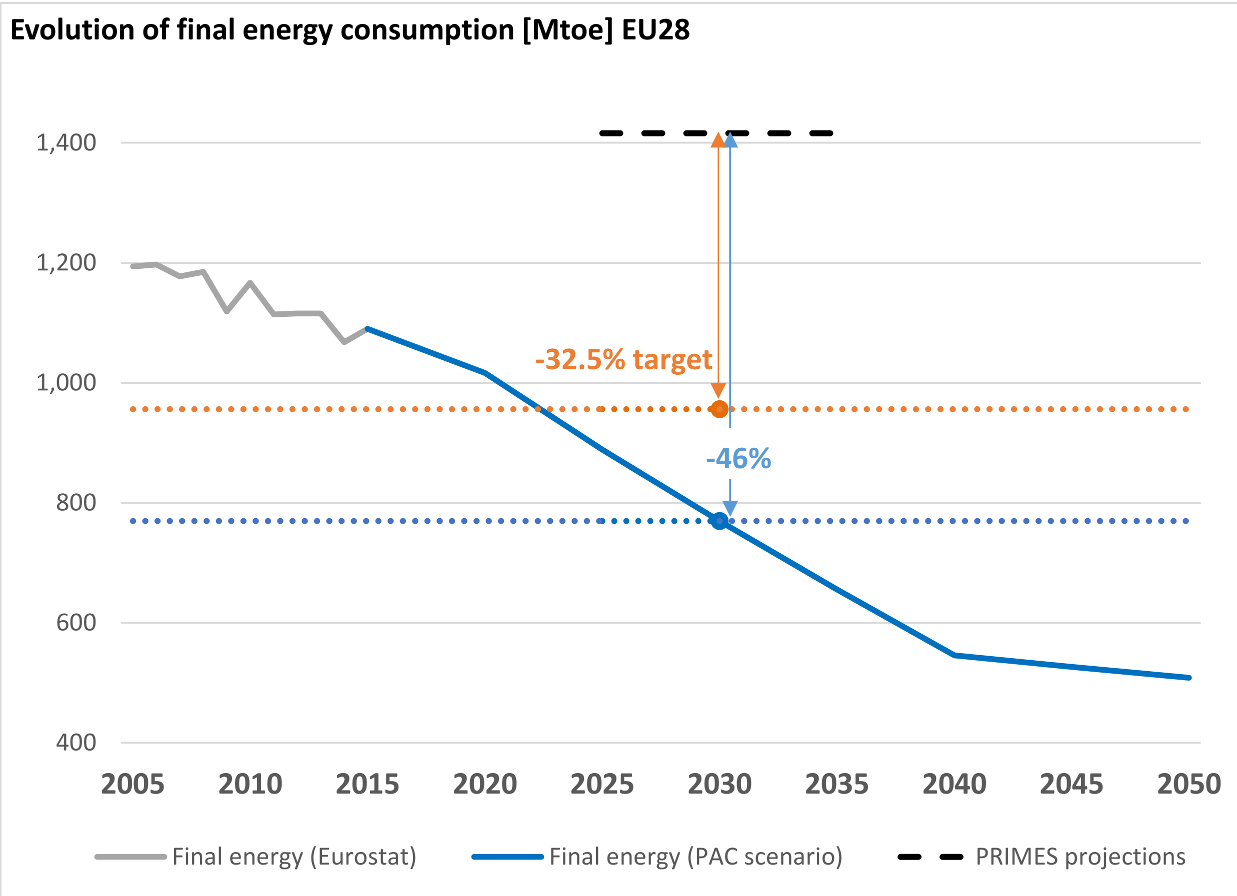


Energy-related CO_2 emissions decrease from 4,124 Mt CO_2 in 1990 to 997 Mt CO_2 in 2030, reaching full decarbonisation in 2040. This is a reduction by 76%. The non-CO_2 emissions from energy as well as the non-energy related emissions however are not included in this number. If they reduce as strongly as the energy-related emissions, total greenhouse gas emissions decrease from 5,650 Mt CO_{2eq} in 1990 to ca. 1,367 Mt CO_{2eq} in 2030. In order to cut the total greenhouse gas emissions by 65% in 2030, the non-CO_2 emissions as well as the non-energy related emissions would only have to be cut by 36% (from 1,526 Mt CO_{2eq} in 1990 to 980 Mt CO_{2eq} in 2030). Considering the current trends in emissions reductions, this reduction by a third of non-CO_2 and non-energy related emissions appears to be realistic. The EU climate target of at least 40% greenhouse gas emissions reductions in 2030 compared to 1990 thus can be outperformed.

