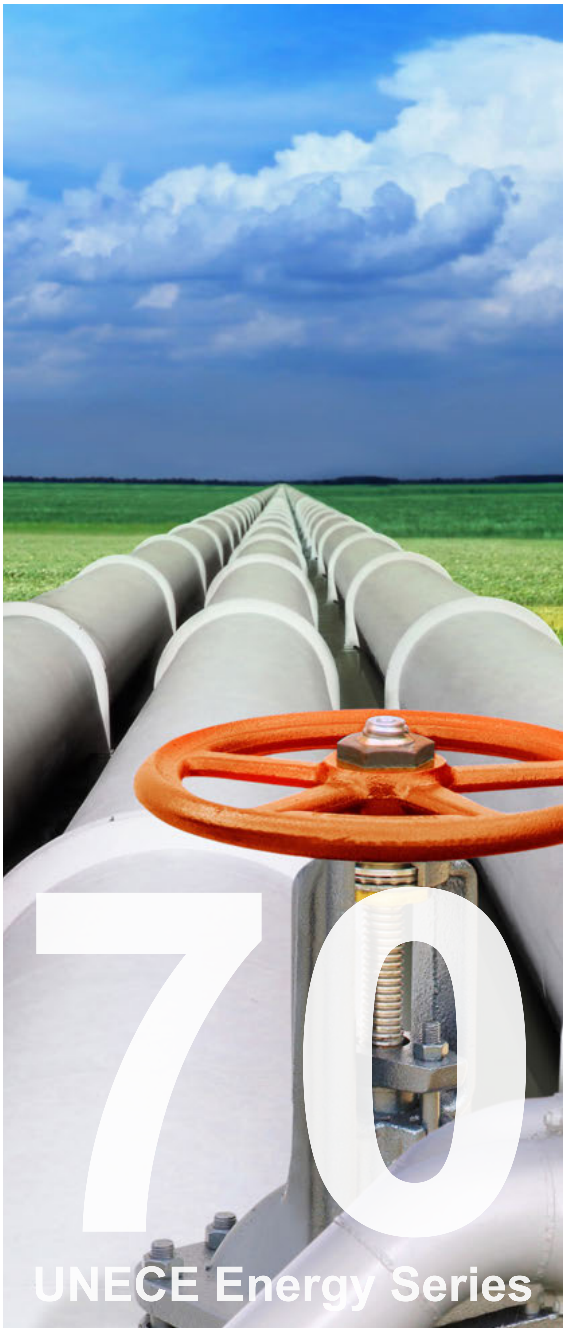
UNECE

Carbon neutrality through synergies between gas and renewable energy



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Carbon neutrality through synergies between gas and renewable energy

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Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

The Paris Agreement and the fight against climate change impose the obligation to decarbonize UNECE economies and to achieve carbon neutrality by 2050. The energy transition will rely on a wide deployment of renewable energy as a key element. The electrical variable renewable energy (VRE[1]) is expected to grow substantially in the following decades, increasing its share in the future energy mix in the UNECE region. However, the higher penetration of VRE into energy systems brings an associated challenge: how to manage, in a cost-efficient manner, the strong fluctuations and intermittency associated to VRE, in order to ensure a reliable and robust energy system at all times.

The Group of Experts on Gas (GEG) and the Group of Experts on Renewable Energy (GERE) have jointly agreed on identifying and assessing the synergies and interplay between the VRE and the gas system. This report shows how gas provides affordably the required flexibility to enable the integration of higher shares of VRE in the energy mix. The report distinguishes two phases:

The first phase, focused on the short term, refers to the use of flexible, cost-competitive, and agile natural gas-fired generation as enabler of VRE integration. The second phase, spanning over the medium and long-term, enlarges the scope of the Renewable Energy concept to cover not only renewable electricity, but also renewable gases. The second phase is based on the hybrid energy system concept which envisages the use of new gases[2] (renewable, decarbonized, and low carbon), together with the sectoral integration concept, and other technologies (e.g., Demand Side Management (DSM), Distributed Energy Resources (DER) and Carbon Capture and Storage (CCS) technologies) as pillars to advance VRE penetration while significantly reducing Green House Gas (GHG) emissions.

The report concludes with several recommendations aimed to guide UNECE Member states in developing a coherent policy and regulatory frameworks for renewable energy across the region in a secure, competitive and resilient manner.

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[1] Variable Renewable Energy (VRE) refers to variable renewable energy sources in the power sector produced with solar and wind.

[2] See Section A “Glossary and Definitions” for a full description of characteristics associated to these gases.

1. Introduction

1. In 2015 the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development with 17 Sustainable Development Goals (SDGs) at its core, to be achieved by 2030. The SDGs address all three dimensions of sustainable development (environmental, economic and social) and aim at shifting the world on to a sustainable and resilient path for the future. One of these goals – SDG 7 – covers sustainable and clean energy.

2. Achieving SDG 7, at least on paper, appears to be a simple matter. In practice, however, reconciling often conflicting environmental, economic, and social priorities is a daunting task in any given country, let alone on regional or global levels where different economic, social, and political circumstances dictate radically different approaches

3. The SDG 7 has set five targets for the UN Member States to achieve. Among them are to:

    a. Increase substantially the share of renewable energy[3] in the global energy mix (target 7.2);

    b. Enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology (target 7.A).

4. This document explores the interplay between the related targets 7.2 and 7.A, arguing that a deep and genuine transformation of today's energy system could be greatly facilitated by harnessing synergies between the traditional and emerging energy sectors – in this case (natural) gas and renewable energy. These synergies could be stated as:

    a. The natural gas and natural gas infrastructure could accelerate the deployment of variable renewable energy (VRE) sources.

    b. In the near future, the new gases[4] (renewable, low carbon and decarbonized gases) should become an important energy carrier together with VRE.

5. The 2015 Paris Agreement aims to limit the increase in the global average temperature to well below 2 °C above pre-industrial levels. To achieve this objective, global greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), will need to be reduced substantially. The current discourse on the transition to a decarbonized energy system future is dominated by renewable energy solutions. However, the initial conditions for this transition may vary across different regions and countries. In the UNECE region, about 80per cent of today's energy mix is fossil fuel based. Even under a scenario that meets the 2 ºC target, fossil fuels will still account for at least 56 per cent of the region's energy mix by 2050. Accelerated decarbonisation and energy transition is therefore crucial.

6. The Climate Action Summit, held on 23 September 2019, reinforced 1.5°C as the socially, economically, politically and scientifically safe limit to global warming by the end of this century, and net zero emissions by 2050 as the global long-term climate objective for all. Countries need to urgently accelerate work to define what this entails for the short-term (2020) and mid-term (2030) commitments that will be captured in their Nationally Determined Contributions (NDC) and ensure the alignment of strategies to meet those commitments.

7. With the above in mind at its 28th session held in September 2019 the Committee requested the Group of Experts on Gas (GEG) and the Group of Experts on Renewable Energy (GERE) to support ECE member States in firstly assessing the synergies between renewable energy and gas. The outcome of this report could be used, in a second stage, to propose and develop policies aimed to:

    a. Harness the above-mentioned synergies between renewable energy and gas,

    b. Accelerate development and deployment of renewable/decarbonized gas projects and seek extra budgetary funding for the creation of a Task Force on this matter.

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[3] For the purpose of this report, Renewable Energy is commonly understood in the short-term as renewable electricity produced out of wind and sun. In the medium and long-term, the concept of Renewable Energy is extended to cover, not only solar and wind electricity, but also non-electric renewable energy, mainly renewable gases, such as hydrogen and biomethane among others. Nevertheless, liquid biofuels are not considered for the purpose of this document.

[4] See Section A "Glossary and Definitions" for a full descriptions of characteristics associated to these gases.

8. The Group of Experts on Gas holds the belief, shared to an extent by the Group of Experts on Renewable Energy, that under certain circumstances and in some ECE member States, gas represents the shortest and least-cost path towards decarbonizing the energy sector and increasing its overall efficiency.

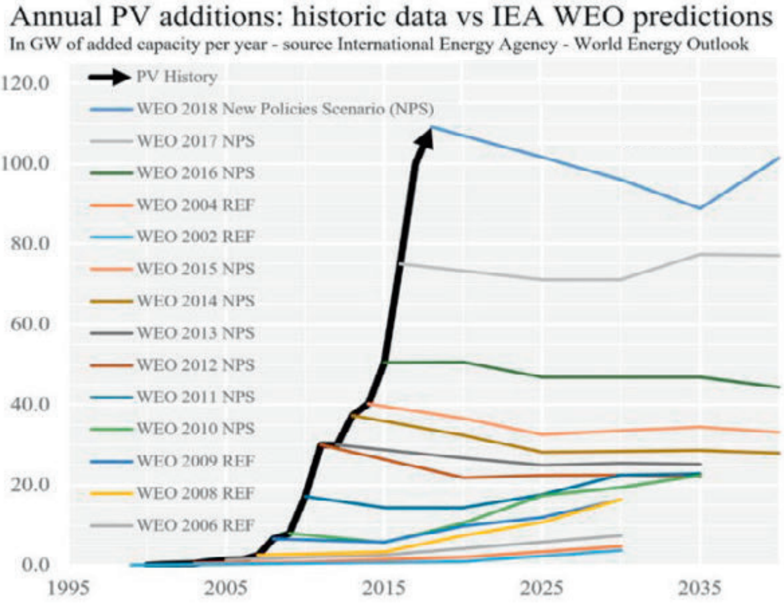
2. Trends, Projections, Scenarios

2.1. Quick Growth of Electric Variable Renewable Energies (VRE)

9. Our society is moving towards a new way of producing and using energy. Together we are creating a more sustainable system that is increasingly reliant on the use of VRE sources like wind and sun.

10. Thanks to sharply falling costs and supportive policies, the deployment of VRE, mainly wind and solar, has expanded dramatically in the last decades. Today, solar photovoltaic (PV) and wind, and some other VRE technologies in the power sector, are turning initial policy and financial support into large-scale deployment. They have grown on a total unexpected and underestimated way as it can be seen in Figure 1.

Figure 1
IEA scenarios versus the reality of solar PV

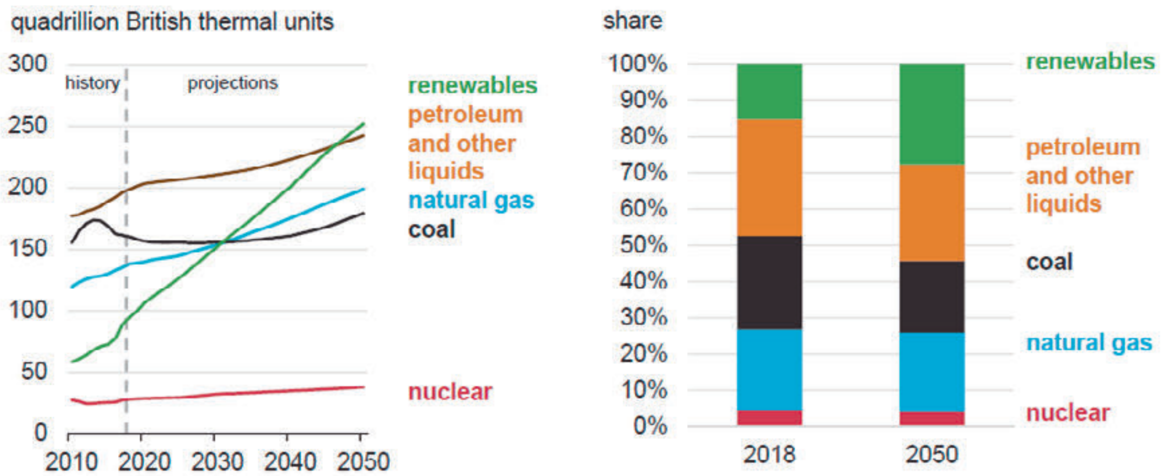


Source: Auke Hoekstra - Eindhoven University of Technology.

11. VRE sources are rapidly transforming the entire worldwide energy system. The reference case presented in the International Energy Outlook 2019 report published by the United States Energy Information Agency (EIA) identifies renewable energy as the fastest growing source of energy at global level, increasing by 3 per cent per year between 2018 and 2050, projected to supply 29 per cent of world primary energy consumption by 2050 and becoming the worldwide leading source by that date.

