BRIEFING

European Parliament

Energy storage and sector coupling

Towards an integrated, decarbonised energy system

SUMMARY

In order to reach the goals of the Paris Agreement on climate change, the European energy system will need to become carbon-neutral by the second half of this century. However, while renewable sources of energy are key to achieving this, some of the most important renewables are variable: the output of solar and wind power depends on the time of day, the seasons and the weather. As the share of variable renewables increases, energy storage is playing an increasingly important role in bridging the gap in time between energy production and energy consumption.

While the share of renewable energy in the electricity sector is growing continually, other sectors, such as transport, buildings and industry, still depend largely on fossil fuels. To decarbonise these sectors, they can either be electrified or the fossil fuels can be substituted by renewable gases such as hydrogen or renewable liquid fuels. Transformation from electricity to gases and vice versa can add further storage capacity and flexibility to the energy system. Research indicates that coupling different sectors in this way would lower the overall cost of decarbonising the energy system.

The EU has reformed its electricity markets to facilitate the participation of storage in managing supply and demand, and revised the renewable energy directive to include renewable gases. When it comes to industrial policy, the EU supports initiatives for batteries and hydrogen.

The debate about the pathways towards a carbon-neutral economy is ongoing, and is based on the Commission's clean planet strategy. The outcome of this debate will influence EU policies in various fields and inform the EU's low greenhouse gas emission development strategy under the Paris Agreement, which must be submitted in 2020.

In this Briefing

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Issue definition

The European Commission's clean planet strategy has as its goal a carbon-neutral EU economy by 2050. The decarbonisation of the European electricity sector is progressing, but other sectors have not reduced their dependence on fossil fuels. This is the case notably for transport, heating and cooling, and industrial processes. The share of renewable energy in EU electricity generation approached 31 % in 2017; whereas in heating and cooling it was 19.5 % and in transport only 7.6 %.

Integrating a growing proportion of renewable energy sources into the electrical grid is challenging. Renewable sources such as wind and solar energy are not dispatchable, but depend on the weather, the time of day and the time of year. With an increasing share of variable renewables on the electricity grid, it is becoming more challenging to balance demand and supply, ensure the stability of the grid and avoid distortions in electricity markets, such as negative electricity prices. Variable electricity production from renewable sources can be handled in various ways: with flexible electricity generation as backup, with flexible electricity demand, and with energy storage (which is the focus of this document). Another issue is that renewable energy sources are often located at some distance from the places where the electricity is consumed, so that new grid connections and transmission capacities are needed if the energy cannot be stored locally. The cost of renewable generation technologies is falling continually, but the cost of accommodating a growing proportion of renewable electricity sources is growing, due to the need for balancing services, grid expansion and the curtailment of surplus renewable electricity production. Moreover, energy demand follows a seasonal pattern. In Europe, it is highest in the winter months due to energy demand for heating. Inter-seasonal storage of energy is therefore a challenge that needs to be addressed. The existing gas infrastructure could be used for inter-seasonal storage of renewable gas (methane or hydrogen), which can produced from renewable electricity by means of electrolysis.

A central question is the overall efficiency and cost of the various possible solutions. It is not sufficient to compare the investment and operational costs of various technologies in isolation, but account must be taken of the costs of the entire system. For example, it may be cheaper to use electricity than renewable gases, but large-scale electrification may induce demand peaks that would require a costly expansion of the electricity transmission and distribution infrastructure. Therefore, the overall system cost may be lower even if more expensive renewable gases are used, for which the existing gas storage and transport infrastructure can be utilised. A solution with lower technical energy efficiency (such as conversion of electricity to hydrogen and back to electricity) may be the more efficient one when the entire system is brought into consideration.

Energy storage

Fuels come in various forms: solid (coal, biomass), liquid (oil, ethanol) or gaseous (methane, hydrogen). Storing these forms of energy is straightforward, and the storage infrastructure is well developed so that the time of consumption can differ from the time of production. EU Member States are obliged to have **oil stocks** for 61 days of consumption or 90 days of net imports, whichever is higher. The EU has **gas storage** capacities that amount to 23 % of annual gas demand. They are used mostly for long-term storage, in order to have sufficient gas reserves for the winter months, when gas demand is highest.

