Carbon capture and storage for clean flexibility

May 2022

AUTHORS	
Hannah Chalmers	Scottish Carbon Capture & Storage
Robert de Kler	TNO
Arthur Heberle	Mitsubishi Power Europe GmbH
Charles-Albert Bareth	Zero Emissions Platform

Cover picture

Amager Bakke is a Waste-to-Energy plant located in Copenhagen, Denmark. This municipal solid waste incineration plant has one of the highest energy recovery efficiencies in Europe. The operator of the plant is looking into the possibility of installing carbon capture by 2025[1].

[1] Waste Management & Research. Environmental assessment of amending the Amager Bakke incineration plant in Copenhagen with carbon capture and storage, Bisinella et al. (2022).

This document has been prepared on behalf of the Advisory Council of the European Zero Emission Technology and Innovation Platform (ETIP ZEP). ZEP exists to advise the European Commission on Carbon Capture Utilisation and Storage Technologies and associated policies. The information and views contained in this document are the collective view of the Advisory Council and not of individual members, or of the European Commission. Neither the Advisory Council, the European Commission, nor any person acting on their behalf, is responsible for the use that might be made of the information contained in this publication.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 826051.

Contents

Executive summary

Among the many challenges that the European Union is facing to reach carbon neutrality by 2050, the decarbonisation of its current energy system is of particular interest. Europe is experiencing a sustained increase in gas prices as it seeks to end its reliance on Russian imports following the invasion of Ukraine. Renewables are the main tool presented by the European Commission to reduce the reliance on Russian energy imports and cut greenhouse gases, but this increasing share of renewables will require additional resources to balance European power grids. Carbon capture and storage (CCS) has an important role to play in energy system integration – enabling the increase of renewable electricity and in balancing the European energy system.

This report investigates the need for clean flexibility in Europe's future energy system and analyses the role of CCS to that end. The report finds that:

- The share of renewables in the EU energy mix will increase strongly.
- There is a strong need for flexible power supply to enable the increased share of renewables and to balance the electricity grids (cross-border connections can be bottlenecks, which need to be taken into account).
- Flexible power supply will reduce the overarching energy system costs.
- CCS coupled with existing gas-fired power plants can ensure clean flexibility to the European electricity grids. CCS should be a requirement for the licence to operate power plants using fossil fuels.
- Continuous decarbonisation requires different complementary solutions depending on regional and temporal conditions with specific requirements of generation and consumption.
- There will be a strong increasing need for clean, flexible power generation. To future-proof the energy system, flexible multi-fuel power plants that can be fuelled by low-carbon hydrogen or low-carbon ammonia will be important.
- Without sufficient flexible generation capacity, the integration of new renewable energy sources will become very difficult.
- A smart deployment of all options of clean power generation is required to secure a robust and cost-effective energy system in the EU.

1. Introduction

Climate change is one of the biggest challenges of our times – temperatures are rising, drought and wildfires are starting to occur more frequently, rainfall patterns are shifting, glaciers and snow are melting, and the global mean sea level is rising. The European Union signed the Paris Agreement, an international treaty whereby the EU commits to pursue *"efforts to limit the temperature increase to 1.5°C above pre-industrial levels"*. The EU consequently adopted the European Climate Law in 2021, a regulation stating that *"solutions that are based on carbon capture and storage (CCS) and carbon capture and use (CCU) technologies can play a role in decarbonisation, especially for the mitigation of process emissions in industry"*[2]. Twenty EU Member States have already included carbon capture and storage in their National Energy and Climate Plans for the 2021 – 2030 period[3].

In 2019, the European Commission presented the European Green Deal, a set of policies aimed to reach climate neutrality by 2050. In 2021, the European Commission adopted the 'Fit for 55' policy package to make the EU climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030. This package includes a revision of the Renewable Energy Directive (RED) to boost the EU's 2030 renewable targets to 40% of the final energy consumption[4]. The European Commission presented the Taxonomy Complementary Delegated Act on 2 February 2022. Under this delegated act, nuclear and natural gas activities would be eligible for preferential funding under the categories 'Electricity generation from fossil gaseous fuel' and 'High-efficiency co-generation of heat/cool and power from fossil gaseous fuels'. The delegated act describes carbon capture and storage as a mean to reduce greenhouse gas emissions from both energy production activities[5].

Following the Russian invasion of Ukraine in 2022, the EU has adopted a package of sanctions against Russia. The fifth package of restrictive measures includes a ban on coal imports from Russia[6]. Phasing out coal represents the possibility to cut greenhouse gas emissions in the EU while reducing the energy dependency on Russia. The Glasgow Climate Pact, signed by the EU in 2021, mentions *"efforts towards the phasedown of unabated coal power"* and the International Energy Agency estimates that up to 1.2 gigatonnes of CO_2 could be abated in the short term by switching from coal to existing gas-fired plants if prices and regulation are supportive. The Agency adds that the *"vast majority of this potential lies*

[2] Eur-Lex. European Climate Law. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality.
[3] CO2Geonet. "State-of-play on CO2 geological storage in 32 European countries — an update" (2021).
[4] Website of the European Council. Policies. European Green Deal. Fit for 55.
[5] Website of the European Commission. Publications. EU taxonomy: Complementary Climate Delegated Act to accelerate decarbonisation.
[6] Website of the European Commission. Press corner. Ukraine: EU agrees fifth package of sanctions against Russia.

in the United States and in Europe"[7]. In 2019, 93 million tonnes of hard coal were delivered to power plants in the EU to produce electricity and heat. For brown coal, this amount was 285 million tonnes[8]. Both productions are on a declining trend, but the EU is still to phase out coal completely.