12. The International Energy Agency (IEA) also identifies renewable electricity (wind and solar) as a winning technology in the race to meet energy demand growth by 2040. Wind and solar PV will provide the majority of the additional electricity generation to 2050 according to both IEA scenarios and IRENA.

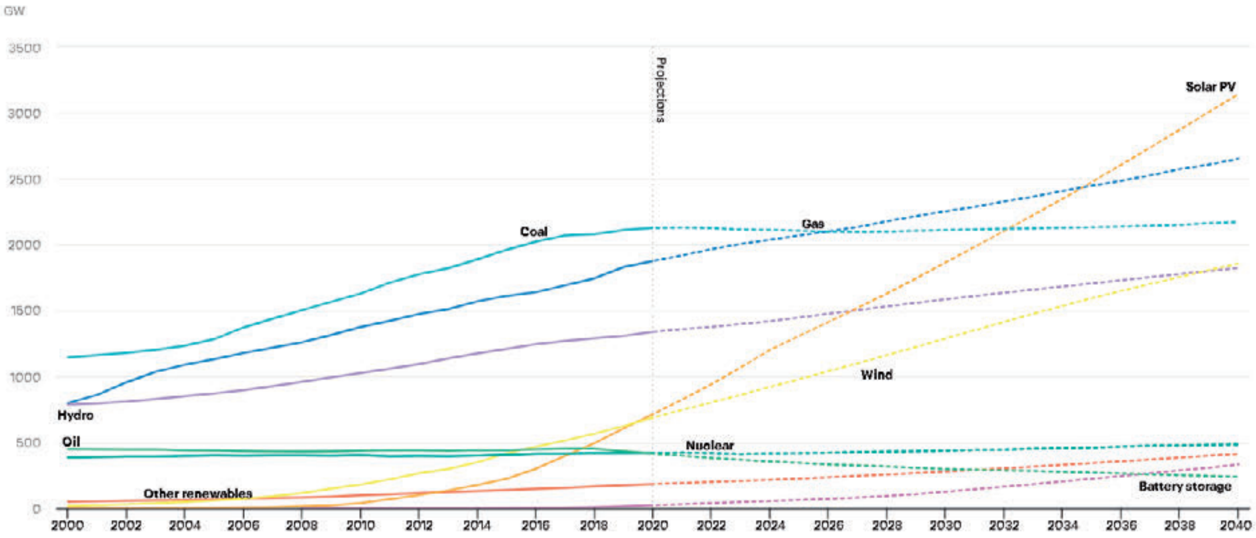
Figure 2
Primary Energy Consumption by Energy Source in the World



Source: EIA International Energy Outlook 2019.

13. IEA WEO 2019 sees solar PV becoming the largest component of global installed capacity in the Stated Policies Scenario. The expansion of generation from wind and solar PV helps renewables overtake coal installed capacity in the power generation mix in the mid-2020s. By 2040, low-carbon sources could provide more than half of total electricity generation. Wind and solar PV are expected to be the star performers, although hydropower (15 per cent of total generation in 2040) and nuclear (8 per cent) will also retain major shares.

Figure 3
Installed power generation capacity by source in the New Policies Scenario, 2000-2040

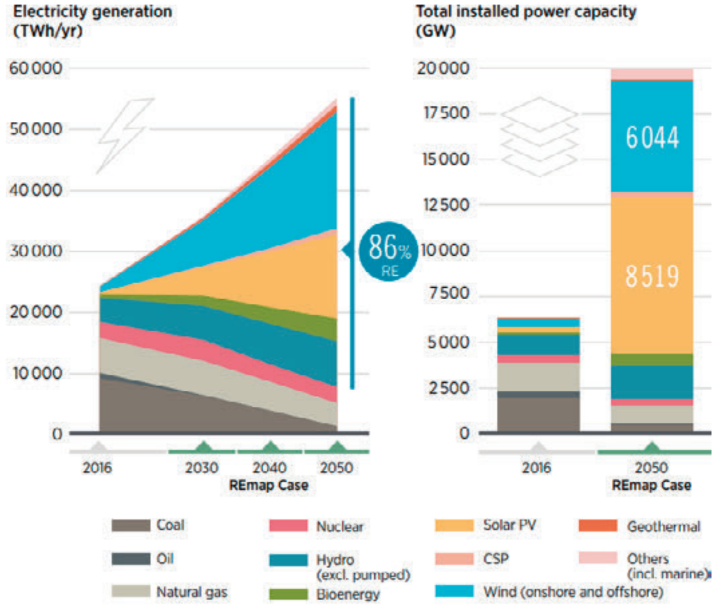


Source: IEA WEO 2019.

14. Among the energy industry, the same growing trend for VRE is fully supported in various publications lately released by the major energy market players and renowned consultancy firms. Some examples underpinning this conclusion are the BP Global Energy Outlook 2019, the Shell Energy Transition Scenarios and Global Supply Outlook to 2100, the ExxonMobil Global Energy Outlook, the TOTAL Outlook 2040, the McKinsey Global Energy Perspective 2019 and the DNV GL Energy Transition Outlook, amongst many others.

Figure 4

Global electricity generation (TWh/y) and total installed power capacity (GW) by fuel, Remap Case, 2016-2050



Source: IRENA[5].

15. As regards the UNECE region, the UNECE Pathways to Sustainable Energy[6] (UPSE hereafter) present a thorough analysis of the current energy situation within the UNECE region, as well as different scenarios and policy recommendations to achieve a sustainable energy system. Nearly two-thirds of all new power generation capacity added in 2018 was from renewables (mainly solar and wind followed by hydropower and bioenergy), led by emerging and developing economies. Increasing installed capacity of renewable energy technologies in many UNECE countries has driven a reduction in capital costs and increased investor confidence in lifecycle costs, improving their economic viability. Therefore, the deployment of renewable energy is growing and being integrating progressively into the UNECE energy mix. However, it must be also noted that the role of renewable energy in the energy mix across the region is highly variable. Whilst Europe and North America account for 23 per cent and 16 per cent of the total renewable generation capacity, the Caucasus, Central Asia, and the Russian Federation collectively account for only 4per cent.

16. Unfortunately, when it comes to renewable energy, the UPSE mainly covers electric variable renewable energy (VRE). The role of renewable gases (including hydrogen) and renewable liquids have been left out of the different scenarios projections. Thus, the synergies between gas and renewable energy within the UNECE Energy Pathways could be even more evident should renewable gases/liquids be taken into account, especially in the medium and long-term. With that in mind, the Group of Experts on Gas in its 2020-21 work plan offered to support ECE member States in developing policies needed to accelerate development, demonstration and deployment of renewable, decarbonized and low-carbon gas projects.

17. According to the UPSE, the traditional energy system is defined by large scale plants that generate single-directional, predominantly fossil-fuel based, power and heat to end-users. However, the projections indicate that the electricity generation portfolio is anticipated to experience significant structural changes. The future power generation system is expected to be increasingly based on more decarbonized, more decentralized, and smarter energy systems. Under these assumptions, electric Variable Renewable Energy (VRE) has been growing fast and it is forecasted to grow even more during the following decades. More concretely, according to the scenarios identified within the UPSE, renewables are set to play a key role together with natural gas.

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[5] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_G20_grid_integration_2019.pdf

[6] UNECE Pathways to Sustainable Energy (2019) Phase I – Insights and Recommendations

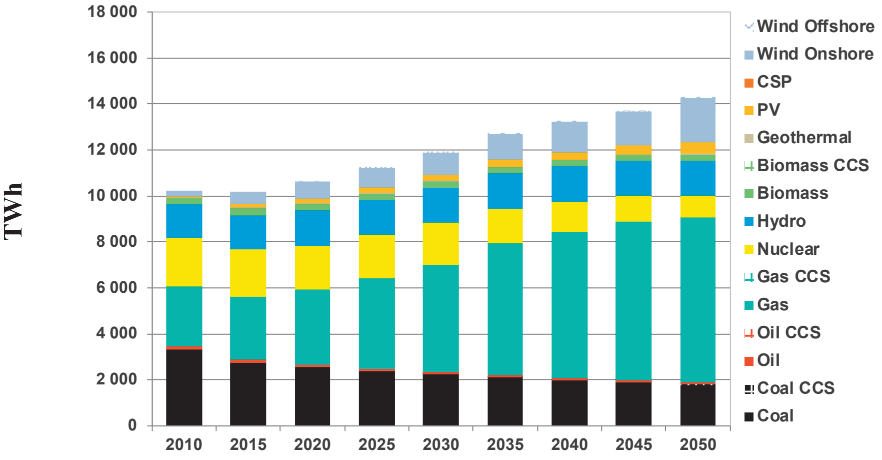
a. In the reference **(REF[7]) scenario**, by 2050, hydro and variable renewable energy are expected to follow fast expansion together with natural gas. Coal and nuclear energy are anticipated to follow a long-term phase out trajectory post-2040.

b. In the **NDC[8] scenario**, higher electricity output is anticipated towards the end of the forecast period. This will primarily be driven by the uptake of electric mobility. Accelerated phase-out of coal-fired power plants is expected to be replaced by natural gas. Renewable energy is forecast to experience rapid expansion from 2020. Retrofitted coal and gas generation with CCS will slowly be introduced, however, will still remain marginal.

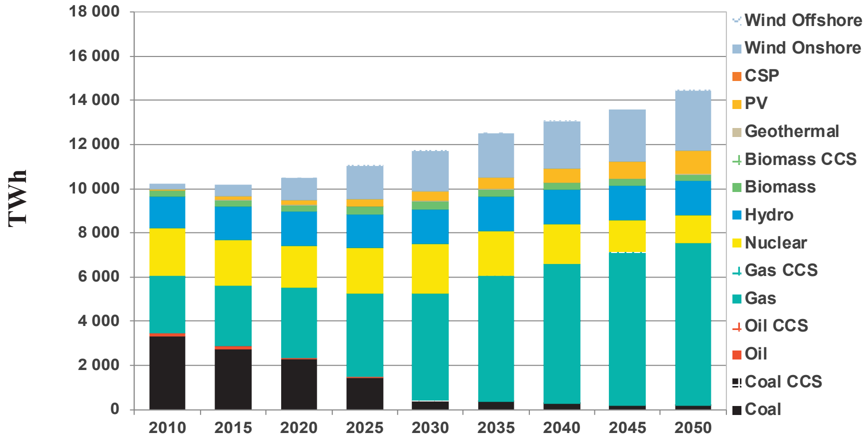
c. In the **Paris to 2°C (P2C[9]) scenario**, on the back of widespread electrification of the energy system, 20per cent higher electricity demand is expected by 2050. This scenario implies a higher degree of diversification with fast uptake of low-carbon emitting technologies. P2C depicts a fundamental realignment of the generation structure with a large share of gas with Carbon Capture and Storage (CCS), fast expansion of offshore wind and solar PV, and a steady expansion of nuclear power. Whilst conventional coal is expected to phase out, some minor coal-fired power generation with CCS is expected to retain the role of coal in the power generation mix.

Figure 5

UNECE Electricity Generation by Policy Scenario (REF, NDC and P2C) REF Scenario



NDC Scenario



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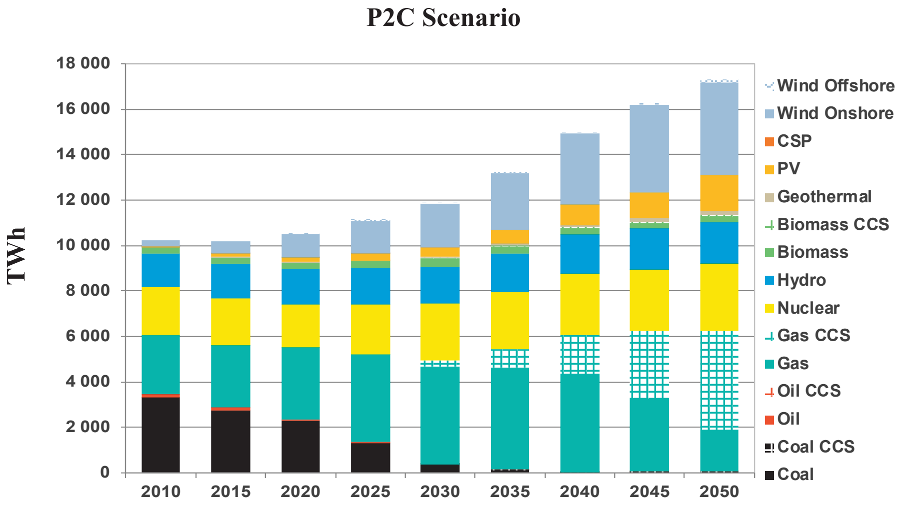
[7] Based on Shared-Socio-Economic Pathway 2 (SSP2), a “Middle of the Road” Pathway, as point of departure, i.e., without dedicated sustainable energy or climate policies.