These approximate calculations do not consider emissions and removals from land use, land use change and forestry (LULUCF) as these are traditionally not part of the EU 2030 climate target. A detailed sector-specific assessment of emissions reductions will be carried out during the second half of 2020.

3.2 Energy savings

The final energy consumption under the PAC scenario halves between 2015 and 2050. With a final energy demand of around 770 Mtoe in 2030, it shows the important energy savings potential that can be mobilised. It is clear that the EU 32.5% energy efficiency target for 2030 can be outperformed. Compared to PRIMES projections[76], final energy consumption is 46% lower.



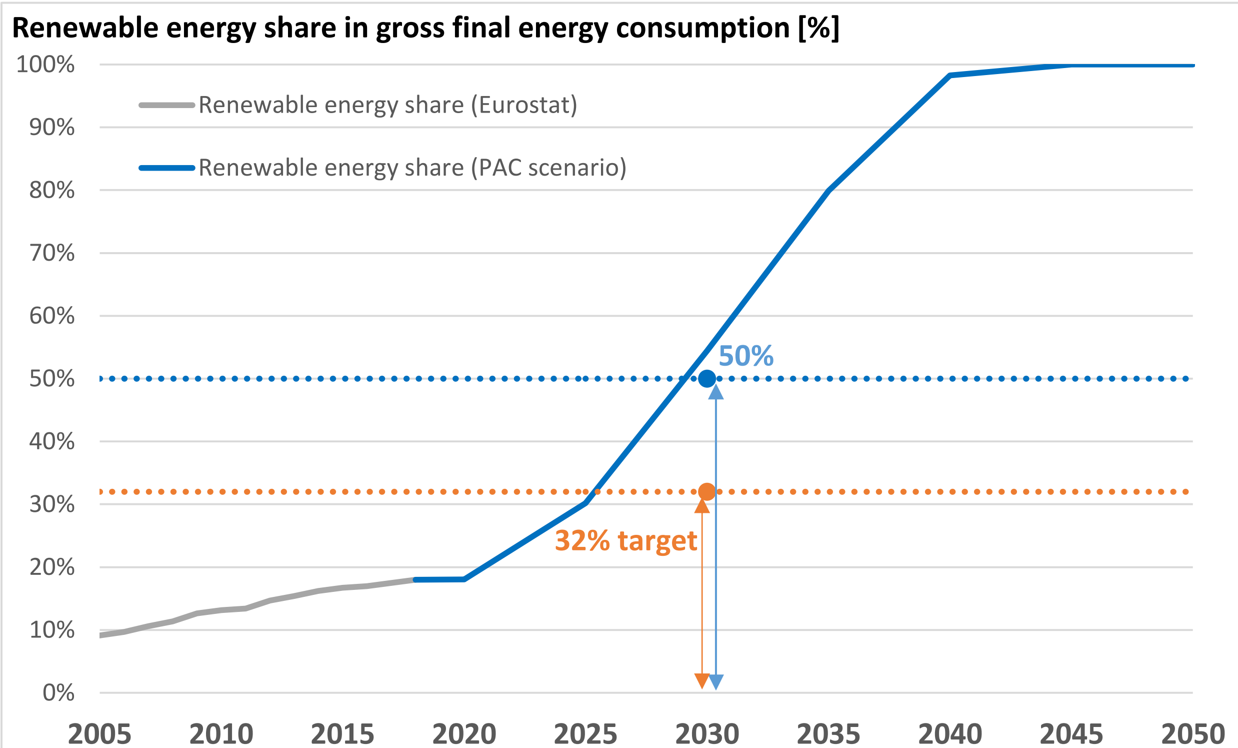
At the same time, expressing the abovementioned evolution in primary energy terms translates into a level of energy consumption of 1,014 Mtoe in 2030. The increasing share of renewable energy contributes to the primary energy decrease: The more renewable energy sources are used, the less primary energy input is lost by burning fossil fuels. The decrease equals a 46% reduction compared to the PRIMES projections.