Storage of electricity is not as straightforward, as electricity production must be equal to consumption at all times. To store electrical energy, it must be converted to a different form: chemical (batteries), potential energy (pumped hydro, compressed air), or thermal energy (heat). Moreover, electricity can be used to produce gases or liquid fuels, which can be stored with the appropriate infrastructure.

Storage technologies can be assessed by the quantity of energy stored (typically measured in kilowatt-hours) and by the maximum power delivered (typically measured in kilowatts). Other important criteria are the efficiency (energy lost), the cost and the speed of reaction.

Pumped storage is one of the oldest and most widely used electricity storage technologies. It functions by using electricity to pump water uphill to a reservoir. When electricity is needed, the water is released from the reservoir to drive a turbine and generator. Pumped storage plays an important role for balancing the electricity system, as it can react quickly if more or less electricity is needed. Pumped storage accounted for 97 % of EU electricity storage capacity in 2017, with a total capacity of less than 2 % of annual EU electricity demand. However, it is difficult to add more pumped storage capacity as most of the suitable places for creating reservoirs have already been taken or are dedicated to other uses.

Batteries are expected to play an increasing role in the future energy system. Batteries come in various sizes, from tiny cells that power electronic devices to grid-scale battery projects with a total capacity of hundreds of megawatt-hours. Batteries that are of relevance to the electricity system include the batteries of electric vehicles, home storage devices (such as Tesla power wall), battery storage attached to renewable energy plants, and grid-scale batteries.

Energy storage is growing rapidly worldwide, with most of the growth coming from lithium-ion batteries. However, most battery cell manufacturing capacity is located outside the EU. In 2018, only 3 % of global lithium-ion battery cell manufacturing capacity was located in the EU, with 85 % in the Asia-Pacific region. The EU is dependent on imports for access to core raw materials for lithium-ion battery production: four major producers control 83 % of global lithium supply, while 64 % of cobalt ore comes from the Democratic Republic of Congo.. The recycling of batteries can help to recover valuable raw materials.

Batteries can provide valuable services for the electricity system: frequency control, temporal shift of consumption, and flattening of demand peaks. They can act as local buffers to store variable renewable energy near the place of production for later local use or injection into the grid at times of high demand and high prices.

Other electricity storage technologies include compressed air, flywheels, supercapacitors, and rail energy storage. Each of these have their particular characteristics and uses. Some are better suited to deal with short-term variations while others allow for longer-term storage.

Thermal storage – storing energy in the form of heat – can be achieved in various ways. The simplest application of thermal storage is to run an electric hot water boiler when electricity is abundant and then use the hot water at a later time. The same applies to heating, refrigeration and air conditioning systems. On an industrial scale, sunlight can be used in a concentrated solar power plant to heat a storage fluid (e.g. molten salt), which can be used at a later time to drive a steam turbine to produce electricity.