The invasion has also led several MEPs to express their support to increase the share of renewables to 45% by 2030. The Commission published the 'REPowerEU Communication: Joint European action for more affordable, secure and sustainable energy' on 8 March 2022 to end imports of fossil fuels from Russia by 2030[9]. The paper puts forward possible actions such as increasing renewables and electrification, including the rollout of rooftop solar photovoltaic systems by up to 15 TWh in 2022 and reaching 10 million heat pumps installed in the next five years, as well as increased renewable hydrogen production, with additional import of 10 million tonnes and production of 5 million tonnes by 2030.

This report shows that an increased share of renewables in the EU's energy mix will require additional flexible power generation to balance power systems. It is particularly important to note that EU policies must be technology neutral as all clean technologies are needed to reach climate neutrality, including carbon dioxide removal (CDR) and CCS. The ongoing debate on energy autonomy is much needed. However, it should not be counterproductive and come at the expense of the EU's long-term climate objectives.

1.1 The challenge

The European Commission published an 'EU Strategy for Energy System Integration' in 2020. This Communication describes how a climate-neutral energy system should be developed and states that *"even a fully integrated energy system cannot completely eliminate CO_2 emissions from all parts of the economy"* adding that *"together with alternative process technologies, carbon capture and storage (CCS) is likely to play a role in a climate-neutral energy system"*[10]. CCS will play a key role in future system integration to enable industrial decarbonisation, carbon dioxide removals, production of low-carbon hydrogen, and enabling and balancing the fast-increasing share of renewable electricity. Therefore, low carbon concepts need to be developed and tested at scale in this decade.

Low-carbon electrification will become increasingly important for energy systems. A Joint Research Centre report states that "*enhanced electrification of final energy demand is a crucial element of the 2°C temperature change scenario, paving the way to climate neutrality"*[11]. Any pathway to climate neutrality by 2050 in Europe will require a deep electrification of our economy, with renewable energy sources as the primary source of power generation. However, the strongly increasing amounts of variable renewable energy sources represent a challenge from many perspectives – for transmission and distribution grid capacity, robustness, security of supply, stability, system balancing, and dispatching. At the same time current sources to balance and stabilise the system are becoming more and more limited.

---

[7] International Energy Agency. 'The Role of Gas in Today's Energy Transitions' (2019).
[8] Eurostat. Coal production and consumption statistics.
[9] Website of the European Commission. Press corner. Joint European action for more affordable, secure energy.
[10] Website of the European Commission. Energy. Topics. Energy system integration. EU strategy on energy system integration.
[11] Website of the Publications Office of the EU. Global energy and climate outlook 2019.

The general assumption seems to be that power generation with CCS is only aimed for base load. ZEP has presented reports on cross-border CO_2 transport, carbon dioxide removal, and the production of hydrogen. There is still a need, however, to describe how CCS enables clean and flexible power generation. The CCUS SET-Plan has updated its targets for 2030 and identified CCS for clean flexible power generation as crucial and also given input on CCS in the energy system integration to the SET-Plan steering group. The increase of renewable energy sources requires an integrated energy system. However, there is a lack of understanding regarding the importance of power system operation and load control.

1.2 This report

This report describes the importance of clean flexible power to enable the vast increase of intermittent Renewable Energy Source (RES) in the European energy system, and to balance the electricity system. The objective of the report is to describe the challenge to the energy system of the increasing use of variable/intermittent renewable energy sources and the key role CCS will play for clean flexible energy production. The report highlights:

- The impact of integration of the vast quantities of variable renewable electricity.
- The need for clean flexible energy production to enable this integration and balance the electricity system, and the role of low-carbon hydrogen for flexible energy production.
- A case study describing the need for control power.
- The possibilities within the current regulatory frameworks and what possible additions would be needed.

2. Moving towards an integrated energy system

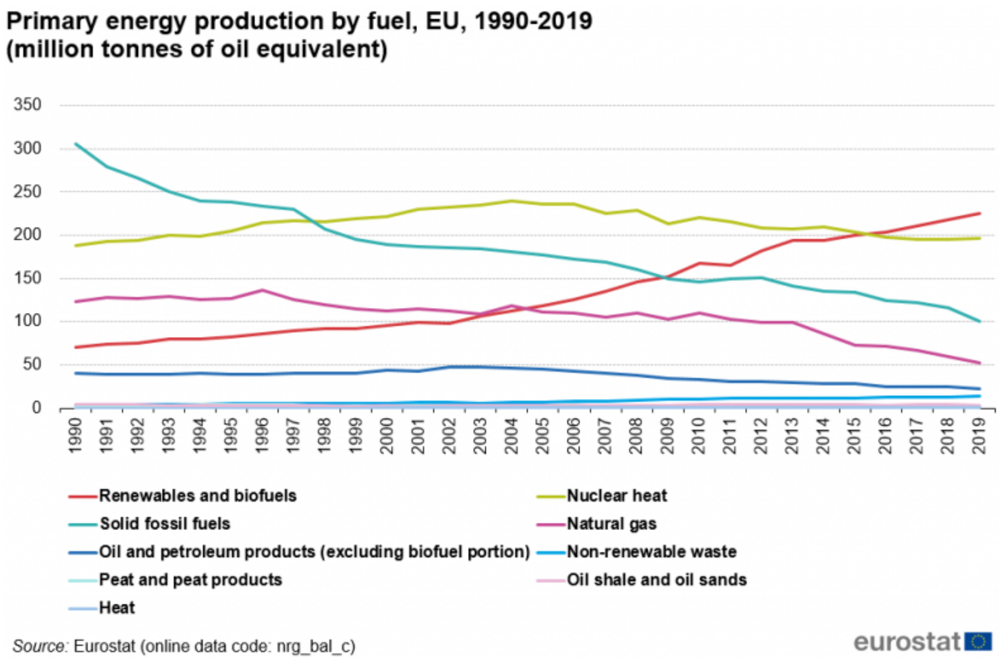
The European Commission put forward an EU strategy for energy systems integration in 2020 to accelerate the transition towards a more integrated energy system. That same year, the Commission put forward a Hydrogen Strategy to clean hydrogen production in Europe[12].