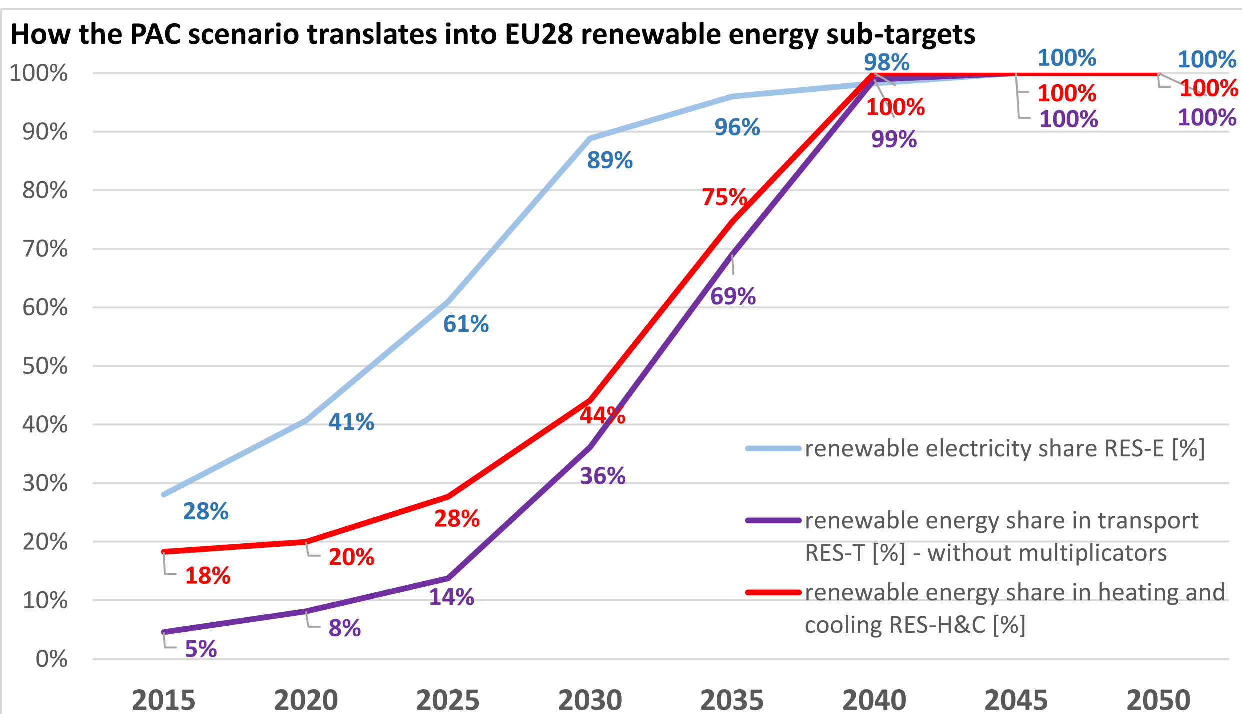
The increase of non-fossil gases and fuels in the 2030s (renewable hydrogen, renewable ammonia, synthetic methane and liquid synthetic fuels) however causes an end to the declining trend. Because of the high losses of primary energy input during the production process of renewable hydrogen and the other gases and fuels, the primary energy consumption increases after 2035 to reach 1,308 Mtoe in 2050.

[76] PRIMES 2007 projections for the year 2030.

