Building a Paris Agreement Compatible (PAC) energy scenario

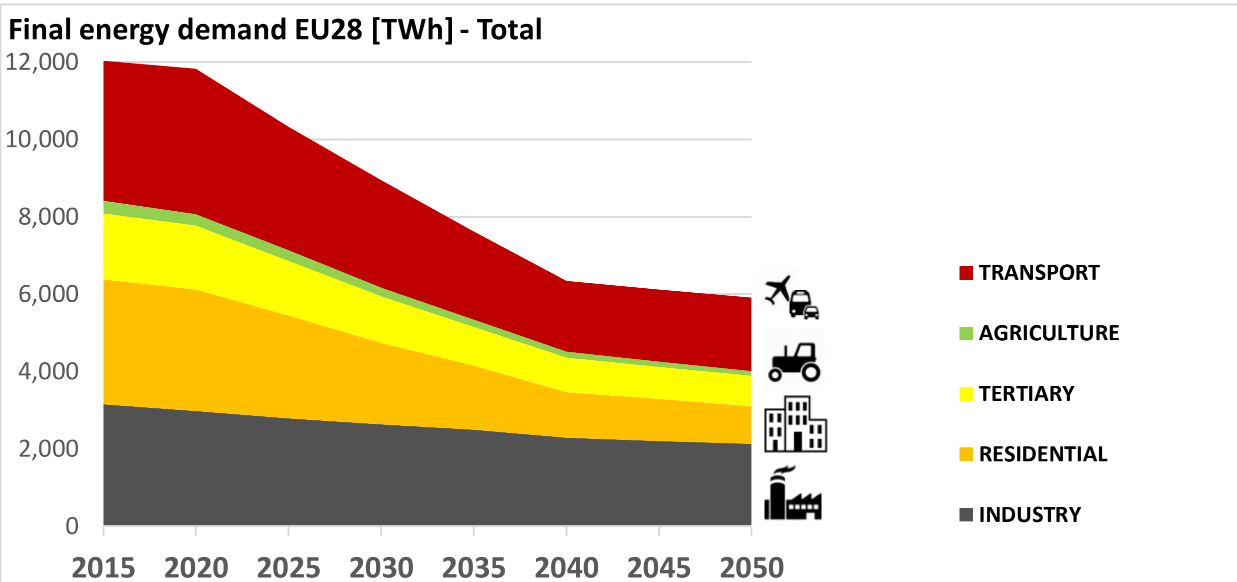
CAN Europe/EEB technical summary of key elements

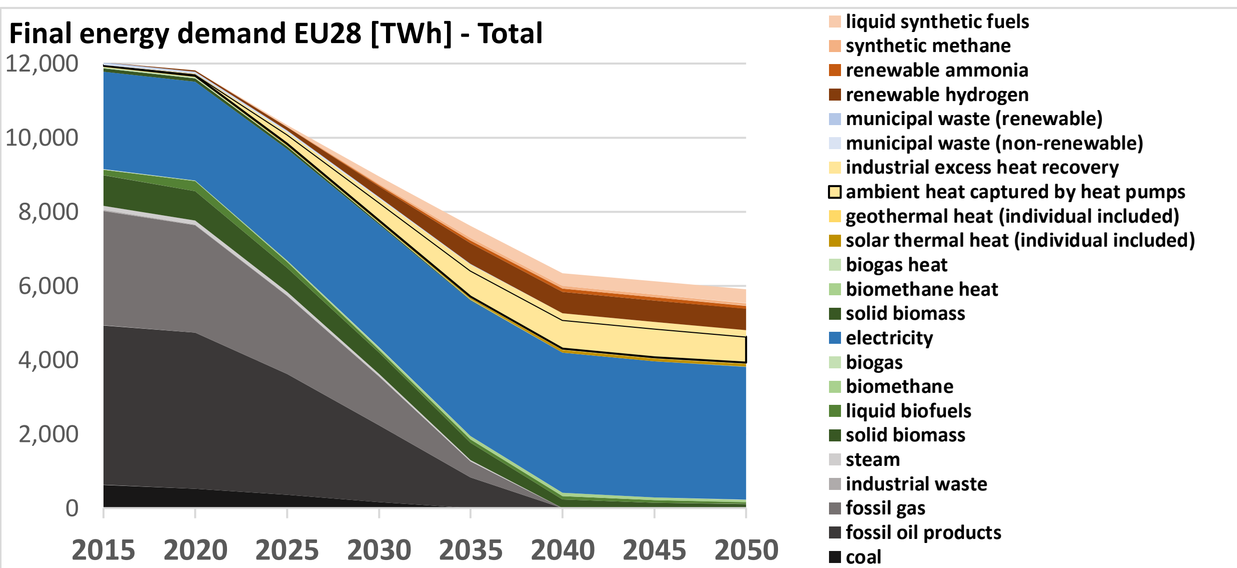
June 2020

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.[1]
- 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).[2] 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.[3]

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.[4]

Sensitivities and limitations

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

[2] 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.