These two strategies need to be complemented by a CCUS Strategy that would propose targets, enabling policies, business models, and needed research and innovation. This Strategy would also allocate resources and address barriers to deployment to put in place a predictable and long-term framework for investors. Both the CCUS and the Hydrogen strategies would need to be planned and executed at the same time.

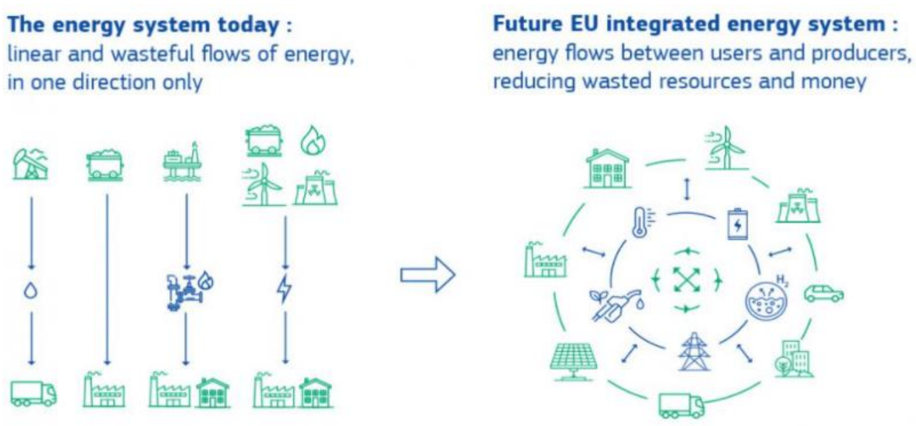
Referring to the Fit-for-55 package and the revision of the Renewable Energy Directive that aims to increase the share of renewable energies to 40% of the total energy consumption in 2030, this challenge can only be solved by a whole-of-society approach including integration of different energy consumers and energy producers from different sectors. Additional measures like demand side management and power dispatch, short- and long-term energy storage, the rapid expansion of the electric grids and European cross-border electricity transmission or the direct use of electricity (electrification) from renewable energy sources (RES) will generate a high-efficient total energy system, which provides energy supply security at minimum cost.

In the EU the total primary energy consumption amounted to 17,417 TWh in 2019. It is estimated to decrease to 13,118 TWh until 2030. In 2018 the primary energy production from renewables and biofuels was 2,538 TWh and the production from nuclear heat approximatively 2,326 TWh. The share of low- and zero-carbon primary energy production in the total primary energy consumption amounts to 13.5% approximatively[13].

[12] Website of the European Commission. Energy. Topics. Energy system integration. Hydrogen.
[13] Website of the European Environment Agency. Primary and final energy consumption in Europe.



The given timeframes for transformation until 2030, 2040 or even 2050 are very tight from today[14]. This makes it all the more important to accelerate the integration of the energy system and to provide the best, cost-efficient solutions available in a technology-open way. This approach requires to link various energy carriers with each other and to create special energy networks[15].



[16]

The shaped integrated energy system will create a great opportunity to decarbonise our societies, while decreasing dependency on energy imports from countries that represent a serious geopolitical risk and/or a threat to democratic regions.

---

[14] Enerdata. Global energy trends - 2021 edition.
[15] Website of the European Commission. Energy. Topics. Energy system integration. EU strategy on energy system integration.
[16] Idem.

3. The increasing role of variable renewable energy sources

The proposed 'Fit for 55' policy package includes a revision of the Renewable Energy Directive (RED) that would increase the EU's 2030 renewable targets to 40% of total energy consumption. Following Russia's invasion of Ukraine, a growing number of MEPs are willing to increase that share to 45%[17]. This growing share of renewables in the energy mix will increase the uncertainty of power supply and require additional flexible power generation to balance European power systems.

The expansion of renewable energy sources (RES) and the vast application of the electrical and thermal energy generated by these sources play an essential role in the decarbonisation of industry and society. The role of electricity is expected to increase in the future as it seems to become a kind of new "oil"[18].

The increasing share of electricity from RES will require energy storage, especially long-term energy storage to counter temporary supply gaps in view of the high volatility of electrical energy from wind and photovoltaics and short-term energy storage to ensure the necessary electrical grid quality[19]. Electrification could be an adequate answer. However, it already appears that rapid and comprehensive direct electrification of all applications in all sectors will hardly be possible. The necessary expansion of power grids would take several years, perhaps even decades. In 2019, for example, the north-south connections in Germany were assumed to take at least 15 years to be built and would also require social acceptance[20]. Electrification by RES can only be implemented at the same pace as the expansion of renewable energy.