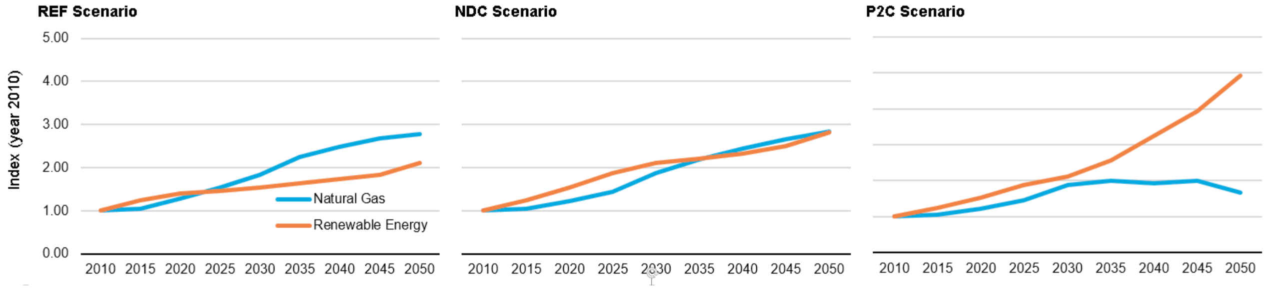
[8] A scenario that implements by 2030 the NDCs under the Paris Agreement but maintains the NDCs beyond 2030

[9] 2°C target of the Paris Agreement by 2100



Source: UNECE Energy Pathways Phase I – Insights and Recommendations (2019).

Figure 6:
Growth of Natural Gas and Renewable Energy in Power Generation, in ECE region by policy scenarios.



Source: UNECE Energy Pathways Phase I – Insight and Recommendations (2019).

18. The figures 5 and 6 are taken from the UPSE. They show a clear potential to enhance the interplay between VRE and natural gas, in order to provide the UNECE region with electricity. In the three scenarios under consideration, natural gas and renewable energy are both multiplying their share in the power generation mix by a factor between 2 and 4 over a 40-year period, becoming the predominant two sources of energy. These scenarios call for a compulsory cooperation among gas and renewable energy. This conclusion would be even more relevant if the role of renewable, decarbonized, and low carbon gases were duly taken in account within the UPSE.

2.2 Flexibility is Required to Integrate VRE into the Energy System

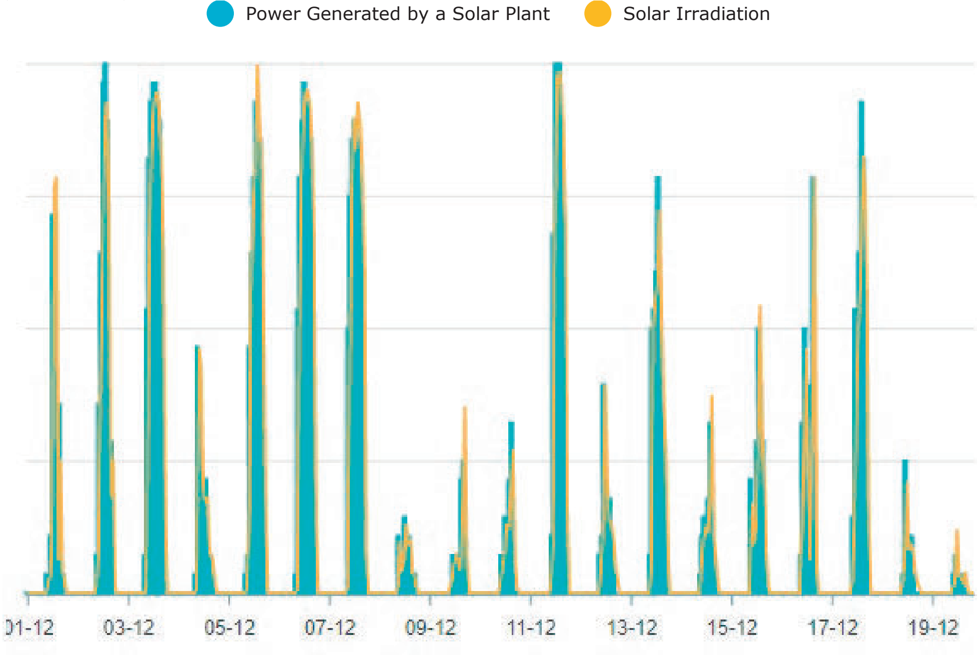
19. Integrating higher shares of VRE technologies, such as wind and solar PV, in power systems is essential for decarbonising the power sector while continuing to meet growing demand for energy. Power systems around the world are undergoing significant change, driven particularly by the increasing availability of low-cost VRE sources, the deployment of distributed energy resources, advances in digitalisation and growing opportunities for electrification. These changes require a profound power system transformation.

20. The future energy system, where the power system is a part of, is undergoing a cost-efficient transition towards a nearly decarbonized power system by 2050. By that date, around half of the primary energy demand could be supplied by renewable electricity, whilst the remaining half could be based on non-electric renewable and decarbonized energy, such as hydrogen, biomethane and other kind of molecules in liquid or gaseous form.

21. VRE is more unpredictable than the conventional power generation technologies and does not offer the required supply continuity when sun and wind are unavailable. The inherent variability of wind and solar PV power generation poses challenges to energy operators and regulators who find themselves in need of ensuring a reliable, effective and cost-efficient VRE integration into their energy systems.

Figure:7:

Variability of a typical solar power plant in Spain during different days of a given month (December)

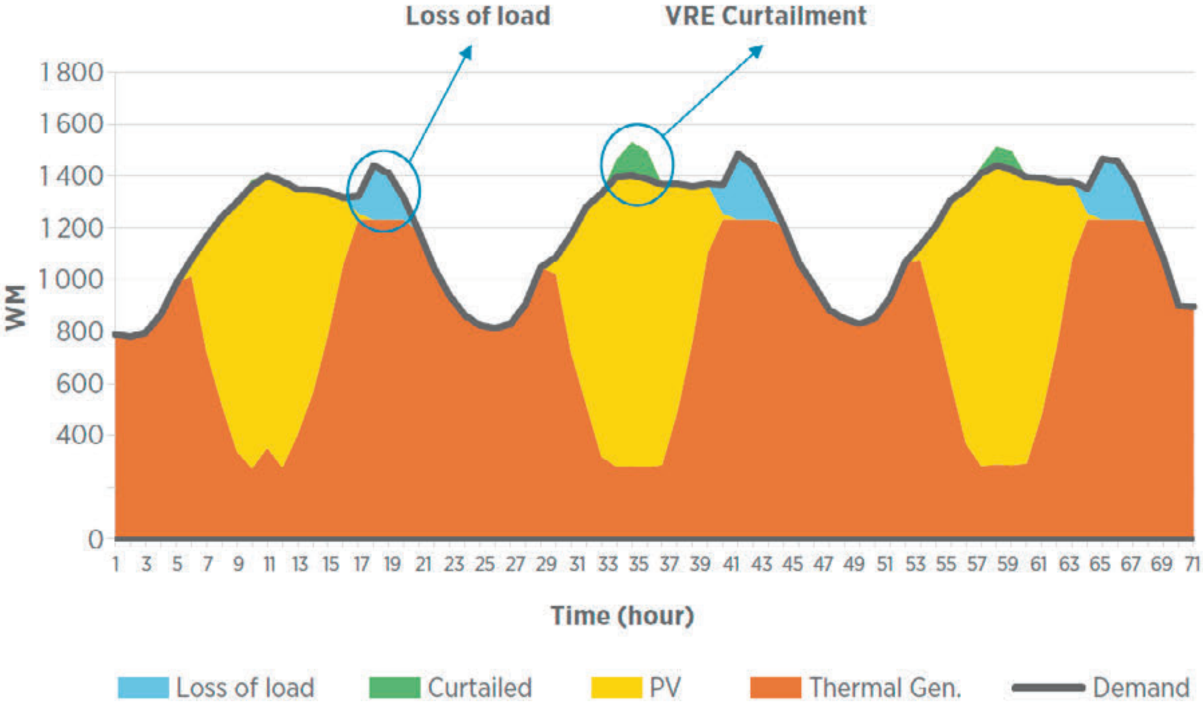


Source: Owner - Spanish Solar Plant.

22. The integration exercise of VRE passes by a number technical and regulatory arrangements which provide both, the market players and energy system operators, the flexibility required to cope with fluctuating power output of VRE sources, while ensuring a resilient and secure operation of the energy system under all circumstances, including the sudden and unpredictable absence of VRE.

23. In a system with relevant amounts of VRE installed capacity, the lack of an adequate level of flexibility puts the power system under operational stress. As Figure 7 and 8 shows, in systems with high shares of VRE, there might be moments when curtailment might be necessary to ensure the safe system operation and avoid overloads and/or network congestion. In other cases, the lack of VRE, might lead to a loss of load that, if not managed properly by the operators, could end up in a system blackout, with all the negative consequences associated with it.

Figure 8:
Flexibility is key for VRE Integration – Example of energy system with high PV penetration



Source: IRENA.

2.3. VRE: System Integration Needs Depend on the Share of VRE

24. The increasing prominence of VRE is among the most important drivers of power system transformation globally. The properties of VRE interact with the broader power system, giving rise to several system integration challenges.

25. The main attribute of VRE that must be addressed is the variability of the resource and how to account for this variability over several time scales. Since VRE is not dispatchable, there are several technical opportunities that allow the integration of higher levels of VRE.

26. However, the integration of large amounts of VRE involves technical, economic, and regulatory elements, related not only to the attributes of VRE generation, but also to the complex nature of the energy sector in general.

27. The impact of VRE, and issues associated with them, is largely dependent on its level of deployment, the size of the system, operational and market design, the regulatory framework, the system topology and fundamentals of supply and demand. VRE also has impacts on the economics within energy markets and on the required institutional arrangements.

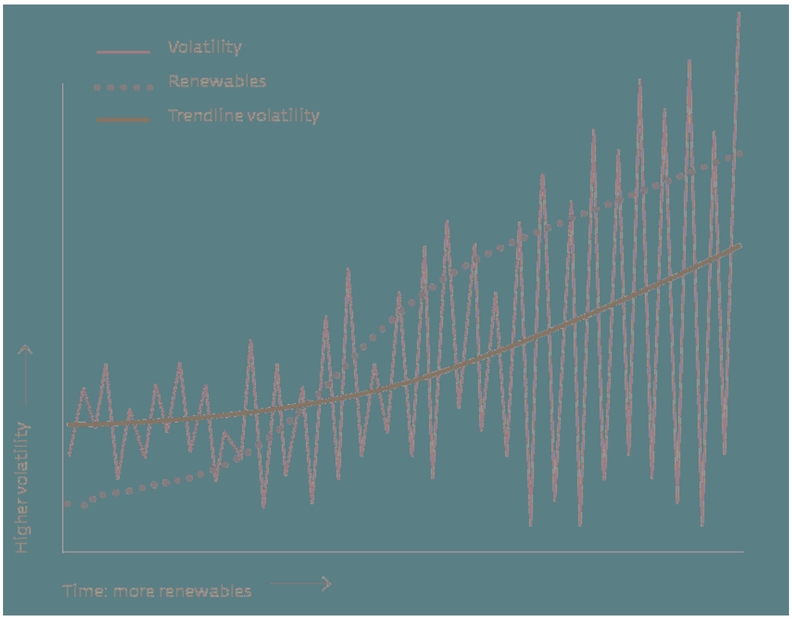
28. In general terms, the key to integrating VRE is flexibility. Flexibility describes the capability of a power system to maintain continuous service in the face of rapid and large swings in supply or demand, whatever the cause might be.