3.3 Renewable energy shares

The PAC scenario projects a fully renewable energy supply by the year 2040. The steep increase of renewable energy in the energy mix allows to outgo the EU 32% renewable energy target for the year 2030. The share of renewable energy sources in the gross final energy consumption of the EU28 reaches more than 50% in 2030.





List of abbreviations and units

CCS Carbon Capture and Storage

CHP Combined heat and power

CSP Concentrated solar power

DSO Distribution system operator

EU28 The 28 Member States of the European Union in 2019, including the United Kingdom of Great Britain and Northern Ireland.

EU ETS European Emission Trading System

GDP Gross domestic product

Gt Gigatonnes; unit to measure mass, equalling 1,000,000,000 tonnes, 1 tonne = 1,000 kilograms

GW Gigawatt; unit to measure the installed capacity of electricity or heat generators; 1,000 kW equals 1 Megawatt (MW); 1,000 MW equals 1 gigawatt (GW).

kWh Kilowatt-hour; unit to measure energy; 1,000 kWh equals 1 Megawatt-hour (MWh); 1 billion kWh equals 1 terawatt-hour (TWh).

kW Kilowatt; unit to measure the installed capacity of electricity or heat generators; 1,000 kW equals 1 Megawatt (MW); 1,000 MW equals 1 gigawatt (GW).

LCOE Levelised cost of energy

MW Megawatt; unit to measure the installed capacity of electricity or heat generators. 1 MW = 1,000 kilowatt.

MWh Megawatt-hour; unit to measure energy; 1,000 kWh equals 1 Megawatt-hour (MWh); 1 billion kWh equals 1 terawatt-hour (TWh).

Mtoe Million tonnes of oil equivalent; unit to measure energy; 1 Mtoe equals 11,630 kWh.

Mt Megatonnes; unit to measure mass, equalling 1,000,000 tonnes, 1 tonne = 1,000 kilograms.

PV Photovoltaic

TSO Transmission system operator

TWh Terawatt-hour; unit to measure energy; 1,000 kWh equals 1 Megawatt-hour (MWh); 1 billion kWh equals 1 terawatt-hour (TWh).

Glossary

Ambient energy

Heat source of the ambient environment (aerothermal or shallow geothermal energy) that is captured by heat pumps to increase its temperature level for the purpose of supplying space heat, hot water or process heat.

Agriculture sector

The agriculture sector covers all energy demand of farms including farming machinery, pumping devices and electricity.

Biogas

Biogas is produced when biomass, which is cut off from light and oxygen in a digester of a biogas plant, is broken down by certain bacteria. Raw biogas consists of methane, carbon dioxide and oxygen, nitrogen and trace gases (including hydrogen sulphide). The main component, methane, can be used as a source of energy. Biogas can be produced from energy crops (e.g. maize, grain) as well as from residual materials such as organic waste, crop residues and straw, and from animal excrements such as slurry and manure. The biogas produced in a biogas plant can be turned into electricity and heat in a cogeneration unit.

Biomethane

Upgraded biogas that has been treated and purified to be physically identic with fossil gas and synthetic methane (CH_4). In contrast to raw biogas, it can also be fed directly into the existing fossil gas network and blended with fossil gas.

Carbon Capture and Storage (CCS)

Carbon Capture and Storage, a technology that strives to remove carbon dioxide emissions before or after combustion of fossil fuels to store them in the underground.

Coal

The term in this document covers the primary energy carriers of hard coal and lignite as well as oil shale in Estonia.

Combined heat and power (CHP)

See: Cogeneration

Cogeneration

Cogeneration is the combined production of electricity and heat. Power generation through burning of fossil or renewable fuels in thermal power plants always releases heat. While stand-alone thermal power plants dissipate the waste heat of the power generation process through a cooling tower, combined heat and power (CHP) units feed the heat into a dwelling’s central heating, into a district heating network or provide it as process heat in the industry. By using a part of the primary energy input in a heat sink, the combustion efficiency of the whole process increases compared to the single use of a fuel for electricity production only.