3.1 The example of Germany

Germany must increase the share of renewable energy sources significantly until 2045 to abide by the requirements of the German Climate Protection Act adopted in 2021[21]. Several German studies (published by dena, BCG, Agora Energiewende and Prognos et al. in 2021) produced an estimation of the demand for renewable energy sources in 2045. The required increase up until 2045 is extremely large when compared to the installed wind and photovoltaic power, which was approximately 110 GW in 2021. A study by the German Energy Agency dena forecasts an increase to more than 433 GW,

[17] EurActiv. Widespread support in EU Parliament for 45% renewable energy target'.
[18] World Energy Council. News & Views. Electricity is the new oil.
[19] International Energy Agency. Articles. How rapidly will the global electricity storage market grow by 2026?
[20] Zukünftige Kraftstoffe ('*Future fuels*'). Indirekte Elektrifizierung mittels eFuels ('*Indirect electrification via e-fuels*'), Bothe (2019).
[21] Website of the German federal government. Klimaschutzgesetz 2021 (*Climate Protection Act 2021)*.

while a study by BCG forecasts an expansion to more than 480 GW until 2045[22,23,24]. Looking at all types of renewable energy sources, Prognos et al. indicates an expansion from approximately 117 GW in 2018 to 268 GW in 2030 and to 608 GW in 2045[25]. Supply from renewable energy sources would have to be multiplied by up to six times by 2045. A more detailed analysis of this challenge is provided in section 7.

3.2 The example of France

According to the IEA, "*France has a very low-carbon electricity mix owing to its large nuclear fleet, the second-largest after the United States"*[26]. Nuclear represented approximately 354 TWh of France's electricity generation by source in 2020, while hydro represented 67 TWh, wind 47 GWh, and natural gas 35 TWh[27].

In 2022 French President Emmanuel Macron announced his intention to build at least six new nuclear reactors, and possibly another eight[28]. This focus on nuclear energy *"is designed to eventually replace fossil fuels, like natural gas, with nuclear and renewables to achieve the country's 2050 net zero target"*[29]. Construction would begin in 2028 with the first plant in operation in 2035. The additional production objective is 25 GW by 2050. This strategy also includes the construction of 50 offshore wind farms to generate 40 GW by 2050. France also plans to increase its solar power capacity to generate over 100 GW by 2030. Finally, nuclear plants would be extended beyond 50 years[30].

RTE, one of France electricity transmission system operator, estimates France's flexible power need at the 2050 horizon to be between 28 and 68 GW[31]. Flexible power needs are due to increase in all scenarios. Scenarios that include 100% renewable energy production would require a lot of new low-carbon thermal power stations. Gas power plants keep playing an essential role to balance the electricity grid in France's energy system[32].

3.3 Hydropower in Norway and Sweden

A few European countries can store excess electricity from RES via hydroelectric power. Norway can rely on more than 1,000 hydropower storage reservoirs with a total capacity of more than 87 TWh[33]. In Sweden the maximum storage capacity is 33.6 TWh[34]. Total energy demand in Norway and Sweden

---

[22] Deutsche Energie Agentur. dena-Leitstudie Aufbruch Klimaneutralität (2021).
[23] Bundesverband der Deutschen Industrie. Climate Paths 2.0 – A Program for Climate and Germany's Future Development (with BCG).
[24] Agora Energy. Pathway to climate neutral Germany.
[25] Prognos et al. Klimaneutrales Deutschland 2045 (2021).
[26] International Energy Agency. Countries. France.
[27] Idem.
[28] Natural Gas Intelligence. France Counting on Nuclear Power to Help Replace Natural Gas, Other Fossil Fuels (2022).
[29] Idem.
[30] RTS. Emmanuel Macron veut six nouveaux réacteurs nucléaires et 50 parcs éoliens en mer (2022).
[31] RTE. Futurs énergétiques 2050 (2021).
[32] Les Echos. Pourquoi les centrales à gaz sont stratégiques pour la France (2020).
[33] Energy Facts Norway. Norway's energy supply system. Electricity production.
[34] Energiföretagen Sverige. Statistik (*Statistics*). Kraftläget - aktuell elförsörjning (*Power situation - current electricity supply*).

amounted respectively to 213 TWh and 360 TWh in 2020[35]. This use of hydropower is made possible by both countries' specific geography. In the case of Norway, this includes *"high mountain plateaus, abundant natural lakes and steep valleys and fjords"*[36]. Continuous decarbonisation therefore requires different complementary solutions depending on regional and temporal conditions with specific requirements of generation and consumption.

Every kilowatt of installed electrical power, which generates kWh of electrical energy from RES, helps reduce the dependency on fossil energy carriers. However, the European energy system is far from being fully low-carbon or fully renewable due to the absence of a totally integrated system. The higher the share of electricity from RES, which mainly comes from wind turbines and photovoltaics, the higher the need for large-scale back-up power generation to stabilise the electrical grid and ensure reliable power supply[37]. This back-up power can be provided by gas power plants, which have short ramp-up times and sufficient inertia rotating masses to provide control power[38]. In any case, CCS should be a requirement for the licence to operate power plants using fossil fuels. Additionally, gas turbines can be retrofitted for fuel switches *e.g.,* using blends of natural gas and hydrogen with up to 100% hydrogen[39].