29. The system integration challenges do not appear abruptly, but rather increase over time along with the increase in VRE penetration. As observed in Figure 9, the higher the share of VRE, the higher the volatility, and consequently, the higher the amount of flexibility required to integrate that VRE share.

30. Integrating the first few percentage points of VRE share in the generation mix is relatively easy because all power systems have technical requirements due to the variability and uncertainty of power demand.

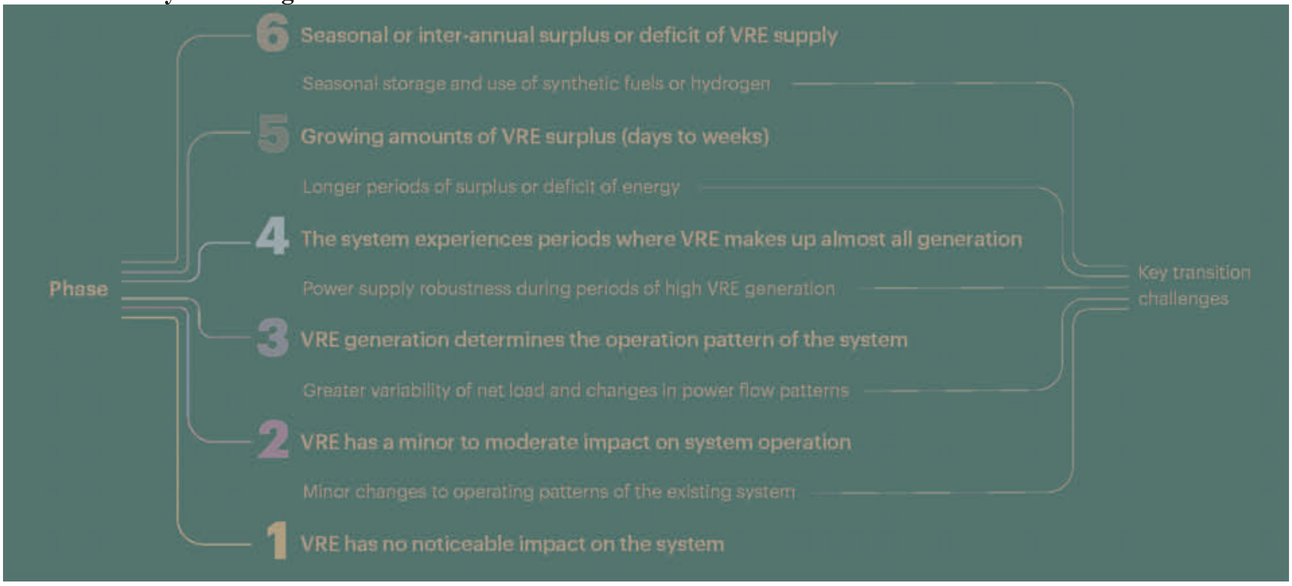
31. Beyond these levels, as VRE penetration increases, power systems can be seen to progress through different stages requiring increasing adaptations (see Figure 10). VRE integration levels of more than 50 per cent have been achieved.

Figure 9:
Evolution of volatile versus amount if installed variable renewable energy



Source: Energy Stock.

Figure 10:
Key characteristics and challenges in the different phases of Variable Renewable Energy (VRE) system integration



Source: IEA.

32. Figure 10 presents different system integration phases which depend on the amount of VRE within the energy system.

   a. Phase 1 captures very early stages where VRE deployment (often no more than a few percent of annual energy demand) has no noticeable impact on the power system operation.

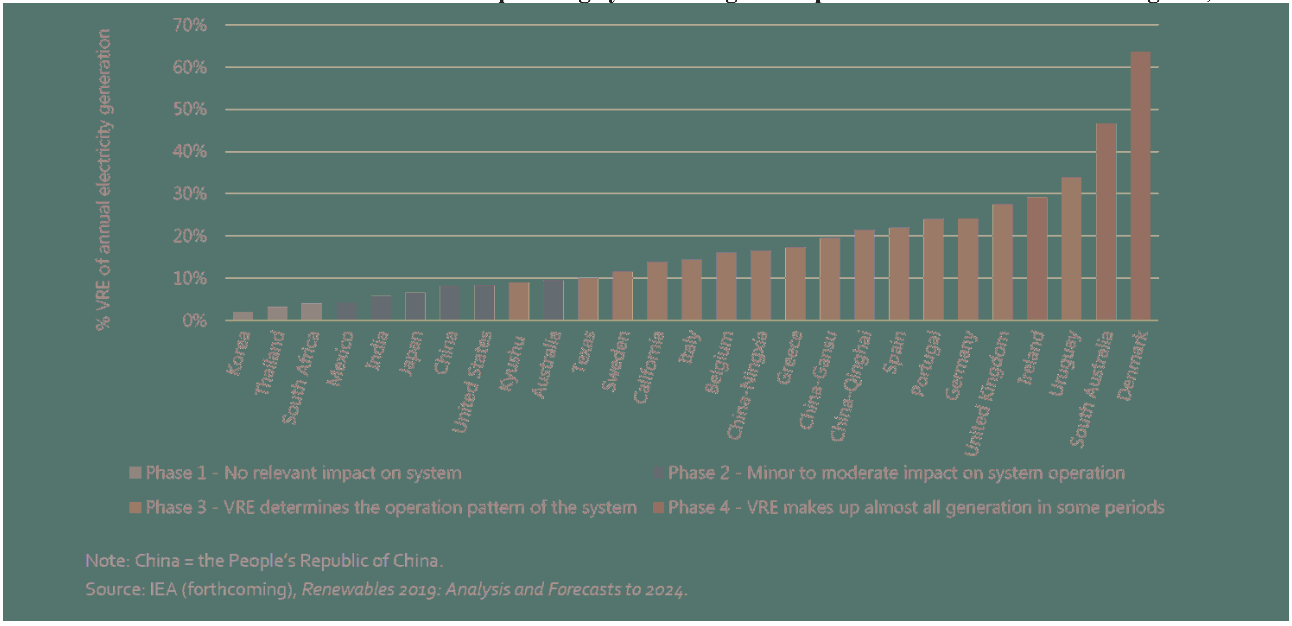
   b. Phase 2 presents flexibility issues emerging when VRE reaches higher shares in the energy system, but the system can cope with them through minor operational modifications and/or adaptations, as well as the use of conventional flexibility sources.

c. Phases 3 to 6 respectively indicate greater influence of VRE in determining system operations; starting from the need for additional investments in the different flexibility options; structural surpluses of VRE generation might lead to curtailment; the structural imbalances in energy supply at seasonal and inter-year periods might require sector coupling.

d. Presently, Phase 4 is the highest VRE integration phase that has been achieved in practice. A small number of countries and regions (e.g., Denmark or Ireland) have reached Phase 4, but many other power systems are still in Phases 1 and 2, having 5-10per cent shares of VRE in annual electricity production. This phase requires advanced flexibility technologies, including the DSM, DER, and seasonal flexible storage, among others.

33. In any case, the general direction of this transition is already clear: higher phases of system integration are forthcoming for most countries and are reflected in the increased levels of VRE deployment and new national efforts to boost power system flexibility. As the number of countries with medium-to-high share of VRE rises significantly, it is expected that power system flexibility will become a more prominent issue in the coming years.

Figure 11:
Annual VRE share and corresponding system integration phase in selected countries/regions, 2018



Note: China = the People's Republic of China.

Source: IEA (forthcoming), *Renewables 2019: Analysis and Forecasts to 2024.*

Source: IEA Status of Power System Transformation 2019.

34. An additional challenge to be faced is not only the integration of VRE technologies into present and future energy systems but also across different sectors, including heating and cooling, transport, gas and liquid fuel distribution, autonomous energy supply systems, etc. This point is addressed later in section 2.7.

2.4. Different Flexibility Options to Integrate VRE

35. In general, when it comes to integrating VRE and providing grid support services, there are four large key categories of technological solutions that provide system flexibility, namely:

a. Flexible power generation

b. Electricity networks and electricity interconnections

c. Energy storage; and

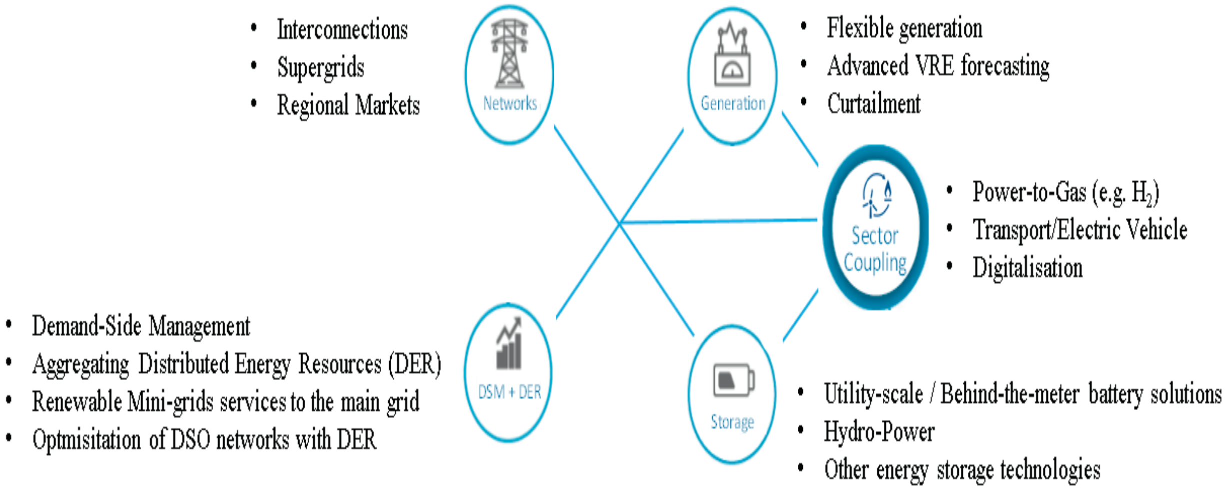
d. Demand Side Management (DSM) and Distributed Energy Resources (DER).

36. Conventional power plants, electricity networks and pumped storage hydropower (PSH) have historically been the primary sources of flexibility. They are playing an important role in grid resilience and stability and are of vital importance to balance the fluctuations of the wind and solar PV.

37. On top of these traditional flexibility options, there are several new additional flexibility options for consideration such as the operational protocol improvements that have occurred in VRE power plants, the advent of affordable Distributed Energy Resources (DER), the development of Demand Side Management (DSM), the battery energy storage systems (BESS), etc. These options offer different operational features, with different timescales, different certainties, and different amounts of flexibility, among others.

38. As power systems transition toward higher phases of VRE system integration, all these flexibility resources can work together in concert, on a complementary way, covering different time scales, and enhancing system flexibility in a cost-effective, reliable and environmental sound manner. Achieving this goal typically requires changes to policy, market and regulatory frameworks.

Figure 12:
Flexibility technological options to integrate variable renewable energy (VRE) into the energy system



Source: Own production based on IEA and IRENA sources.

39. In addition, new independent energy companies and private initiatives are entering the market. The number of platforms for energy trading are growing. These developments will generate significant changes for energy portfolio management. New services from flexibility providers could be needed to shape the best energy sourcing strategy.

40. IEA studies[10] show that, if appropriate measures are taken to address VRE integration issues, it is possible to integrate high levels of VRE (above 30per cent) at a modest incremental cost. To achieve this, power system planning, regulatory frameworks, and policy measures will need to be undertaken with the objective of minimizing total system costs.

41. The challenges related to VRE integration (e.g. increasing curtailment levels and reserve requirements) do not emerge if the right procedures are proactively put in place. Technical solutions to VRE integration challenges always exist, so the limitation is largely economic rather than technical. Therefore, economically speaking, the maximum ideal level of VRE integration (economic carrying capacity) is the one at which any additional cost outweighs the benefits of the additional VRE unit and, therefore, no additional VRE capacity is economically desirable.