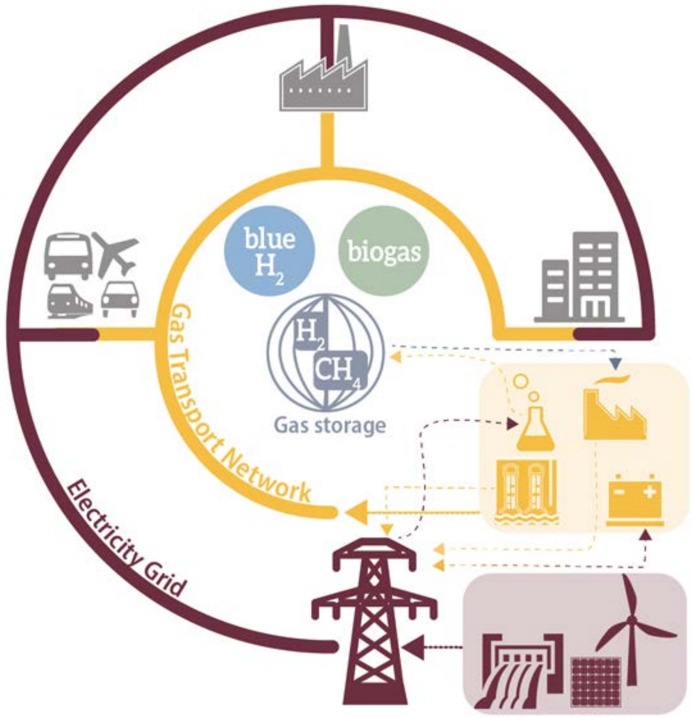
Hydrogen

Hydrogen (H_2) is n gaseous energy carrier that can be used in various ways. It can be used to generate electricity by means of fuel cells, converted into gaseous and liquid fuels, mixed with natural gas (up to a certain proportion, depending on local conditions and equipment), used for heating purposes, and used for steel production and as a chemical feedstock. Hydrogen can be produced either from natural gas (steam methane reforming), or from electricity by an electrolysis process. Today most hydrogen is produced from natural gas by means of steam methane reforming, a process with high carbon emissions. If the CO_2 resulting from the process is captured and stored, the hydrogen produced is referred to as '**blue hydrogen**'. Hydrogen produced by electrolysis with renewable energy is called '**green hydrogen**'. However, electrolysers are still very capital-intensive, so that it would not make economic sense to run them only during times when electricity is cheap and abundant.

Sector coupling

The concept of 'sector coupling' (or 'sectoral integration'), originally developed in Germany, addresses the issue whereby the electricity sector is being rapidly decarbonised, but other sectors (buildings, transport, industry) are proving more difficult to decarbonise. The European Commission (DG Energy) considers sector coupling 'a strategy to provide greater flexibility to the energy system so that decarbonisation can be achieved in a more cost-effective way'. Sector coupling aims to replace the use of fossil fuels in these sectors with decarbonised electricity or energy carriers produced from decarbonised sources. Two general approaches are distinguished: end-use sector coupling and cross-vector integration.

Figure 1 – Sector coupling



Sector coupling involves:

- the electrification of transport, industry and households through the electricity grid,
- production of gases such as hydrogen (H_2) and methane (CH_4) from renewable electricity,
- storage of energy in pumped hydro, batteries and as gases (H_2 and CH_4),
- supply of end-use sectors with renewable gases, and
- electricity production from hydrogen through fuel cells and from gas with thermal power plants.

Source: European Parliament, EPRS.

End-use sector coupling means the large-scale electrification of energy use in the end-use sectors. Most studies (summarised in the annex of this document) agree that carbon-free electricity would play an increasing role in a decarbonised energy system. End-use sector coupling aims for maximal electrification of sectors that currently depend on fossil fuels (transport, heating and cooling, industrial processes). In the transport sector, this could be achieved by using electric and hydrogen-powered vehicles and through a modal shift from road to rail transport. In the heating sector, electric heat pumps can substitute fossil-fuelled furnaces. This strategy would result in costs for electric vehicles, heat pumps and other electrical end-use equipment, electricity generation and storage capacity and expansion of the electricity transmission and distribution networks to handle the increased demand and demand peaks.

Cross-vector integration, or 'power-to-X', involves indirect electrification by using electricity to produce heat, gaseous or liquid energy carriers for use in the end-use sectors. This strategy involves the use of electricity to produce heat, hydrogen and other gaseous and liquid fuels. It would result in additional costs: electrolysers, fuel cells, hydrogen storage and transport and conversion of end uses, such as steel production, to utilise hydrogen in the place of fossil fuels. However, the possibility to make use of existing gas transport and storage infrastructure would reduce the amount of new investment required. Compared with end-use sector coupling, less investment in electricity generation capacity, transmission and storage would be required. The existing gas grid could be used for hydrogen, either by adding hydrogen to natural gas or by converting the gas grid completely. Currently, it is possible to mix hydrogen with natural gas in a few EU countries (Belgium, Denmark, Germany, the Netherlands, and the UK). Conversion of the gas transport and storage infrastructure would require considerable investment.