[3] 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.

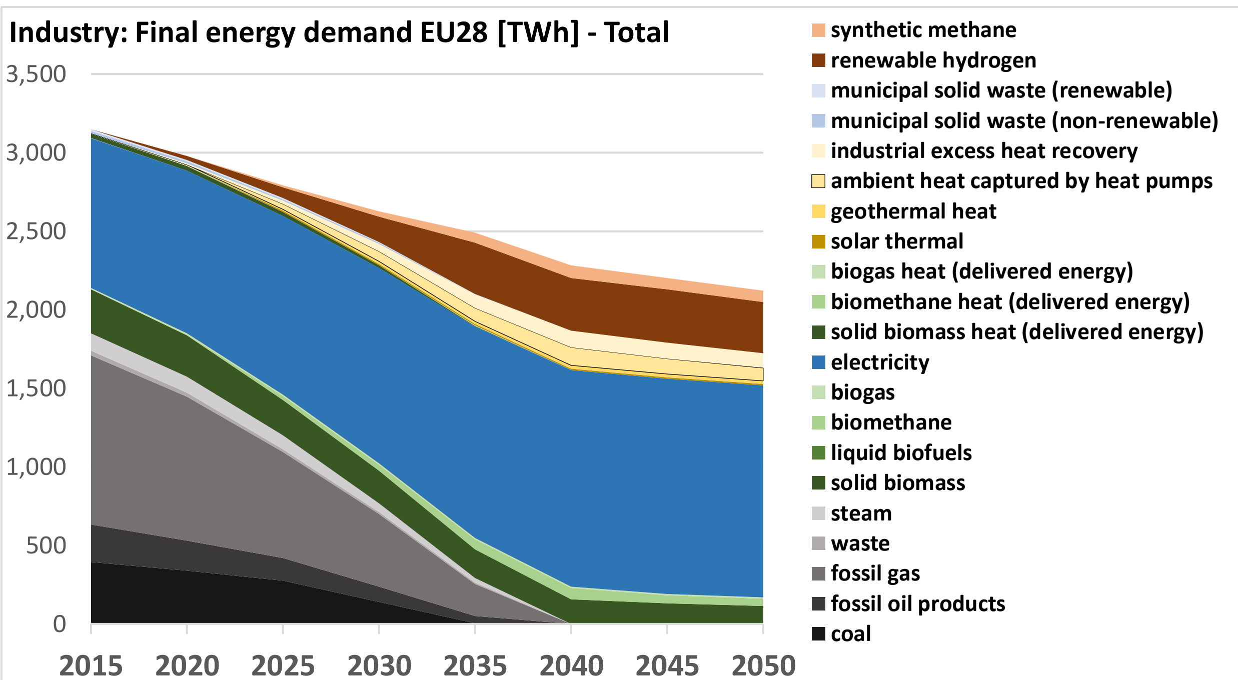
[4] CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops on 24 April 2019, 9 July 2019, 9 October 2019, 7 November 2019 and 31 January 2020.

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[5] 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.[6]
- 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.[7]

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.[8]

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.[9]

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.[10]