2.5. Natural Gas as a Major Enabler of VRE Deployment

42. Conventional thermal power plants[11] are currently the predominant source of system flexibility being used to accommodate supply and demand variability and uncertainty in modern power systems. They are dispatchable generators able to adjust their output to follow demand.

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[10] IEA report “The Power Transformation” (2014), IEA report “Status of Power Transformation” (2019)

[11] It mainly refers to coal-fired power plants and gas-fired power plants

43. Important progress has been made in recent years towards increasing the flexibility of conventional thermal power plants, as the demand side was largely unresponsive and provided very little flexibility. Flexible power plant operation can take many forms, from rapidly changing plant output, to starting and stopping more quickly, to turning plant output down to lower level without triggering a shutdown. There are a diverse range of strategies that can make existing conventional power plants more and more flexible. These strategies can be categorized into two areas: changes to operational practices, and flexibility retrofit[12] investments for existing plants.

44. Flexible generation from thermal generators, and more concretely the gas-fired generation, is a highly cost-effective, mature and readily available option to balance VRE variability and uncertainty. This option is critical to ensuring security of supply during sustained periods of low VRE generation.

45. According to the above UPSE, there is a clear potential to enhance the interplay between VRE and gas-fired power generation for electricity generation within the UNECE region.

46. Natural gas capacities will be required as an enabler in the short-term (and may be mid-term) to ensure secure and continuous power generation due to renewable energy intermittency.

    a. According to data from UPSE, based on REF scenario in 2030, natural gas and renewable energy are expected to account for 40per cent and 26per cent respectively of the total electricity generation mix. By 2030, according to the NDC and P2C scenarios, higher penetration of renewable energy is anticipated. Natural gas is expected to marginally increase its share from 40per cent to 41per cent while renewable energy would grow from 26per cent to 36per cent.

    b. By 2050 greater penetration of renewable energy is anticipated in all scenarios. In the REF scenario, natural gas and renewable energy are expected to account for 51per cent and 30per cent respectively of the total electricity generation mix. A slight change is expected in NDC scenario – the share or natural gas in the power generation mix is expected to remain at 51per cent and the renewable energy is expected to increase its share until 39per cent. In P2C scenario, structural changes occur as countries embrace more stringent climate mitigation policies. The share of natural gas is anticipated to half down to 24per cent whilst the renewable energy is expected to expand to 56per cent.

    c. Unfortunately, when it comes to renewable energy, the UPSE mainly covers electric variable renewable energy (VRE). The role of renewable gases (including hydrogen) and renewable liquids have been left out of the different scenarios projections. Thus, the synergies between gas and renewable energy within the UPSE could be even more evident should renewable gases/liquids be taken into account, especially in the medium and long-term.

    d. The UPSE project underlines the benefits of gas in terms of large flexibility provider, low capital costs and the operational advantages. UPSE confirms that gas is a vital source of energy to provide the load requirements for introducing VRE into the power grid on a sustainable manner.

47. As presented in Figure 12, gas-fired generation is not the only flexibility tool. Different technology options can provide system flexibility across the various timeframes and in different quantities. Emerging innovations are not only further increasing flexibility on the supply side but also widening the availability of flexibility in all segments of the power system, including grids and the demand side. Hence, there is a broad portfolio of solutions that can be combined and optimized to reduce costs and maximize system benefits.

48. Reservoir hydropower is an example of a potentially extremely flexible, renewable energy generation technology. Open-cycle gas turbines and banks of reciprocating engines are also highly flexible generation resources widely available. When combined with sufficient levels of thermal storage capacity, concentrating solar power can be a flexible generation option in hot and dry climates, where hydropower resources are usually limited.

49. In general terms, it can be said that the power plant flexibility has various dimensions: ramp rates, output control range, response accuracy, minimum run times and off times, start-up time, cycling cost, and minimum generation

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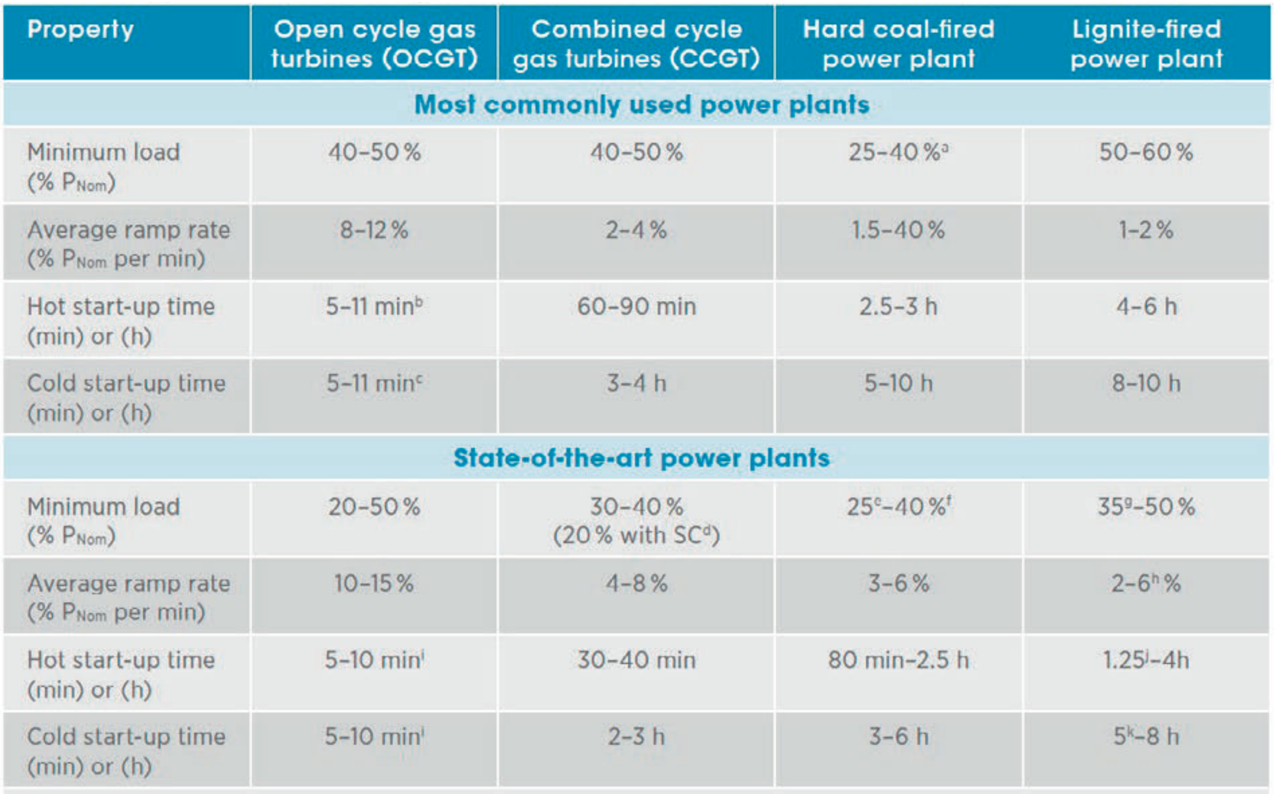
[12] Southern California Edison's Centre Peaker plant in Norwalk, California provides a key example of an innovative flexibility retrofit investment of an existing power plant. In this case, a natural gas peaking power plant was coupled to a 10 MW/ 4.3 MWh battery, enabling the plant to offer spinning reserves without burning any fuel, while also offering valuable frequency response services. The battery storage component of the hybridized power plant covers the spinning reserve requirements during the first few minutes required for the gas plant to start-up, after which the plant can ramp up to full capacity while the battery output decreases.

level. Some forms of flexibility are inherent to particular types of generators, whereas others can be affected by the plant design or the way in which it is operated. The extent to which different generation technologies offer greater or lesser flexibility depends on these dimensions.

50. A flexible generator is one that can ramp up or down fast, has a low minimum operating level and fast start-up and shutdown times (IEA, 2018). For example, hydro generators and open-cycle gas turbines are considered to be among the most flexible conventional generation types, while large steam turbines such as those in coal and nuclear generators usually are considered as less flexible. Table 1 compares coal and gas technologies based on their characteristics that affect technical flexibility.

Table 1:
Comparison of Technical characteristics between coal-fired and gas-fired power generation technologies



Property	Open cycle gas turbines (OCGT)	Combined cycle gas turbines (CCGT)	Hard coal-fired power plant	Lignite-fired power plant
Most commonly used power plants				
Minimum load (% P_{Nom})	40–50 %	40–50 %	25–40 %[a]	50–60 %
Average ramp rate (% P_{Nom} per min)	8–12 %	2–4 %	1.5–40 %	1–2 %
Hot start-up time (min) or (h)	5–11 min[b]	60–90 min	2.5–3 h	4–6 h
Cold start-up time (min) or (h)	5–11 min[c]	3–4 h	5–10 h	8–10 h
State-of-the-art power plants				
Minimum load (% P_{Nom})	20–50 %	30–40 % (20 % with SC[d])	25[e]–40 %[f]	35[g]–50 %
Average ramp rate (% P_{Nom} per min)	10–15 %	4–8 %	3–6 %	2–6[h] %
Hot start-up time (min) or (h)	5–10 min[i]	30–40 min	80 min–2.5 h	1.25[j]–4h
Cold start-up time (min) or (h)	5–10 min[i]	2–3 h	3–6 h	5[k]–8 h

Source: Agora Energiewende.

51. At the operation level, supply-side resources that are quickly ramping and that have short time activation and short reaction time can add great flexibility to the grid. Typically, hydropower and gas-fired plants offer such fast ramping and fast reaction times. Pumped hydro storage plants can provide a great degree of flexibility, at virtually zero marginal costs, in terms of both supply (firm electricity as needed) and demand (pumping to refill reservoirs in times of excess supply). However they are not available everywhere across de UNECE region, and the amount of existing flexibility is commonly lower than the existing/planned available gas-fired power generation capacities. Even if the flexibility cost increases with the steepness and the length of the ramp, and even if they are exposed to gas fuel costs, gas-fired plants offer a continuous and large source of flexibility to the energy system.

52. Natural gas generation is very well placed to address the issues associated with VRE integration. Whereas traditional coal or nuclear steam cycle generators can take up to more than 10 hours to reach full load, usual gas combustion technologies have start-up times measured in minutes. Start-up and ramp up rates for gas-fired generation systems vary with the technology in place for the installed capacity but generally they are faster than other thermal technologies. Part-load efficiency of gas-fired technologies is also higher than coal-fired power plants. The start-up times (hot start-up) for new Open Cycle Gas Turbines (OCGTs) are around 5-10 minutes. Gas reciprocating engines can start and ramp up to full load more quickly[13]. The current Combined Cycle Gas Turbine (CCGT) power plants

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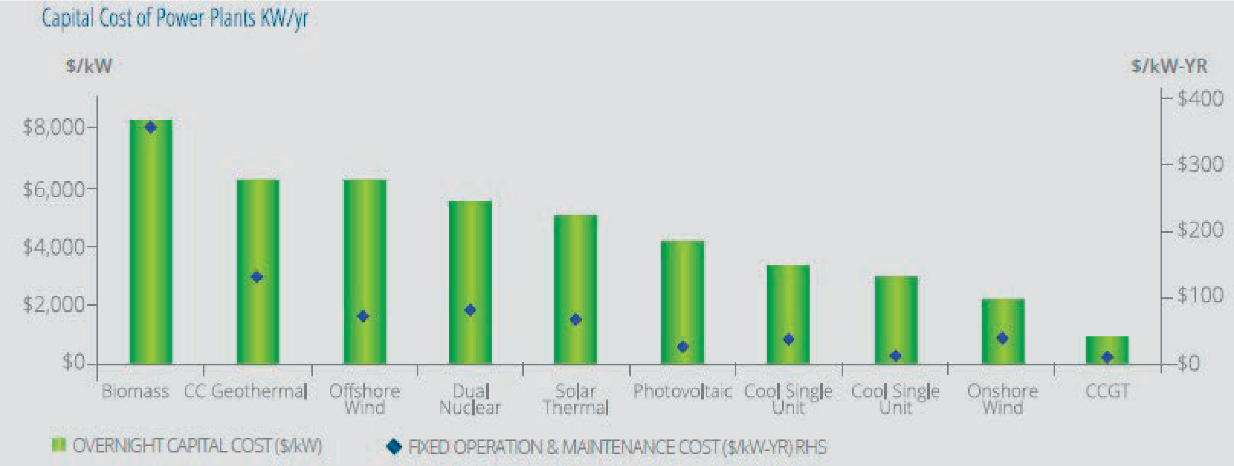
[13] Combustion Engine vs Gas Turbine (Wärtsilä) [link]

require approximately 60 to 90 minutes for hot start-up. However, the new, “fast-acting” CCGTs can achieve full load output in less than 40 minutes[14].