Experts expect both these approaches to play an important and complementary role in a future low-carbon economy, but there is a debate as to how to combine them in the most efficient and cost-effective manner (see 'Stakeholder views and expert analysis' below).

Transport

The EU transport sector is still largely dependent on fossil fuels, which offer high energy density and can be easily transported and stored. Electrification of transport (using low-carbon electricity) is an option for reducing emissions in this sector. This can be achieved through a shift to already electrified modes of transport (e.g. trains) and by electrification of vehicles. The weight and volume of the batteries make it harder to electrify heavy-duty vehicles (trucks and buses) than light-duty vehicles (cars and vans). Another route is the use of renewable hydrogen, in combination with a fuel cell that powers an electric engine. This would also be suitable for heavy-duty transport and non-electrified rail lines. Other gases or liquid fuels produced from renewable sources (methane, methanol) can also play a role. Finally, biofuels are used to reduce transport greenhouse gas (GHG) emissions in combination with internal combustion engines, but the sustainability of biofuels remains an issue (the Renewable Energy Directive sets out sustainability criteria for biofuels as regards GHG savings compared with fossil fuels, and seeks to ensure the environmental sustainability of biofuel production).

For aviation, liquid jet fuel produced from renewable sources is currently favoured, as the weight of batteries makes them unsuitable for aircraft. In the shipping industry, batteries are starting to be used for short passages (e.g. ferries), while renewable gas appears more suitable for longer routes.

The role of electric vehicles

Electric vehicles can contribute to the decarbonisation of the transport sector, if they are powered with electricity from renewable sources. Increasing electrification of road transport will lead to growing electricity demand and require the reinforcement of electricity networks. If a large number of electric vehicles are charged at the same time, typically in the evening, this can lead to higher demand peaks. A German study estimates that a 30 % share of electric vehicles could lead to blackouts in the electricity system if too many vehicles are charged at the same time.

On the other hand, electric vehicles, which are equipped with a large battery, can help to stabilise the electricity system, using vehicle-to-grid technology. With this approach, vehicles would be charged when electricity is cheap and abundant, thus preventing the curtailment of surplus renewable power. In times of high electricity demand and high prices, they would feed electricity back into the grid. They could also help to stabilise grid voltage and frequency by reacting quickly to any changes. The owners of electric vehicles could participate in the electricity market and be paid for electricity fed into the grid and for network services.

Batteries represent around half the cost of an electric vehicle. In 2018, only 3 % of global lithium-ion battery cell manufacturing capacity was located in the EU, while 85 % was located in the Asia-Pacific region. If Europe does not significantly expand its battery production capacity, the European car industry will remain dependent on imported batteries for its electric vehicles.

Heating and cooling

While cooling is mostly electric, most heating in the EU depends either on fossil fuels (mostly gas, with a shrinking role for heating oil and coal) and on biomass (mostly wood). Heat pumps are an efficient technology for the electrification of the heating sector. They achieve high efficiency by extracting heat from the ambient air or ground water. Heat pumps and electric water heaters can be run when electricity is abundant and cheap, in order to store energy in thermal form for later use. Indirect electrification of the heating sector is possible by converting renewable electricity into gas that is used for heating. With this approach, less expansion of the electricity grid is needed and the energy can be stored for long periods in existing gas storage facilities. This would bridge the gap between the summer months when solar electricity is abundant and the winter time when the energy demand for heating is the highest.

Industry

Fossil energy sources (coal, oil and gas) perform a double role in industry. They serve both as a source of energy (especially high-temperature heat) and as a feedstock for industrial processes (oil and gas for the chemical and plastics industry; coal coke for iron and steel production). Iron and steel producers are major industrial carbon emitters. Raw iron and steel production traditionally uses coal coke in a blast furnace as an energy source and as a reducing agent to extract iron from the ore. Steel producers are starting to use hydrogen as an energy source and reducing agent. Hydrogen can also play a role in substituting oil or natural gas in refining and in the chemical industry. For the production of industrial heat, heat pumps can be used for lower temperatures, while higher temperatures can be achieved with hydrogen or other renewable gases.

Aluminium production and steel recycling are heavy users of electricity that can contribute to the stability of the electric grid by reducing electricity demand at times of peak demand and high prices.