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

6 Taking over assumptions from EUCalc.

7 Fraunhofer ISI: Study on Energy Savings Scenarios 2050. January 2019.

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

9 Taking over assumptions from Fraunhofer ISI.

10 CAN Europe/EEB: Summaries of PAC scenario workshops.

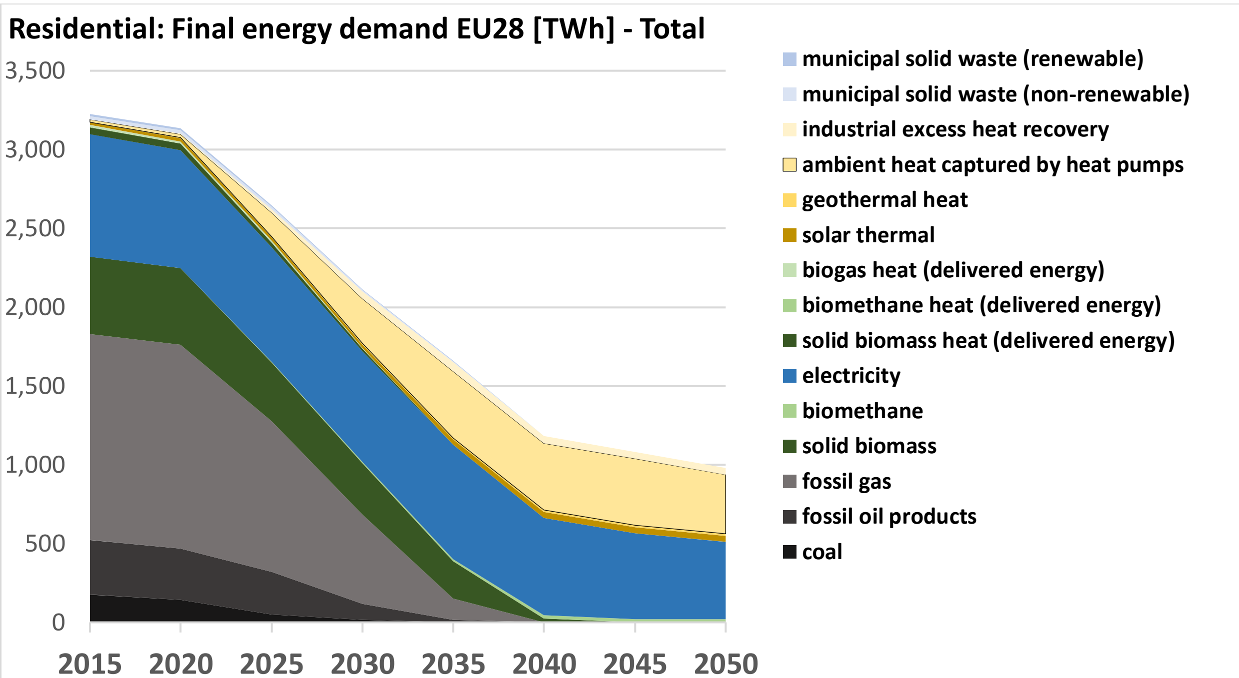
Sensitivities and limitations

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.[11] 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.



11 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.[12]
- 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.[13]

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.[14]

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.[15] 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.

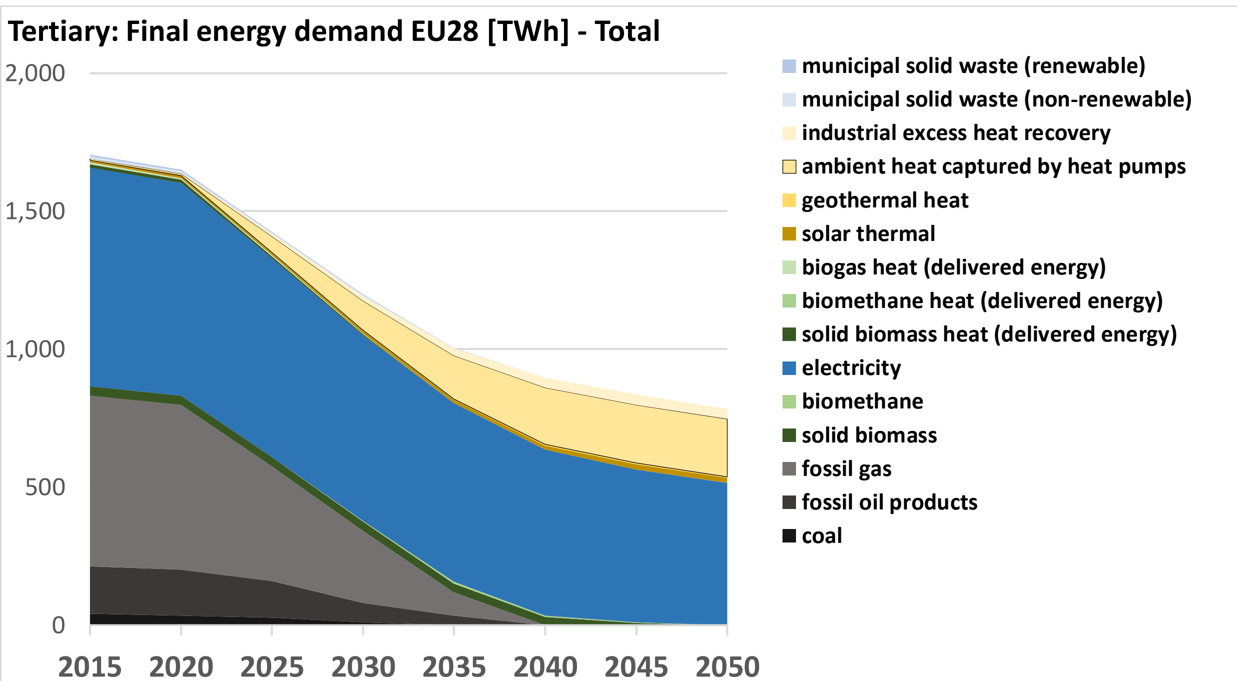
12 Taking over assumptions from EUCalc.
13 Taking over assumptions from Fraunhofer ISI.
14 Aalborg University.
15 Taking over assumptions from Fraunhofer ISI.