53. While it is also well-known that gas-fired power plants do have certain limitations in start-up times, ramp rates, turn-down ratios and part load operation, they are usually identified as a major option to integrate VRE. This is due to its efficient, very flexible, cheaper, secure and resilient technology. Flexible gas-fired power plants are considered a large source of flexibility that significantly helps to address the VRE integration challenges in system operation, and which are complemented by other flexibility options such as grid infrastructure, storage, demand-side management, etc.

54. Besides the technical specifications related to flexibility (adjustability, ramping and lead time), there are other factors to be taken into account when selecting a flexibility option such as capital investment costs and emissions. The Figure 13 compares the capital costs for different technologies used in power generation. It concludes that gas turbines are the most economical among all the options considered. In terms of emissions and air quality, the Figure 14 confirms the environmental superior performance of natural gas against coal and oil. Compared to coal, natural gas emits less CO_2, 100per cent less SOx and $PM_{2.5}$, and more than 80per cent less NOx.

Figure 13:
Comparison of gas-fired power generation with other technologies



Source: IGU.

55. The CO_2 emissions from the combustion of natural gas are certainly lower than those from coal. This is particularly true when assessing full lifecycle greenhouse-gas emissions, after taking account of methane emissions released during the supply of the respective fuels. The Figure 14 offers a comparative LCA analysis of gas versus coal. IEA detailed estimates, taking into account both CO_2 and methane, show a wide variation across different sources of coal and gas. Nonetheless, an estimated 98per cent of gas consumed today has a lower lifecycle emissions intensity than coal when used for power or heat (this comparison excludes any coal use for which gas could not be a reasonable substitute, such as coking coal used in steel production).

56. This analysis shows that, on average, coal-to-gas switching reduces emissions by 50per cent when producing electricity and by 33per cent when providing heat.

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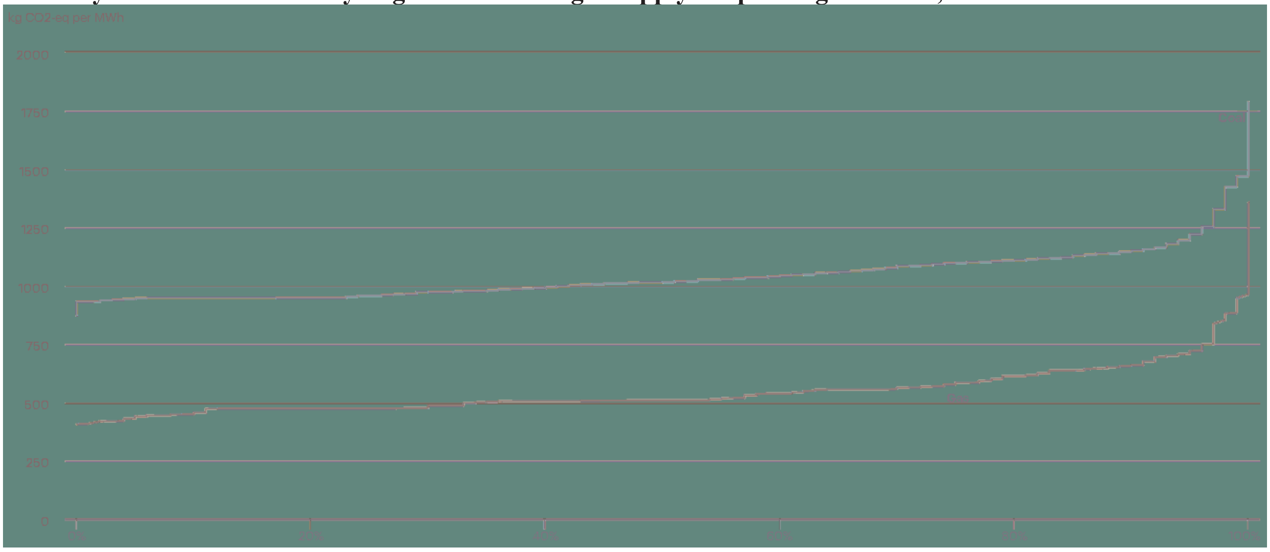
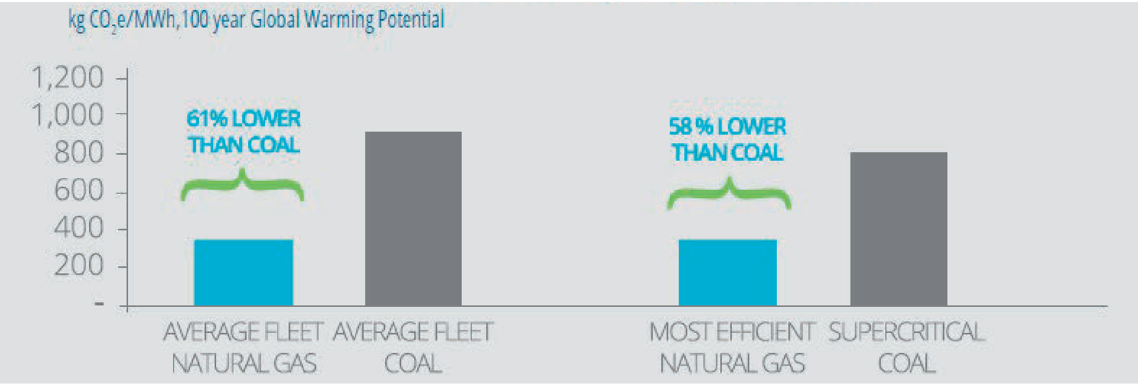
[14] Hot start-up time

Figure 14:
Full lifecycle emissions intensity of global coal and gas supply for power generation, 2018



Source: IEA Methane Tracker (2019).

Figure 15:
Comparison of gas-fired power generation with coal technologies



Source: IGU.

57. Based on the results from Table 1 and Figures 13 to 15, it can be concluded that, generally speaking, natural gas combustion turbines, are among the most flexible generators, whereas existing coal plants are less flexible. Gas-fired power plants are also able to ramp faster than coal plants. In terms of economics, the gas-fired power plants offer the lowest capital cost among a large variety of technological power generation solutions. Furthermore, gas-fired power plants are also more environmental friendly than other thermal technologies (coal and oil), reducing substantially the Green House Gas (GHG) emission and drastically improving the air quality. All these major advantages, among others, make natural gas as the major flexibility option to enable the integration of VRE across the UNECE region.

2.6 Gas as enabler of VRE: Case Studies

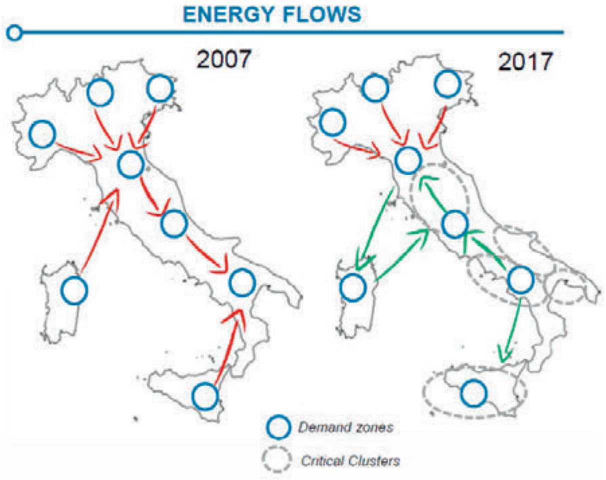
58. Currently, gas-fired power plants in many countries can offer greater flexibility by better responding to changes in net demand. Examples of increased flexibility in gas-based generation can be found in various countries such as Denmark, Canada, the United States, Germany, and Spain, among others. In addition, countries with a large fleet of combined-cycle gas turbines (CCGTs), such as Italy, have taken steps to make CCGTs fleet more flexible in view of large uptake of VRE.

59. A number of case studies are presented below to give evidence about the interplay between gas and VRE in various UNECE countries.

Italy

60. Italy began developing solar PV and wind projects in the early 2000s. VRE capacity rose quickly from roughly 1 GW in 2004 to almost 5 GW in 2009, and this trend has continued so far. In 2018, solar PV and wind installed capacity in Italy eclipsed 20 GW and 10 GW, respectively. The VRE has been largely installed in southern regions while main load centres remain in mid-northern cities. This has changed energy flow patterns and led initially to energy congestion and curtailment (Figures 16 and 17).

Figure 16:
Energy flows dominant in Italy



Source: IRENA.
Note: Green lines represent dominant paths altered in the period 2007 – 2017; red line in 2017 remain unchanged from 2007.

61. Since then, a set of measures has been applied in the country, with Dynamic Line Rating (DLR)[15] contributing greatly to easing curtailment due to transmission constraints. DLR is a relatively low cost measure with a short lead-time that has been instrumental in significantly reducing curtailment levels down to 1-2per cent in Italy in a very short period. Such levels have remained almost unchanged since then, with the help of other measures that have followed, such as transmission expansion and the current development of smart grids in the region of Puglia.

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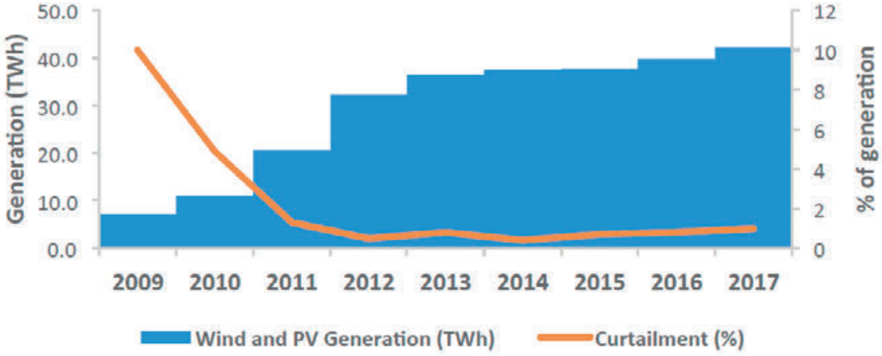
[15] Dynamic Line Rating refers to the activity of dynamically adjusting current capacity of transmission lines based on environmental conditions such as local temperature, solar irradiation and wind speed and direction. As a general illustration, line capacities tend to be higher under low-temperature environments and decrease as temperature increases. It opposes static line rating in which the capacity to transmit energy is based on average-static environmental conditions and remains flat irrespective of current weather conditions. This approach is largely considered when setting line parameters.

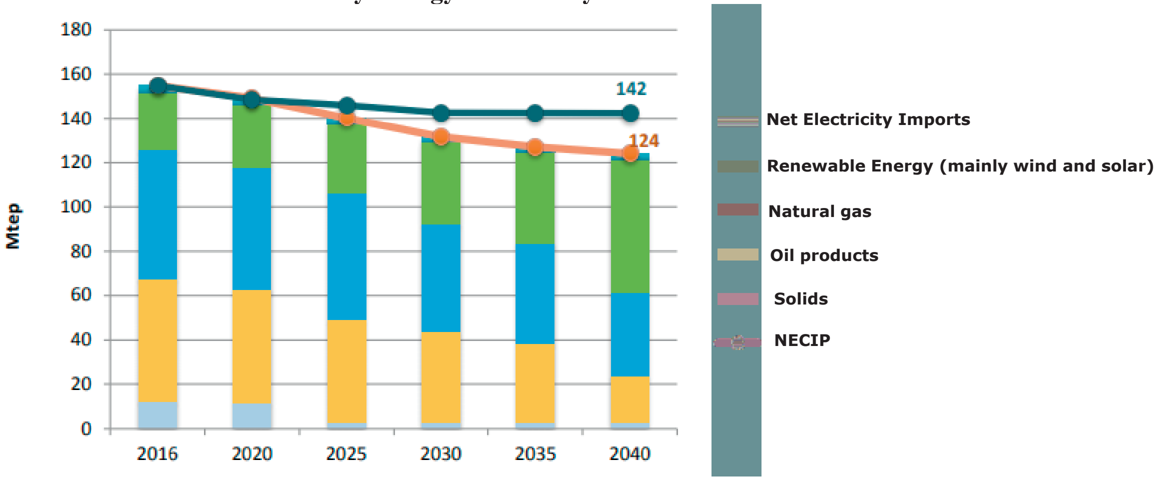
Figure 17:
Variable renewable generation and curtailment in Italy



Source: IRENA.