Stakeholder and expert analysis

Various organisations have recently carried out studies and scenario analyses on the most efficient and cost-effective transformation of the energy system towards carbon-neutrality.

The **European Commission** clean planet strategy communication compares eight scenarios, all of which based on improved energy efficiency and heavy use of renewable energy. Five scenarios focus on approaches such as electrification, hydrogen, e-fuels, end-user energy efficiency and the circular economy, which are used with differing intensities to reach emission reductions of around 80 %. The sixth scenario combines the previous five options to reduce emissions by around 90 %. The seventh scenario achieves carbon-neutrality by pushing all zero-carbon energy sources (including nuclear) and additionally relies on negative emissions. The eighth scenario builds on the previous one, but focuses on a highly circular economy, climate-friendly consumer choices and a strengthened land-use sink reducing the need for negative emission technologies. The communication sets out seven strategic building blocks for a net-zero emission economy, and stresses the importance of starting to plan early for a socially fair and politically feasible transition.

A 2018 Policy Department study for the European Parliament's Committee on Industry, Research and Energy identifies techno-economic and policy and regulatory barriers to end-use sector coupling and cross-vector integration. It makes policy recommendations including integrated planning and operation of energy infrastructure, coherent energy policies and adequate incentives for flexible, low-carbon technologies. Regarding hydrogen, its future role should be further assessed, and its deployment facilitated. Energy (service) markets should reflect positive and negative externalities for each participant and provide a level playing field for all technologies and vectors contributing to energy supply, system flexibility and adequacy. Finally, EU research and innovation policy should focus on integrated energy system planning and operation, and facilitate high-risk innovations.

The Integrated Energy Transition study by **dena** (the German energy agency) develops and compares transformation paths for the German energy system to achieve the German climate policy targets for 2050. It uses an innovative, cross-sectoral scenario approach and builds on the expertise of more than 60 study partners from the relevant sectors as well as politicians, scientists and the public. It concludes that use of a broad mix of technologies and energy carriers could save up to €600 billion in comparison with electricity-focused approaches. Synthetic renewable fuels and energy efficiency are expected to play a major role. The highest investment is needed in the building stock and the energy sector. Decarbonisation of the transport sector would be based on electrification, carbon-neutral fuels, and new mobility strategies to curb or reduce traffic.

A 2018 study by the **Florence School of Regulation** highlights the need for integrated infrastructure planning, advocates better correlation between gas and electricity market design and price structure, and stresses the importance of research, development, demonstration and deployment for decreasing the capital costs of new projects.

The **International Energy Agency** published a report on the future of hydrogen, at the request of the Japanese G20 presidency. It makes several recommendations for scaling up hydrogen: giving hydrogen a role in long-term energy strategies and stimulating commercial demand for clean hydrogen; addressing the investment risks of first-movers and supporting research and development to bring down costs; removing unnecessary regulatory barriers and harmonising standards; and engaging internationally and tracking progress. It identifies key opportunities to boost hydrogen use in the short term.

Hydrogen Europe has published a vision on the role of hydrogen and gas infrastructure that outlines the role of hydrogen in decarbonising the energy system, identifies barriers and makes recommendations for the long-term regulatory framework.

The **European Commission** is currently carrying out a study on sector coupling, with a focus on the role of gas in a decarbonised energy system. Its objective is to identify regulatory gaps and barriers and develop policy recommendations. The publication is expected in July 2019.

Further **modelling studies** are summarised in the annex to this briefing. Despite differences, these studies have a number of points in common. All envisage a profound change in the energy system as a whole and all apply systemic modelling and analysis to find the most effective solution for the EU economy. Electricity use is generally expected to grow along with the use of renewable energy sources and electrification of end uses. The energy efficiency and insulation of buildings is important in all scenarios, often leading to a decrease in total energy consumption. All scenarios see a growing role for renewable gas and hydrogen, but they do not all agree on its optimal use.

EU policy and initiatives

The EU has adopted legislation designed to facilitate the participation of storage in the electricity markets and is supporting the development of battery and hydrogen production through research and industrial policy.