Concentrated solar power (CSP)

Solar thermal energy is concentrated with mirrors or lenses to reach higher temperatures for driving turbines for electricity production.

Delivered energy

Unlike the use of a primary energy carrier for direct heating, e.g. burning solid biomass in a wood stove, delivered energy is distributed to end consumers through a district heat network or through other infrastructure. Solid biomass that is burnt in cogeneration can supply electricity and in parallel heat as delivered energy to a district heat network or to another final customer.

Distribution system operator (DSO)

Distribution system operators (DSOs) are responsible for transporting and delivering electricity or gas to final customers through the networks on the local level. While the transmission system can be compared with a motorway for electricity or gas, the distribution system more resembles to the ramifications of rural roads or residential streets.

District heat network

Infrastructure of insulated pipes that transports thermal energy to end consumers. The energy is used for heating buildings or industry processes and mostly comes from heating or cogeneration plants.

European Emission Trading System (EU ETS)

Cap-and-trade system that puts a limit on the emissions of several thousands of manufacturing plants and fossil fuel-fired power plants in the EU. The limit is reduced annually. Emitters need a sufficient number emission allowances equalling their annual emissions. Emission allowances can be traded amongst emitters at varying prices.

Final energy demand

Final energy is all energy that is delivered to the door of an end consumer, e.g. electricity used in a building, fossil gas that is sent to a household’s kettle or delivered energy through a district heat network. Losses from transmission and distribution as well as from conversion of primary energy carriers are deducted.

Fossil gas

Methane of fossil origin, used for producing heat or electricity or driving an internal combustion engine of a vehicle, also called natural gas, including refinery gas and liquefied petroleum gas.

Fossil oil products

All liquid fossil oil products such as heating oil, residual fuel oil, diesel oil and kerosene.

Geothermal energy

Renewable thermal energy from below the earth's surface that is used in geothermal power plants, in heating stations or heat pumps.

Gross final energy consumption

Includes final energy demand, transmission and distribution grid losses from gross final energy output to end consumers.

Heat pump

Heating system that captures geothermal energy or the heat source of the ambient environment to raise their temperature level to a higher level. To do so, it makes use of the effect that gases heat up under pressure, e.g. as in the case of a bicycle pump.

Individual heating

Heating system used by single end consumers on premises, e.g. a heat pump, kettle, boiler or stove, in contrast to a district heat network that supplies delivered energy from a distant heat source through a dedicated infrastructure to end consumers at another place.

Industrial excess heat

Heat from industrial production processes that is not needed for the production process but distributed to other end consumers as waste heat to cover their heat demand.

Industry sector

The industry sector comprises the energy demand of thirteen industries (steel, chemicals, cement, ceramics, glass, non-ferrous metals, pulp, paper and printing, food and beverages, transport equipment, machinery equipment, textiles and leather, wood and wood products and other industries.

Levelised cost of energy (LCOE)

LCOE is defined as the revenue required (from whatever source) to earn a rate of return on investment equal to the discount rate (also referred to as weighted average cost of capital, WACC) over the life of the wind farm. Tax and inflation are not modelled.

Liquid biofuels

Fuel produced from biomass that can be used to power internal combustion engines (e.g. in vehicles or cogeneration units) or in heating systems. So-called first generation liquid biofuels include biodiesel and bioethanol. Biofuels produced from organic waste and residues as well as synthetic biofuels often are referred to as so-called second generation biofuels.

Liquid synthetic fuels

Comprises fuels identic to fossil diesel or kerosene derived from renewable hydrogen.

Non-fossil gases

Gaseous energy carriers that are either produced with renewable electricity through electrolysis (renewable hydrogen, renewable ammonia, synthetic methane) or produced with sustainably sourced biomass such as organic waste, residues and manure (biogas, biomethane).

Primary energy supply

In contrast to the final energy arriving at the door step of the end consumer, losses from later conversion into other energy carriers such as heat or electricity are not yet deducted, neither losses of transmission and distribution, e.g. through a district heat network or a gas pipeline.