The European Commission foresees an increasingly important role of renewable and low-carbon fuels in the long term as a substitute to oil and gas[40]. The Complementary Climate Delegated Act also mentions carbon capture and 'renewable or low-carbon gases' as a mean of abatement to produce heat/cool or power[41]. There is, however, a crucial need to define the term 'renewable and low-carbon gasses' precisely. These definitions are vital to enable a secure switch to renewable and/or low-carbon gaseous fuels by 31 December 2035. In all cases, a reliable energy supply is required to guarantee industrial activity, employment and the prosperity of the European society.

35 Eurostat. Final energy consumption (Europe 2020-2030).
36 International Hydropower Association. Country profile. Norway.
37 Electronics. Backup Capacity Planning Considering Short-Term Variability of Renewable Energy Resources in a Power System. (2021).
38 Idem.
39 International Journal of Hydrogen Energy. Exploring the competitiveness of hydrogen-fueled gas turbines in future energy systems (2022).
40 European Commission. Commission Staff Working Document accompanying 'Stepping up Europe's 2030 climate ambition'.
41 Website of the European Commission. Publications. EU taxonomy: Complementary Climate Delegated Act to accelerate decarbonisation.

4. The role of CCS for clean flexible power generation

The need for clean, flexible power generation is imminent as the share of renewable energy is growing. Balancing power is also necessary to secure electricity supply and to reduce the overarching energy system cost[42,43]. A possible route is based on new emerging (clean) fuels, existing power plants, and new to-be-built power plants created to use those fuels. The import of clean and sustainably sourced energy will play an important role in a future robust energy system. In a 2020 report, the IEA mentioned that *"gas security is increasingly linked to electricity security, as the reliance on flexible natural gas-fired power generation is set to increase across the EU with the coal-phase-out and some countries' decision to end the use of nuclear energy"*. The report adds that *"natural gas can boost coal to gas switching and support the transition to cleaner fuels, including for hydrogen"*[44].

In the short term, potential clean energy sources could be, for instance, biomethane, blue ammonia and blue hydrogen. CCS is a necessary element to produce low-carbon ammonia[45] and low-carbon hydrogen. CCS should also be a requirement for the licence to operate power plants using fossil fuels. Plants that use blue ammonia and blue hydrogen could also switch to fuels that are produced via renewable energy sources in the future, e.g., wind or photovoltaics. As such, a flexible multi-fuel power plant that is capable of being fuelled on hydrogen or ammonia is future-proof. On top of that, a future power plant must be efficient, flexible, and ideally require low capital expenditure and low operational expenditure. In most cases, the dispatch call of a flexible asset will depend on the non-availability of renewable energy sources. There is, therefore, a need to develop appropriate business models and policy support. This will ensure that any plant with low operational hours that is needed to ensure reliable electricity supply can recover its costs.

The import of clean fuels via energy carriers also reduces the need for costly hydrogen storage. A recent study of the Port of Rotterdam, where the port would function as an energy hub, illustrates the crucial importance of importing hydrogen[46].

---

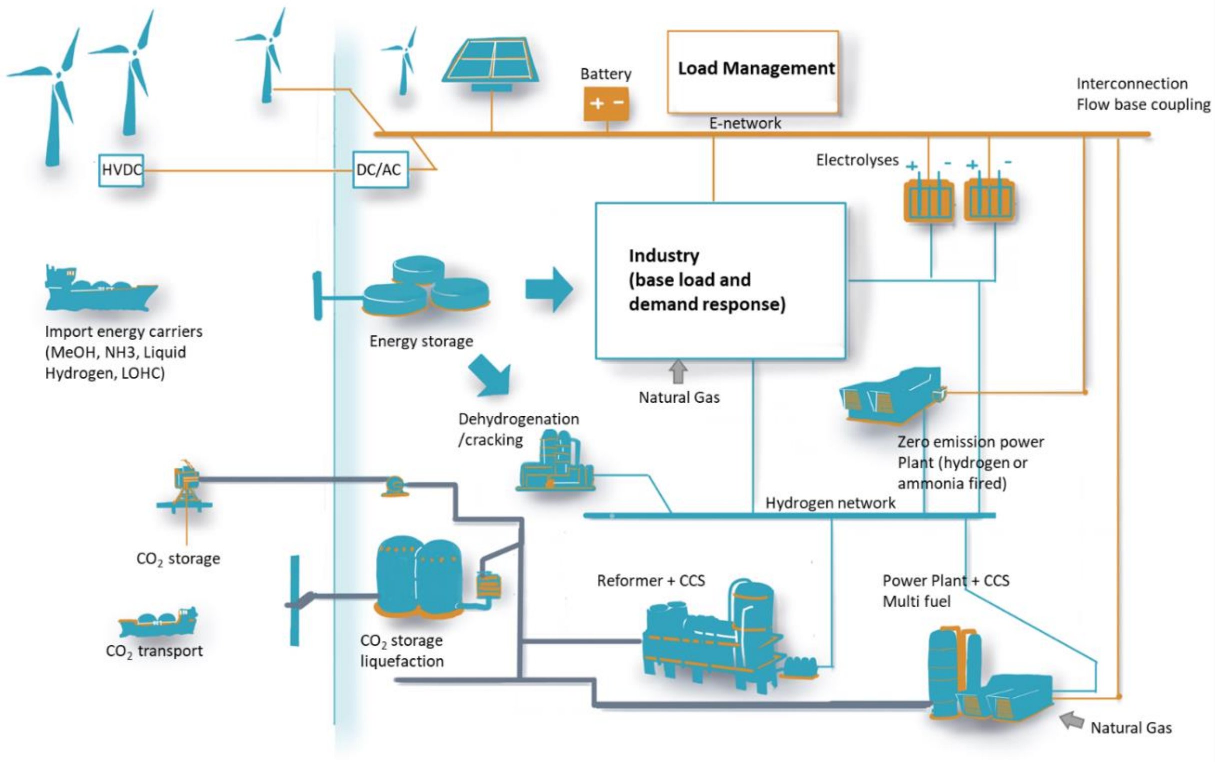
[42] Elia Group. Electricity market and system. System services.