The new rules for the EU electricity market, adopted in March 2019, facilitate the integration of storage within the electricity system. The Electricity Directive gives customers the right to participate in the electricity market. Customers that own storage facilities can buy and sell electricity from the grid and offer services such as flexible demand and frequency control. The Electricity Regulation sets out the market design, which puts storage on an equal footing with generation and demand response. It restricts the ownership and operation of storage facilities to transmission and distribution system operators. The European Parliament supported the reform of the electricity market on a technology-neutral basis, in order to facilitate the integration of renewables, storage and demand response.

Recently adopted EU legislation (CO_2 emission standards for cars and vans and for heavy-duty vehicles and public procurement of clean vehicles) is expected to boost the share of battery-electric and hydrogen-powered vehicles. The revised Renewable Energy Directive (RED II) extends guarantees of origin to renewable gases and counts 'renewable liquid and gaseous transport fuels of non-biological-origin' towards fulfilling the 14 % renewable energy target for the transport sector.

In the field of industrial policy, the Commission launched the European Battery Alliance in October 2017. The strategic action plan on batteries, published by the European Commission in May 2018 as part of the 'Europe on the move' package, is geared towards creating a competitive and sustainable battery manufacturing industry in Europe. The European Technology and Innovation Platform on Batteries was launched in February 2019. In April 2019, the Commission published a report on the implementation of the strategic action plan on batteries and an evaluation of the Batteries Directive.

In June 2019, the Commission launched a public consultation on EU requirements for sustainable batteries. The EU supports research into advanced battery technologies under the Horizon 2020 research framework programme with a total of €114 million. In May 2019, the European Investment Bank approved a €350 million loan to build a gigafactory for lithium-ion battery cells in Sweden, with support from the European Fund for Strategic Investments (EFSI).

In April 2019 the **European Court of Auditors** published a briefing paper on EU support for energy storage. With regard to battery manufacturing, it warns that the EU is behind its competitors and may not achieve its strategic objectives for clean energy under the current strategic framework. It identifies seven main challenges: a coherent EU strategy, stakeholder support, complexity of EU research funding, support for research and innovation in energy storage, deployment of energy storage technologies, obstacles facing investors, and alternative fuel infrastructures.

Over the past 10 years over €1 billion has been invested in hydrogen technologies through the Fuel Cells and Hydrogen Joint Undertaking, a public-private partnership involving the European Commission, the hydrogen and fuel cell industry and the research community. It pools resources to overcome barriers to deployment and accelerate the market introduction of the technologies. During the June 2019 meeting of G20 environment ministers, the EU and Japan resolved to strengthen cooperation in the energy field, with the development and deployment of fuel cell and hydrogen technologies and a regulatory framework, with a view to trilateral EU-Japan-US cooperation.

Outlook

The EU is in the midst of a debate on how and when to achieve a zero-carbon economy, following the publication of the Commission's clean planet strategy in November 2018. The strategy advocates carbon-neutrality by the middle of the century. The European Parliament adopted its position in March 2019, calling for an overarching approach to achieving net-zero GHG emissions by 2050. The strategy has been discussed in various Council configurations and at the June 2019 European Council. In 2020, the EU will have to formulate and submit its low GHG emission development strategy under the Paris Agreement to the United Nations Framework Convention on Climate Change.

The Commission has already begun preparatory work on reforming the EU gas market rules. As regards development of the electricity and gas networks, the European networks of transmission system operators for electricity (ENTSO-E) and gas (ENTSOG) are jointly preparing 10-year network development plans for the gas and electricity grids, with a view to a better integration.

The long lifetime of energy-related infrastructure means that action in the coming years will be critical for phasing out GHG emissions around 2050. While the Juncker Commission and the eighth European Parliament shaped EU energy and climate policy up to 2030, it is up to the next Commission and the ninth Parliament to develop policies that can foster the transition towards a carbon-neutral EU economy by the middle of this century.