PRIMES

EU energy system model simulating energy consumption and supply.

Renewable ammonia

Gaseous or liquid carrier of converted renewable hydrogen.

Renewable hydrogen

Chemical element that is produced by splitting water into its component parts, oxygen and hydrogen (H_2), in an electrolyser that uses renewable electricity. It is the base for producing renewable ammonia, synthetic methane and liquid synthetic fuels.

Residential sector

Comprises the energy demand of private households, including space heating and cooling, hot water and electricity.

Self-consumption

Self-consumption is the activity of using a certain share of power and/or heat generation from self-generation on the premises of a consumer directly to cover the consumer’s energy demand. Self-consumption is a central, but not the unique activity within the concept of self-generation. Self-generators normally also feed excess electricity into the public grid.

Solar thermal energy

Solar energy's heat is absorbed by solar thermal collectors, in which water or another heat carrier is heated and used for heating rooms or to supply hot water. Concentrated solar power (CSP) also uses solar thermal energy for electricity generation.

Solid biomass

Wood that is used as a primary energy source such as residual wood from forestry or landscape maintenance, industrial wood residues, e.g. by-products of sawmills or waste wood. Typical solid biomass energy carriers are wood logs, wood pellets and wood chips.

Synthetic methane

Gaseous energy carrier that is produced on the base of renewable hydrogen transformed into methane by adding carbon dioxide using the Sabatier process. Physically, it is identic with fossil gas and biomethane (CH_4).

Tertiary sector

Comprises the energy demand in public and private buildings, i.e. offices, wholesale and trade, hotels, gastronomy, education, health care and other building facilities for services. It includes space heating and cooling, hot water and electricity demand, as well as public lighting.

Transmission system operator (TSO)

A company running the high-voltage electricity transmission grid or the fossil gas transmission grid. In contrast to the distribution system operators (DSO), they are responsible for the stability of the interregional and cross-border "motorways" of energy.