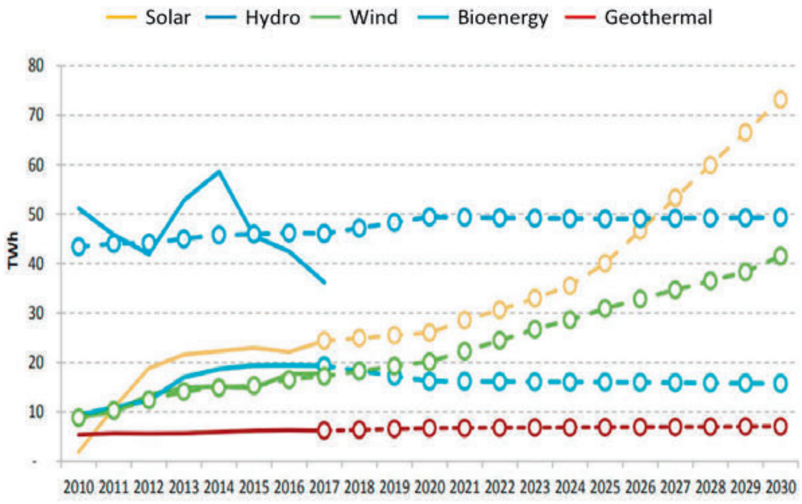
62. Moreover, the growing share of VRE in Italy has been extensively supported by the flexibility provided by the thermal generation unit, mainly gas-fired plants, since coal represents a minor share of the power generation mix and will be phased out in 2025. The Italian National Energy and Climate Plan is focusing on ambitious development plan for renewable energy sources. Italy's target is to double the wind power generation and triple the solar power generation compared to status in 2019. In addition, around 5 GW of additional energy storage capacity is envisioned to come online to provide frequency regulation and time shifting of renewable energy.

Figure 18:
Evolution of Primary Energy mix in Italy until 2040



Source: Italy's National Energy and Climate Plan (December 2019).

Figure 19:
Electricity growth trajectories from renewable sources to 2030



Source: Italy’s National Energy and Climate Plan (December 2019).

63. Today gas plays a paramount role and will continue to do so in the Italian system, where the overall demand should continue more or less flat (or with very slight decline) towards 2025, reaching a value of more than 670 TWh in that year. From there, gas demand could start declining until 440 TWh in 2040. Therefore, the role of gas in Italy will evolve. Gas-fired generation will move away from the current profile of baseload-flexible generation towards a more flexible-peaking generation role which supports renewable generation wide penetration. The aspect of flexible gas and the value of flexibility is therefore essential for the future energy system in Italy. The lower curtailment is enabled by non-spinning reserves provided by the flexible gas capacity with extremely fast start-up time. Furthermore, the new flexible gas generation capacity optimizes operation of the entire Italian power system, allowing for a more stable operating profile.

Germany

64. The participation of renewables in the German power system has been increasing during the last decade as a consequence of the Energiewende. In 2018, more than 40per cent of demand was met by renewables. On 3 March 2019 – a particularly windy Sunday - wind and solar accounted for 90per cent[16] of all power consumption. VRE now accounts for 47per cent of German power capacity. A renewed policy emphasis on renewables means new targets of 98GW of solar, 20GW of offshore wind and 73GW of onshore wind by 2030. This would imply an additional 48GW of solar and 33GW of wind capacity by 2030.

65. Set against this growth in variable renewable generation is a rapid reduction in installed firm capacity. 16GW of nuclear, coal and lignite closures are scheduled by the end of 2022, and 29GW by 2030.

66. In 2019 the German coal commission provided recommendations to phase out Germany’s coal and lignite capacity by 2038, starting in 2022. These recommendations have been drafted into a legal text to formalize the pathway to zero-coal. Under this legislation, coal and lignite capacity will be capped at 15GW each by 2022, at 8 and 9GW respectively in 2030 and at 0GW by the end of 2038. In addition to coal closures, Germany will also close its remaining nuclear fleet by 2022 as part of the Energiewende. 12GW of nuclear capacity has been closed under this policy already, with coal generation making up the shortfall. The remaining 8GW of nuclear is due to close in 2022, but with coal capacity also closing, the current policy intention is for renewables to plug the gap.

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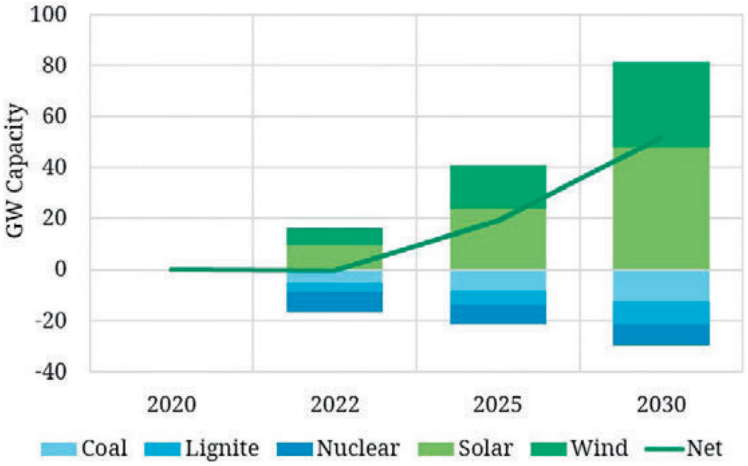
[16] Agora Energiewende, 2019

Figure 20:

Known Germany Capacity Changes assuming Germany meets its wind and solar targets



Source: Timera Energy.

67. Such strong VRE growth, however, has put pressure on the electricity grid. The German power system has been balanced by conventional thermal power units (gas and coal) in addition to exports to neighbouring countries. Gas-fired generation has traditionally represented a lower share in the power generation mix compared to coal. However, in the last years the share of the electricity production associated to gas–fired power generation has evolved upwards together with the VRE. The main reasons of this change are due to the gas' superior environmental performance and lower CO_2 emissions, as well as its higher flexibility compared to less-flexible conventional coal plants. The ETS price adjustment introduced in 2018 has helped to make gas more competitive against coal. In 2019, for the first time[17], natural gas overtook hard coal as a source of electricity in Germany. Once all the coal and nuclear power plants are closed, gas-fired plants will be only power generation plants providing dispatchable flexibility for massive VRE integration.

68. Despite the role of conventional thermal plants (coal and gas), redispatch events have taken place due to energy and voltage imbalances resulting from bottlenecks in the German transmission network. These events have increased year by year and essentially occur at moments of congestion in the north–south direction, when power plants in the south and west must ramp up to meet the region's demand, previously scheduled to be met by wind from the north.

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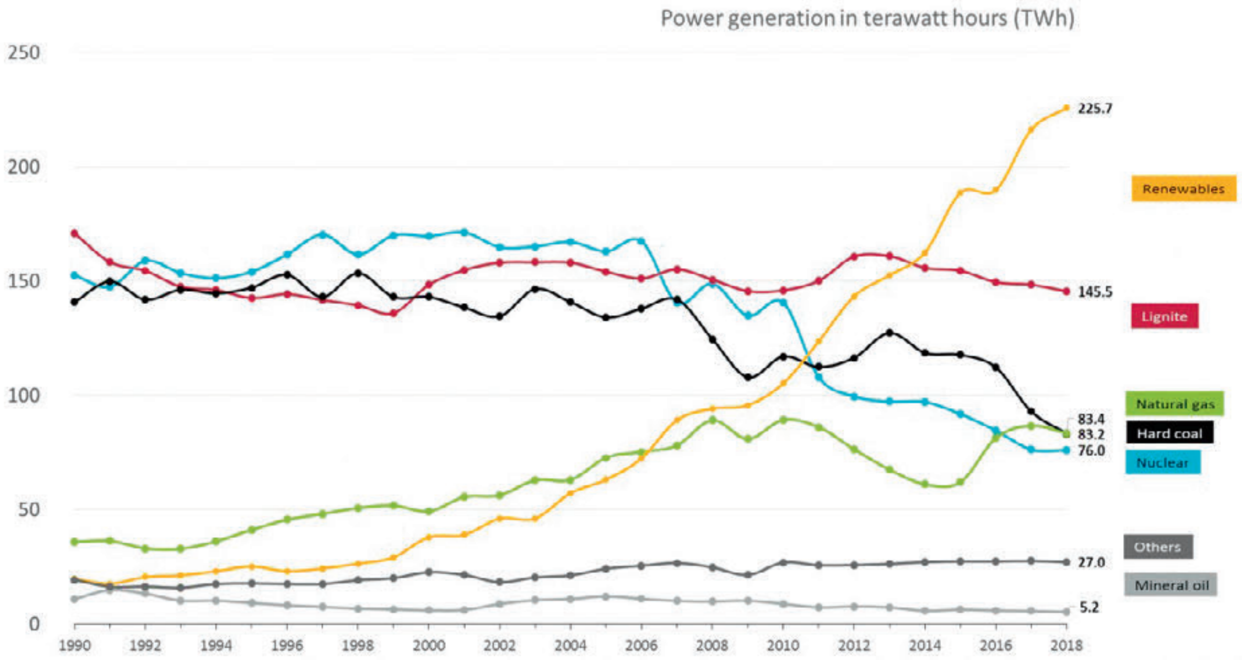
[17] According to the German energy association BDEW, natural gas is at the end of 2019 the third most important energy source for electricity behind lignite and wind power on land.

Figure 21:
Gross power production in Germany 1990 – 2018, by source (TWh)



Source: Clean Energy Wire.

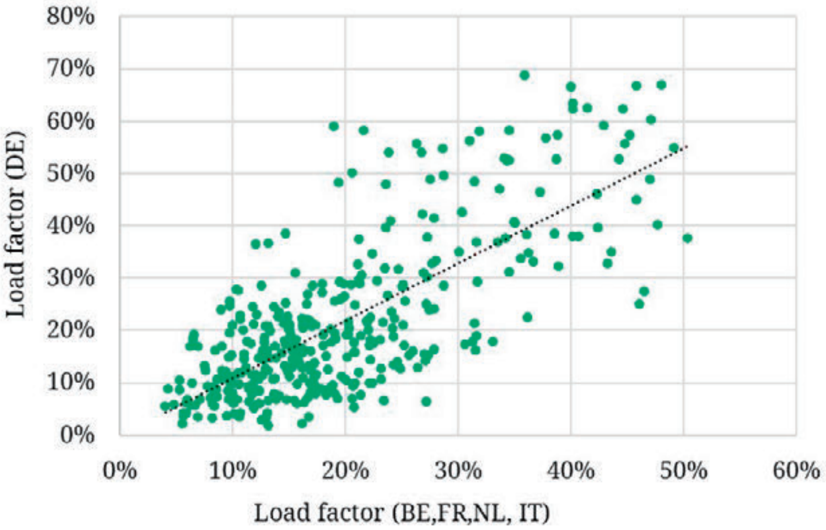
69. Historically, periods of low renewables have been met with an increased dispatch of gas and coal generation. As coal and nuclear generation falls away, and renewables grow quickly, Germany will need to rely increasingly on existing gas, new flexible capacity and imports to balance the system.