Annex: Modelling studies

The European Commission has conducted a series of analyses based on METIS, a model of the European energy system for electricity, gas and heat. The study on optimal flexibility portfolios for a high-RES 2050 scenario analysed pathways to reach carbon neutrality of the power sector and contribute to the decarbonisation of other sectors via power-to-gas and power-to-liquid. The decarbonisation of other sectors (transport, industry) through hydrogen or new, flexible electricity usage contributes additional flexibility to the system and facilitates the integration of renewable electricity. Full decarbonisation of the European power sector is feasible with an increasingly interconnected European power system and the deployment of low-cost storage technologies. In the analysis, the role of gas in the power sector remains restricted to capacity services while total gas demand remains very limited and can thus be met by synthetic gas or biogas. The study on the role and potential of Power-to-X in 2050 evaluated the economic conditions under which power-to-gas and power-to-liquid (power-to-X technologies) could compete with alternative low-carbon production processes by the year 2050. The economics of power-to-X depend on low electricity prices. Electrolysis (green hydrogen) is found to be competitive in countries that have low electricity prices (below €10/MWh) for more than 2 000 hours per year, compared to hydrogen production by steam methane reforming with carbon capture and storage, in particular if the electrolysers are associated with large-scale hydrogen storage. In contrast, power-to-methane and power-to-liquid technologies are more capital-intensive and therefore competitive only in countries with more than 3 000 hours of low electricity prices (subject to the evolution of the technology capital expenditure, cost and availability of alternative solutions, and demand levels for bio-methane and advanced liquid biofuels).

On behalf of the Commission, the ASSET project carried out a modelling study of three scenarios, in which hydrogen is used as energy carrier, as feedstock for the production of gaseous and liquid fuels, and for electricity storage. It found that a 'balanced scenario' that combines the three options is most cost-effective. The **SET-NAV** project, meanwhile, modelled scenarios that would reduce EU carbon emissions in 2050 by 95 %. The study on the role of natural gas in an electrifying Europe predicts a large reduction in EU gas consumption and less seasonal variation, as gas use shifts from heating to industry and transport. As no new gas infrastructure would be needed under this scenario, the study recommends redirecting EU support (projects of common interest) towards electricity infrastructure and energy efficiency measures.

ADEME, the French environment and energy agency, examined various scenarios for the French energy mix between 2020 and 2060. It found that the scenario with a high use of renewable gas results in the largest reduction in CO_2 emissions and is among the scenarios with low electricity prices and low total costs. A supplementary analysis notes that the flexible use and intelligent charging of electric vehicles can make a key contribution to dealing with intra-day variations in the production of solar electricity.

A 2019 study by the European Climate Foundation and Cambridge Econometrics analysed six scenarios in which all sectors of the EU economy are carbon-neutral by 2050, and compared them to a baseline scenario. All six scenarios have some features in common: high thermal efficiency of buildings, clean electricity and smart electrification and long-term storage. The scenarios fall into two classes: 'high electron' scenarios, where electrification plays a greater role, especially in the transport sector, and green hydrogen is only used where is adds the highest value (seasonal storage for peak electricity supply in wintertime), and 'high molecule' scenarios where green hydrogen is used more extensively. The economic analysis finds that the total cost is higher in the 'high molecule scenarios' and that the infrastructure cost is much higher because of the need to build new hydrogen storage and transport infrastructure. It therefore recommends the selective use of green hydrogen, which should not compete with smart electrification and building efficiency.

In a study commissioned by the gas industry, **Navigant** examined two scenarios that arrive at a net-zero emissions EU energy system by 2050. The 'minimal gas' scenario builds on extensive electrification while the 'optimised gas' scenario sees a wider role for renewable methane and hydrogen. The former scenario would result in higher costs (€217 billion more per year) and require nine times as much solid biomass energy than the latter scenario. Blue hydrogen is seen as a cost-effective technology for the time until the cost of green hydrogen production comes down.

Eurelectric examined three scenarios for decarbonising the EU economy, with GHG emission reductions of between 80 and 95 %. All three scenarios foresee strong growth in electricity consumption, with the strongest growth in the transport sector. Hydrogen and renewable gases are expected to play a role in inter-seasonal storage and in applications that are hard to electrify, such as aviation, marine transport and certain industrial processes.

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