Transport sector

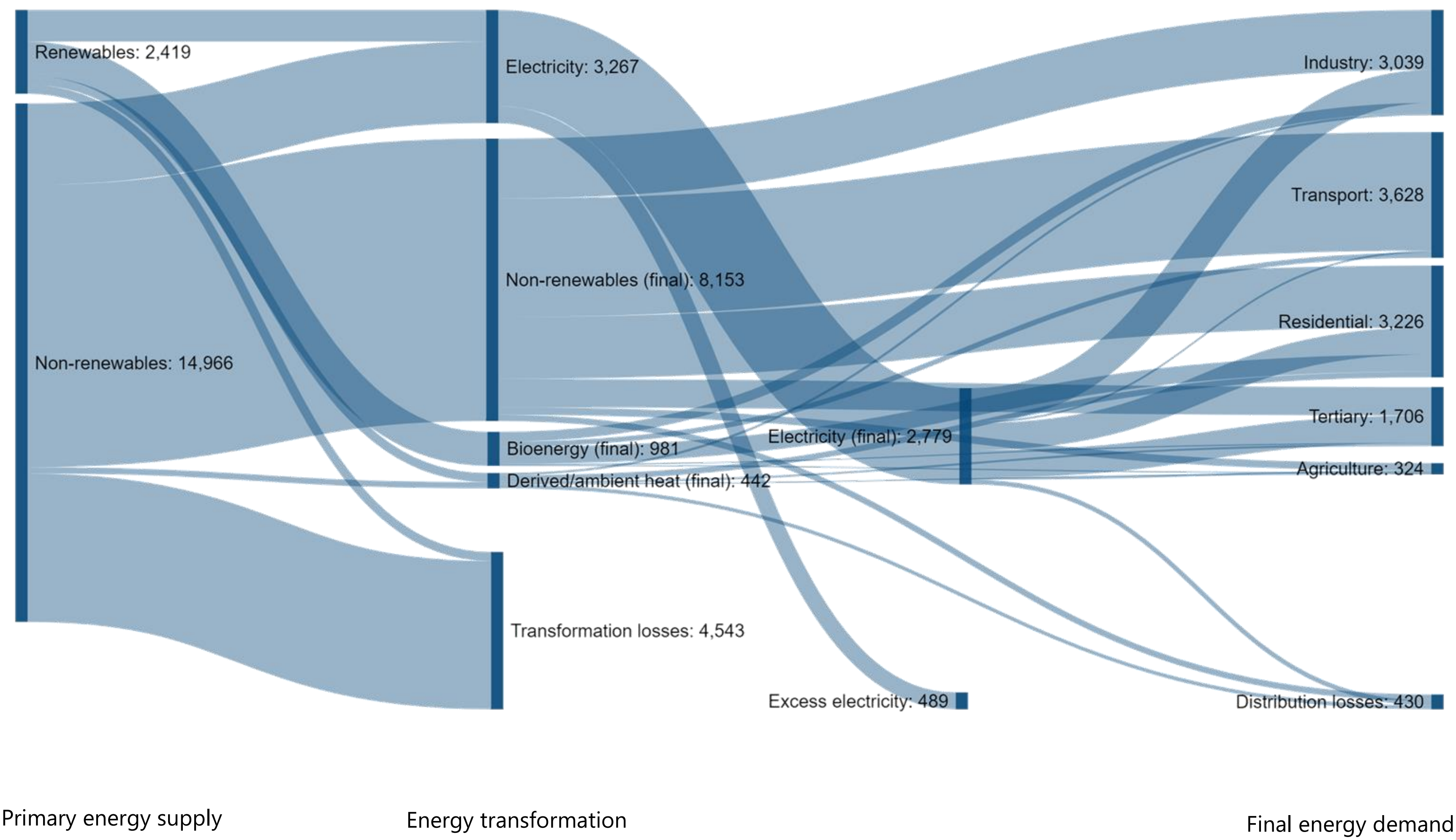
Comprises the energy demand of motorised passengers (motorbikes, passenger cars, vans, buses, trains, freight covered by trucks and trains, shipping and aviation.