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.[16]
- 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.[17] 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.

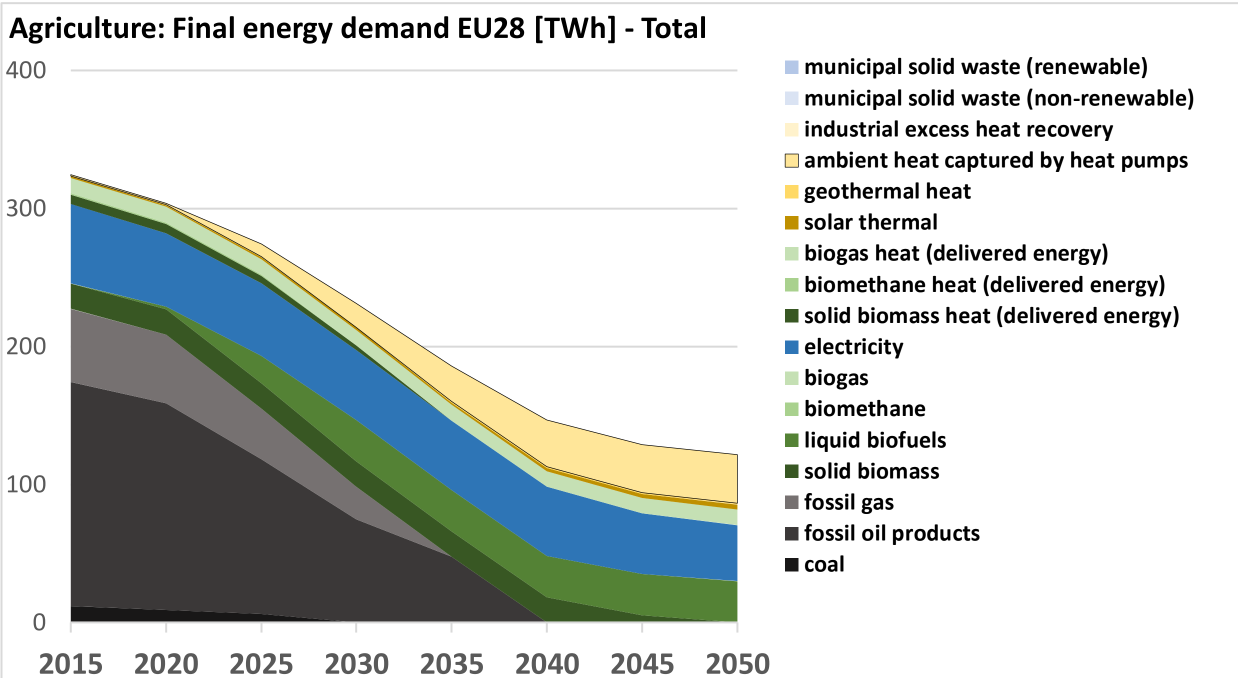
Key results

- 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.

16 Key assumptions are taken over from tertiary sector figures in Fraunhofer ISI.

17 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.

- 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[18]. 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.[19]
- 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.[20]
- Aviation will be mostly covered by liquid synthetic fuels and marginally by second-generation biofuels[21], 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[22] rail freight between 2015 and 2040[23], and a 12% shift[24] 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[25]. 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[26], the PAC scenario kept a moderate growth in transport activity to remain consistent with other sectors.