[43] Government of the United Kingdom. Department for Business, Energy and Industrial Strategy. Transitioning to a net zero energy system (2021).

[44] International Energy Agency. Country report. European Union 2020.

[45] Toyo Engineering. Low-carbon ammonia for fuel. "*Blue ammonia is produced from fossil fuels and the CO2 emissions generated in the manufacturing process are shown to be suppressed by CCS (Carbon dioxide Capture & Storage), […]*".

[46] Port of Rotterdam. Hydrogen for the Port of Rotterdam in an International Context – a Plea for Leadership (2020).



47

[47] Courtesy of Robert de Kler, TNO.

5. An overview of options and mechanisms for balancing power

The energy transition has a major impact on the current energy system and leads to a changing and growing demand for flexibility. The current electricity system already consists of a substantial demand for flexible power generation to match demand variability. The main flexibility providers of today's electricity system are the fossil-based generation (mainly natural gas), a strongly interconnected grid, and some limited participation of demand response.

The growth of variable wind and solar power generation and the electrification of energy demand is expected to lead to increasing demand for flexibility because of the variability of wind and solar generation increasing load and generation connected to the distribution grid level and leading to an increase in the amount of electricity grid congestion and more pronounced peaks in demand.

The current strategic view of the electrical grid operators is supporting the development of new flexibility sources such as demand response, storage, and renewable flexible generation. According to the grid operators it is key to ensure that flexibility that is currently provided by conventional generation plants is not lost in future electricity systems. For instance, TenneT, the Dutch TSO, has stated that unlocking flexibility is a key element to drive the energy transition. TenneT plans to[48]:

- share its insights in sum quantities and characteristics of flexibility resources with stakeholders, in particular market parties and policymakers.
- account for new flexibility, in particular demand response and storage, in the annual Adequacy Assessment, which has historically focused on generation adequacy.

5.1 Demand response from industry

The focus on demand response is an important element for the energy transition. However, it requires industrial applications that are flexible in electricity consumption or can switch between different (renewable) energy vectors. The current energy intensive industry is mainly running baseload at a high production. This helps to ensure safety, availability, and reliability levels. As such, the expectation and wish for demand response from the industry is, on the short term, a technical and economical stretch for most industrial players.

[48] Website of TenneT. TenneT Flexibility Monitor (2019).

5.2 Demand response using electrolysers

Balancing can be achieved by using electrochemical hydrogen production and power generation using hydrogen combustion in fuel cells. Alkaline electrolysers represent an advanced and commercially available technology that has been available for decades[49]. State-of-the-art proton exchange membrane (PEM) fuel cells exhibit high efficiencies, part load situation, and fast load-following response. These characteristics are favourable for balancing purposes. However, like for batteries, the limited scale of the technology is a major disadvantage[50].

5.3 Storage batteries

Lithium-ion and sodium-sulphur batteries are state of the when it comes to large-scale batteries[51]. Both have high power and energy densities, high part-load efficiencies, and fast load-following features. Disadvantages of balancing the system through the use of large-scale batteries are high production costs, safety risks, and the fact that there is barely any support for seasonal storage of energy. Currently, power grid smoothing is the only application for batteries, which does not fulfil the requirements for a large-scale balancing system that must also be suitable for large seasonal variations in generating renewable electricity.

To balance power, flow batteries are limited. Even though flow batteries feature high energy densities, they lack efficiency. The main application of flow batteries, especially the vanadium redox flow batteries, is smaller-scale energy storage systems. Like lithium-ion and sodium-sulphur batteries, flow batteries are not suited for seasonal balancing of renewably generated electricity.

5.4 Strong increasing need for control power

In the Netherlands the current need for ramp-up and ramp-down capacity is approximately 1.5 GW per 15 min. With the planned increase of wind capacity in the North Sea, the Netherlands might require a ramp-up and ramp-down capacity of at least 4 GW per 15 min[52]. The deployment of sufficient control power is currently not guaranteed and there is limited understanding on how to meet future requirements.

In conclusion, there is a strong increasing need for clean, flexible power generation. Relying only on flexible back-up power from other countries as cross-border back-up power should be considered as very risky. This applies equally for all countries. Without sufficient new flexible generation capacity and as the share of fossil-based generation capacity shrinks, the energy system in the EU will be challenged and adequate functioning is not guaranteed, which will delay the deployment of renewable energy. Therefore, a smart deployment of all options of clean power generation is required to secure a robust and cost-effective energy system in the EU.

---

[49] Bioenergy resources and technologies. Technologies for renewable hydrogen production, Syed (2021).
[50] PEM Water Electrolysis, Bessarabov and Millet (2018).
[51] Journal of Power Sources. Lithium-ion batteries - Current state of the art and anticipated developments (2020).
[52] TNO. The demand for flexibility of the power system in the Netherlands, 2015-2050 (2017). The FLEXNET project was carried out by a consortium consisting of the Energy research Centre of the Netherlands (ECN) and several members of Netbeheer Nederland, including TenneT.