Waste

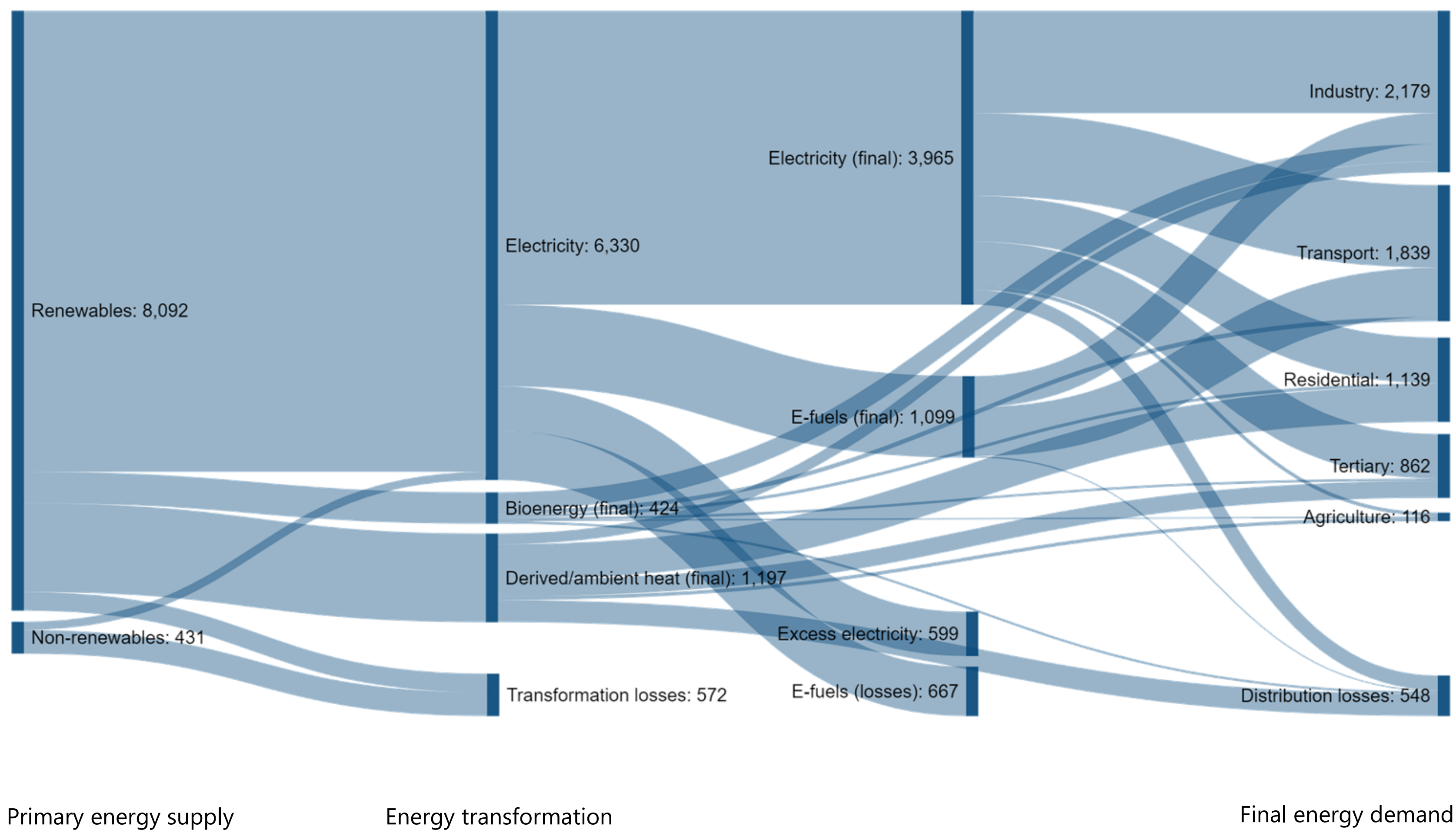
Solid primary energy source that is either used for direct heating in industry or as municipal solid waste in waste incinerators that produce electricity and heat in cogeneration. Per definition, 43% of municipal solid waste statistically is classified as renewable energy source, taking into account its biomass share.

Annexe

PAC scenario energy flows – 2015 [TWh]



PAC scenario energy flows – 2040 [TWh]



"E-fuels": non-fossil gases and fuels excluding biogas/biomethane (renewable hydrogen, renewable ammonia, synthetic methane, liquid synthetic fuels

Storyline central matrix[77] with key assumptions mirroring the TYNDP 2020 scenario template for comparison

Category	Criteria	PAC scenario 2040 change from today
Primary energy mix	Coal	---
	Fossil oil products	---
	Nuclear	---
	Hydro	o
	Geothermal	+++
	Biomass	o
	Imported non-fossil and so-called ‘decarbonised gas’	---
	Fossil gas	---
	Wind energy onshore	+++
	Wind energy offshore	+++
	Solar PV	+++
	Wind energy for producing renewable hydrogen	+++
	Solar PV for producing renewable hydrogen	+++
	Total demand (all energy)	--
High temperature heat	Electricity demand	+++
	Gas demand	--
	Total demand (all energy)	--
Low temperature heat	Electricity demand	+++
	Gas demand	---
Transport	Total demand	-
	Electricity demand	+++
Electricity and lighting	Gas demand	---
	Electricity demand	+++
CCS	Carbon capture and storage (CCS) for electricity generation	---
	CCS in industry	---

Change from today mirroring the scales of the Ten Year Network Development Plan (TYNDP) template:

---	--	-	o	+	++	+++
phase-out	moderate reduction	low reduction	stable	low growth	moderate growth	high growth

[77] The table allows for a comparison with key assumptions of ENTSO-E/ENTSOG: TYNDP 2020 Scenario Report, November 2019, www.entsos-tyndp2020-scenarios.eu.