Sensitivities and limitations

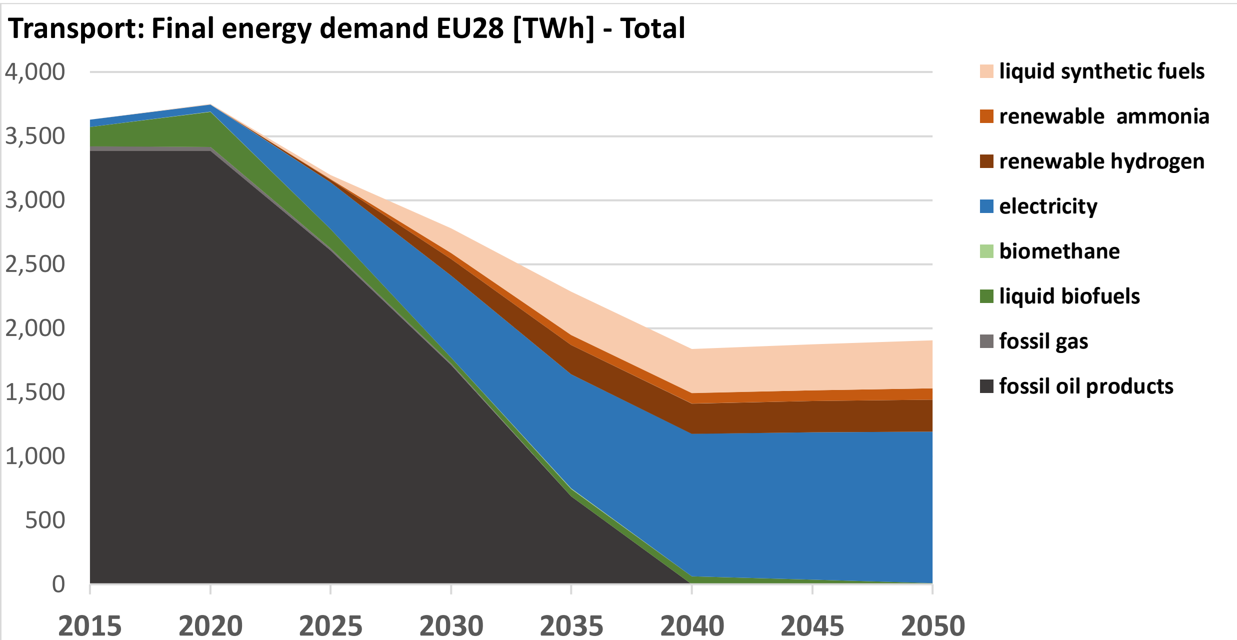
Reaching net zero emissions by 2040 could be challenging for the transport sector, meaning vehicles with internal combustion engine (ICE) sold after 2020 will need to have a shorter lifetime in order to reach a fossil-free fleet by 2040.

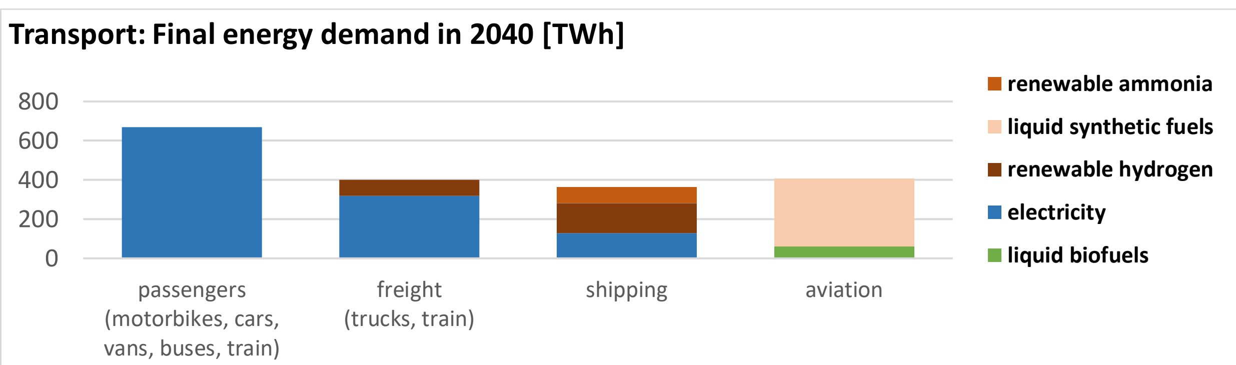
18 Transport and Environment: Roadmap to decarbonising European cars, November 2018.
19 Transport and Environment: Roadmap to climate-friendly land freight and buses in Europe, June 2017.
20 Ammonia has a higher energy density than hydrogen and therefore allows for longer distances. Transport and Environment: Roadmap to decarbonising European shipping, November 2018.
21 Transport and Environment: Roadmap to decarbonising European aviation, October 2018.
22 In tons of freight*km, from around 400 billion to around 800 billion.
23 Transport and Environment: Roadmap to climate-friendly land freight and buses in Europe, June 2017.
24 In passenger*km.
25 CAN Europe/EEB: Summaries of PAC scenario workshops and General Assemblies workshops.
26 OECD: Decoupling the environmental impacts of transport from economic growth, December 2016.

Also, the high pace of electrification requires particular attention in sustainable battery and electricity supply to remain Paris Agreement compatible.[27]

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.





27 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.