6. What would be needed from a regulatory point of view?

Clean flexibility for power generation will be required to allow for a smooth increase in renewables in the EU energy mix. Carbon capture combined with gas-fired power plants will provide the required flexibility and safety to electricity grids across Europe. Several EU policies mention CCS and/or CCU and CO_2 infrastructure, such as the EU Taxonomy for Sustainable Activities, the TEN-E Regulation, and the EU ETS, but there is no overarching policy framework for CO_2 transport infrastructure development. The Commission should consider introducing such a regulatory framework, focused on the development of non-discriminatory, open-access CO_2 transport infrastructure to complement the Directive on the geological storage of carbon dioxide[53]. An efficient and transparent policy framework will be needed to establish a clear legal and regulatory basis for planned projects, in particular for cross-border cooperation.

An EU CCS and CCU strategy, where the focal point is the creation of a predictable and long-term framework for investors, would also be useful[54]. The strategy will be an important tool for the Commission to safeguard European industrial activity, enabling industry to contribute to the decarbonisation towards climate neutrality. Collaboration between EU member states, the Commission, and industry will be required to address any challenges or barriers that may arise. The main focus of the strategy should be the successful development and large-scale deployment of cross-border, European CO_2 transport and storage infrastructure.

It is particularly important to note that short-term solutions can hinder investments into long-term solutions. The upcoming REPowerEU plan, aimed at achieving enhanced political and energy autonomy, intends to address the overreliance on Russian energy exports. There is a real risk, however, that this plan may have counterproductive consequences in terms of climate objectives.

[53] Zero Emissions Platform. ZEP proposal for a regulatory framework for CO2 transport infrastructure (2022).
[54] Zero Emissions Platform. EU Strategy for CCS and CCU (2021).

7. Case study: Germany and the need for control power

The German federal government put forward an amendment to the Climate Change Act in May 2021 that entered into force in August 2021. This amendment reinforces significantly climate ambitions and anchors the goal of climate neutrality by 2045[55]. According to the Act, GHG emissions must be reduced by 65% by 2030 compared to 1990 levels. These goals represent tough challenges for Germany. Following the adoption of this Act, different German think tanks such as the Agora Energiewende, Deutsche Energie-Agentur (dena) and the Federal Association of German Industry (Bundesverband der Deutschen Industrie) highlight the challenges and solution pathways in their commissioned studies[56,57,58]. These studies show that the 2045 climate goals are reachable, and describe what developments are expected in different sectors until 2045, and what actions should be taken.

The electric power industry is a particular point of focus in these reports. GHG emissions in the power sector must be reduced, while the electrification of other sectors is considered to achieve decarbonisation plans. Energy efficiency and electrification are described as one of the mega-trends in the 2045 horizon. The studies conclude that, in terms of electricity, the primary energy demand will decrease from more than 3,600 TWh in 2018 to less than 1,800 TWh in 2045[59]. The gross electricity demand will increase from 595 TWh in 2018 to a 910-to-1,092 TWh range until 2045[60]. This implies that electricity demand will double. On the other hand, energy supply will require at least the same amount of secured power in 2045 as it does today.

It is necessary to keep in mind the expansion of the power generation from renewable energy sources, the expansion of energy storage capacities and the flexibility of electricity consumers in all sectors. These trends imply that high flexible thermal power generation will be needed at significant capacity levels to provide control power and compensate dark lulls. The dena report shows *“a need for the construction of additional gas-fired power plants with a capacity of 15 GW by 2030 alone”* to control power and indicates that *“large quantities of gas-fired power plants need to be installed in the short term, which should be directly hydrogen-capable or convertible with manageable effort as early as 2025 but would initially still be operated with natural gas”*[61].

The studies describe the use of gas-fired power plants as the most cost-efficient flexible power generation solutions, which will be switched from natural gas to green gases, mainly hydrogen in a

55 Website of the German Federal Government. Klimaschutzgesetz 2021.
56 Agora Energy. Pathway to climate neutral Germany.
57 Bundesverband der Deutschen Industrie. Climate Paths 2.0 – A Program for Climate and Germany's Future Development (with BCG).
58 Prognos et al. Klimaneutrales Deutschland 2045 (2021).
59 Deutsche Energie Agentur. dena-Leitstudie Aufbruch Klimaneutralität (2021).
60 Idem.
61 Idem.

mid- and long-term perspective. Demand for installed power plant capacity is estimated to reach 47 GW in 2030 and 59 GW in 2045 to reach the Climate Change Act objective[62]. Compared to an installed capacity of 32 GW in 2019, the 2045 forecast almost leads to a duplication of demand for installed capacity. It is important to remember that CCS should be a requirement for the licence to operate power plants using fossil fuels.

Since all studies foresee a high need for gas-fired power plants, it appears that batteries or demand side management are not a "one-size-fits-all" solutions capable of completely replacing flexible thermal power generation at an affordable cost. However, the combination of all these solutions will contribute to the security of energy supply and to the decarbonisation of the German economy.

[62] Deutsche Energie Agentur. dena-Leitstudie Aufbruch Klimaneutralität (2021).

Conclusions

The main climate policy objective of the European Union is to reach climate neutrality by 2050 to avoid irreversible consequences on the livelihood of European citizens. This objective requires assessing the energy system integration with a specific focus on CCS. Current policy orientations will lead to a rapidly growing amount of variable renewable energy in the European energy system. The measures of the upcoming REPowerEU programme will most probably increase the amount of renewable energy sources even further.

CCS will be necessary for energy system integration and enabling renewable energy sources, as balancing power is needed to protect the integrity of the European power grid. Moreover, energy systems look different in different countries. While some countries like Norway and Sweden can rely on a high share of hydropower in their energy mix, balancing power is set to decrease in continental Europe. Demand-side management and energy storage in batteries will play a role but will not be sufficient. CCS aimed at ensuring clean flexibility is therefore needed and should be included in policies that aim to shape Europe's future energy system and be a requirement for the license to operate any power plant relying on fossil fuels. A technology-open approach to solutions which are sustainable, available, and cost-efficient is required.

References

- **Bioenergy resources and technologies**. Technologies for renewable hydrogen production, Syed (2021).
- **BDI Bundesverband der Deutschen Industrie e.V.**. Pathway to climate neutral Germany. Climate Paths 2.0 – A Program for Climate and Germany's Future Development (Expert Report of BCG).
- **CO2Geonet**. "State-of-play on CO2 geological storage in 32 European countries — an update" (2021).
- **Deutsche Energie Agentur**. dena-Leitstudie Aufbruch Klimaneutralität, Abschlussbericht, published by Deutsche Energie-Agentur GmbH (dena) in October 2021
- **Electronics**. Backup Capacity Planning Considering Short-Term Variability of Renewable Energy Resources in a Power System. (2021).
- **Elia Group**. Electricity market and system. System services.
- **Enerdata**. Global energy trends - 2021 edition.
- **Energiföretagen Sverige**. Statistik (Statistics). Kraftläget - aktuell elförsörjning (Power situation - current electricity supply).
- **Energy Facts Norway**. Norway's energy supply system. Electricity production.
- **EurActiv**. Widespread support in EU Parliament for 45% renewable energy target.
- **Eur-Lex**. European Climate Law. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality.
- **European Commission**. Commission Staff Working Document accompanying 'Stepping up Europe's 2030 climate ambition'.
- **European Commission**. Energy. Topics. Energy system integration. EU strategy on energy system integration.
- **European Commission**. Energy. Topics. Energy system integration. Hydrogen.
- **European Commission**. Press corner. Joint European action for more affordable, secure energy.
- **European Commission**. Press corner. Ukraine: EU agrees fifth package of sanctions against Russia
- **European Commission**. Publications. EU taxonomy: Complementary Climate Delegated Act to accelerate decarbonisation.
- **European Council**. Policies. European Green Deal. Fit for 55.
- **European Environmental Agency**. Primary and final energy consumption in Europe (2021).
- **Eurostat**. Coal production and consumption statistics.
- **Eurostat**. Final energy consumption (Europe 2020-2030).
- **German federal government**. Klimaschutzgesetz 2021 (Climate Protection Act 2021).
- **International Energy Agency**. 'The Role of Gas in Today's Energy Transitions' (2019).
- **International Energy Agency**. Articles. How rapidly will the global electricity storage market grow by 2026?.
- **International Energy Agency**. Countries. France.
- **International Energy Agency**. Country report. European Union 2020.
- International Hydropower Association. Country profile. Norway.
- **International Journal of Hydrogen Energy**. Exploring the competitiveness of hydrogen-fueled gas turbines in future energy systems (2022).
- **Journal of Power Sources**. Lithium-ion batteries - Current state of the art and anticipated developments (2020).

- **Les Echos**. Pourquoi les centrales à gaz sont stratégiques pour la France (2020).
- **Natural Gas Intelligence**. France Counting on Nuclear Power to Help Replace Natural Gas, Other Fossil Fuels (2022).
- **PEM Water Electrolysis**. Bessarabov and Millet (2018).
- **Port of Rotterdam**. Hydrogen for the Port of Rotterdam in an International Context – a Plea for Leadership (2020).
- **Prognos, Öko-Institut, and Wuppertal-Institut**. Klimaneutrales Deutschland 2045. Wie Deutschland seine Klimaziele schon vor 2050 erreichen kann (2021).
- **Publications Office of the EU**. Global energy and climate outlook 2019.
- **RTE**. Futurs énergétiques 2050 (2021).
- **RTS**. Emmanuel Macron veut six nouveaux réacteurs nucléaires et 50 parcs éoliens en mer (2022).
- **TenneT**. TenneT Flexibility Monitor (2019).
- **TNO**. The demand for flexibility of the power system in the Netherlands, 2015-2050 (2017). (The FLEXNET project was carried out by a consortium consisting of the Energy research Centre of the Netherlands (ECN) and several members of Netbeheer Nederland, including TenneT).
- **Toyo Engineering**. Low-carbon ammonia for fuel.
- **Government of the United Kingdom**. Department for Business, Energy and Industrial Strategy. Transitioning to a net zero energy system (2021).
- **Waste Management & Research**. Environmental assessment of amending the Amager Bakke incineration plant in Copenhagen with carbon capture and storage, Bisinella et al. (2022).
- **World Energy Council**. News & Views. Electricity is the new oil.
- **Zero Emissions Platform**. EU Strategy for CCS and CCU (2021).
- **Zero Emissions Platform**. ZEP proposal for a regulatory framework for CO2 transport infrastructure (2022).
- **Zukünftige Kraftstoffe**. Indirekte Elektrifizierung mittels eFuels, Bothe (2019).

EU Office
Square de Meeûs 37
1000 Brussels
Belgium
Tel: +32 2 791 75 74

zeroemissionsplatform.eu