70. There is conventional wisdom that a way to support renewable energy integration is the achievement of a stronger integrated European market that increases cross-border energy trade and allows for additional energy flow exchanges. In the German case this may happen once Germany removes the internal grid constraints. Nevertheless, while this cross-border integration is of course necessary, it is also advisable to analyse the load-factors of neighbouring countries to see how interconnections could help. The Figure 22 plots the daily German onshore wind load-factors for the entire onshore wind fleet against the average wind load-factors in France, Italy, Belgium & the Netherlands, with each dot representing one day's average load-factor. As we can see, there is a strong correlation between Germany's wind load-factors and its neighbours.

71. Increased renewables in neighbouring countries will therefore further raise price volatility as similar wind conditions are likely to occur in neighbouring countries. In periods of low renewable output, market prices will surge to meet the high variable cost of peaking units. In periods of high renewable output, prices will plunge to low or negative levels to clear the market.

72. There are other technologies which will play an important role in shifting load from periods of high renewables to low, as interconnection alone cannot provide a solution. The future German strategy includes energy storage, sector integration and sector coupling by means of electric vehicles (EVs), electrification of heat and power to gas/hydrogen. Moreover, other technologies such as Demand-Side Response, energy efficiency, etc. are also envisaged

Figure 22:
Daily load-factors for German onshore wind fleet versus Belgium, France, Netherlands and Italy (year 2019)



Source: Timera Energy.

Europe – Solar Eclipses

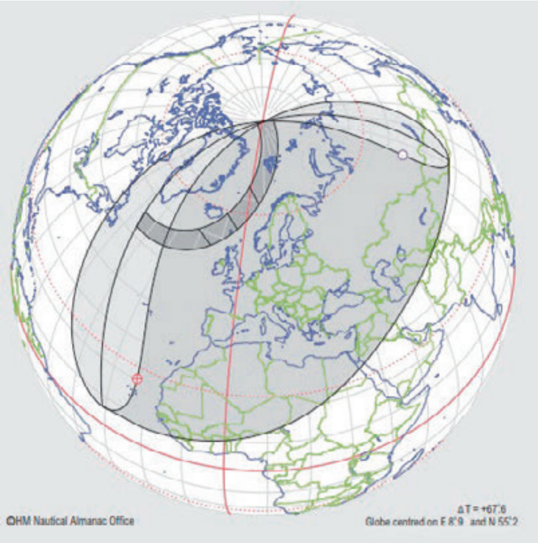
73. On 20 March 2015 a solar eclipse covered most of Europe. This phenomenon had relevant impact on the energy systems. At that time, the European Union had a solar power output of about 90 GW. The analysis in advance of the solar eclipse showed that the influence of the eclipse might potentially cause a reduction of the PV feed-in by more than 34 GW in case of clear sky conditions in Continental Europe. Finally, the dip was less than expected, with a 13 GW drop in Germany happening due to overcast skies. This was the first time that an eclipse had a significant impact on the power system, and the electricity sector took measures to mitigate the impact. The power gradient (change in power) was estimated to be 2 to 4 times higher than normal daily PV ramping. Places in Netherlands, Belgium and Denmark were 85.2 per cent obscured. Temperature decreased by 3 °C, and wind power decreased as winds were reduced by 0.7 m/s.

74. This situation could have posed serious challenges to the regulating capability of the interconnected power system in terms of available regulation capacity, regulation speed and geographical location of reserves. Beyond the lower PV generation during the eclipse, the most important expected challenge was the decrease of generation by 20 GW within 1 hour, and the increase of generation by almost 40 GW after the maximum impact of the eclipse.

75. Technical and operational arrangements were necessary to deal with this situation. The German grid operator TenneT GmbH brought on 8 GW of thermal generating capacity to compensate for the loss of solar power as the sun disappeared, doubling the usual amount. It also kept hydropower plants that can store energy on standby and coordinated its flows with neighbouring grid operators. Power prices in Germany's wholesale market surged then dipped for a short time as the first eclipse of the emerging solar age passed, briefly switching off thousands of panels that on the brightest days provide 40 percent of Germany's Power.

76. A solar eclipse, similar to that of 20 March 2015, will occur again in 2026. By then, the installed capacity of solar panels in Europe will have tripled. Solar Power Europe foresees that in 2021, the amount of installed PV capacity would add up to 170GW. In 2026 it would reach 250GW. At that point in time, and with a decreasing coal power fleet due to climate change policies, the flexibility provided by gas-fired power plants will be critical to maintain the energy system operation.

Figure 23:
Solar Eclipse trajectory 20 March 2015



Source: ENTSOE.

Spain

77. The Spanish market is a clear example of how gas-fired power plants can enable the integration of growing shares of renewable energy.

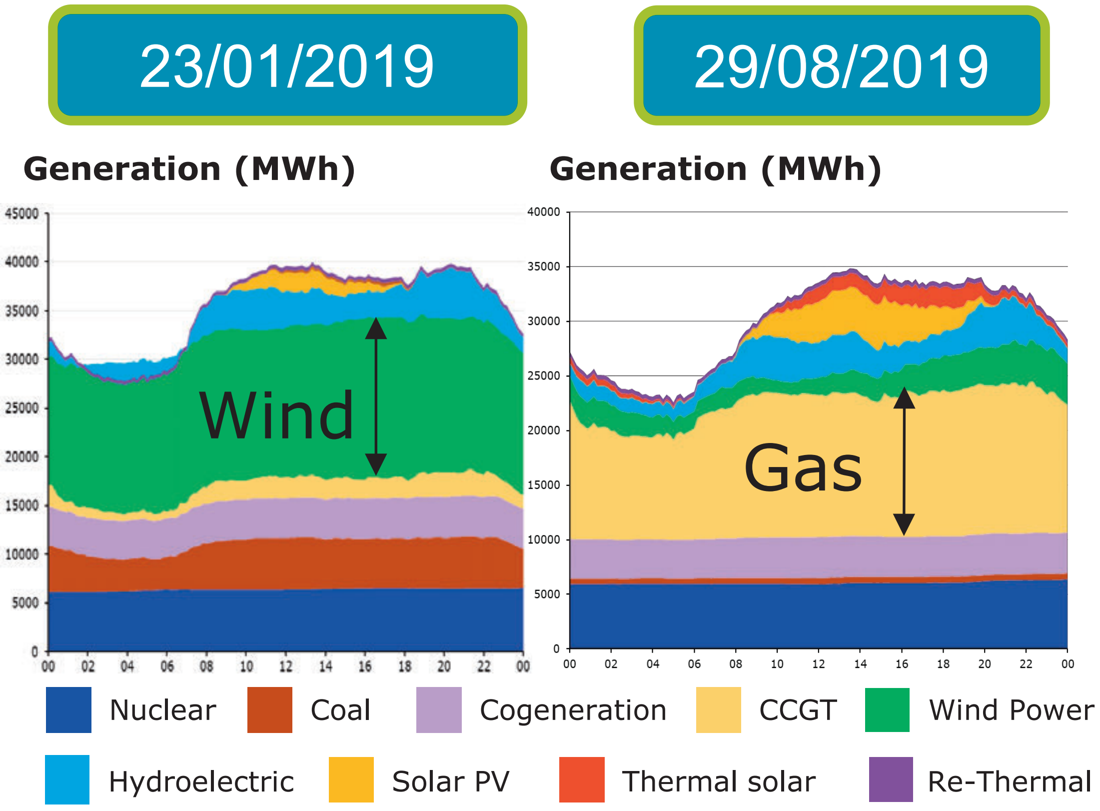
78. The flexibility of the energy system, provided mainly by the gas-fired power plants, combined with advanced forecasting and advanced unit commitment, has allowed VRE plants to frequently serve more than 60 per cent of the demand without posing reliability issues for the system.

79. The electricity TSO, Red Electrica de España (REE), established the first dedicated renewable energy power control centre (CECRE), which is responsible for forecasting, controlling, and scheduling renewable energy generation. Through the CECRE, REE receives the telemetry of 98.6per cent of the wind power generation installed in Spain every 12 seconds, of which 96per cent is controllable (with the ability to adapt its production to a given set-point within 15 minutes). The use of advanced forecasting techniques has led to very accurate predictions, even for day-ahead forecasts. Monitoring and controlling VRE generation in real time decreases the number and quantity of curtailments, maintaining the quality and security of the electricity supply at the same time that renewable energy integration is maximized.

80. The regulatory framework has also contributed to the implementation of advanced forecasting. As a condition of benefiting from the incentives scheme, VRE plants with capacities higher that 10 MW had to be connected to a centralized dispatching centre or establish their own predictions and execute the operator's orders in real time. Moreover, VRE (wind, PV, and hydro) generators which are under the regulated tariff scheme are requested to predict the amount of power to be produced one day in advance (one hour before the market closing time). Penalties for deviation from predictions are proportional to the deviations from real production, encouraging producers to achieve better predictions to increase revenues.

81. Solar forecasting has also been introduced in system operations. This helps the system operator to improve the aggregated forecast and minimize the amount of operational reserves that need to be committed for balancing and regulation.

Figure 24:
Power Generation Mix in two different days in Spain



Source: Enagas (based on data published by REE).

82. Flexibility to manage the variability and forecast errors has been provided by the CCGTs. Their role has been evolving in the last decade from primarily mid-merit operation to a much more flexible load following operating regime to successfully integrate high levels of VRE generation (see Figures 24 and 25). This illustrates the role that gas-fired generation, in combination with state-of-the-art forecasting, can play in providing flexibility.

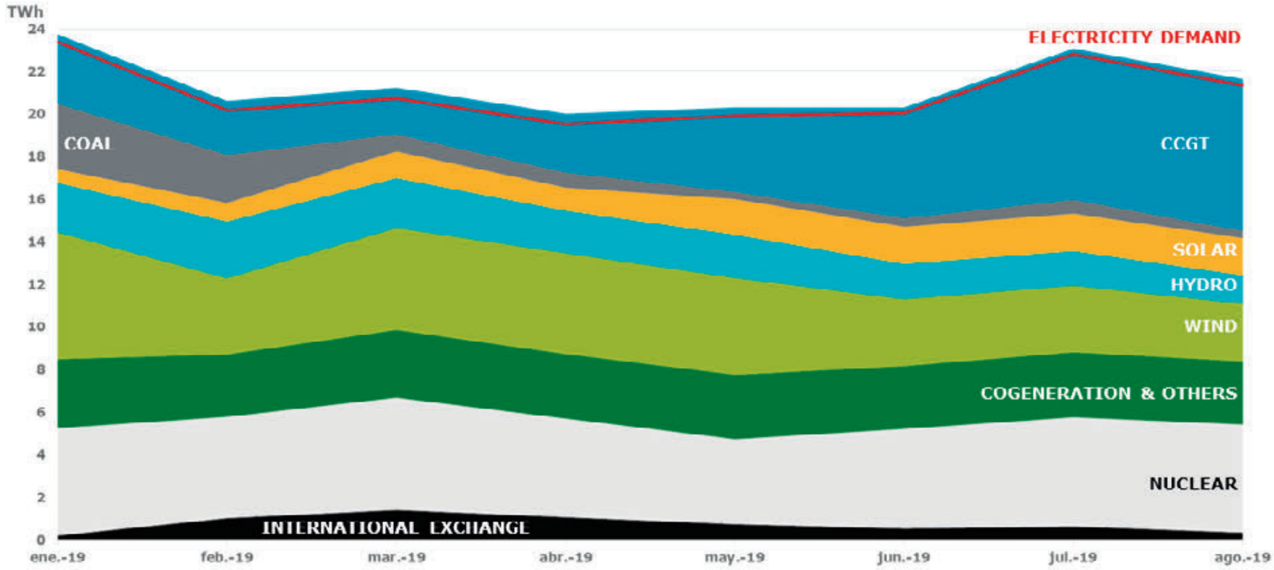
83. The Figure 24 above illustrates a comparison between two different days in 2019. On 23 January, very few CCGT units were operating while wind energy was supplying the largest part of the demand. In the second case, 29 August, the lack of sun and wind obliged to the operation of a large part of gas-fired power plants to cover the national demand.

84. These two days are evident proof of the gas and VRE interplay within the Spanish market. Gas provides the required flexibility during the year to enable the integration of VRE and keep lights on when sun is not shining and wind is not blowing. This conclusion is also underpinned by Figure 25 which shows the evolution of gas and VRE along the year, clearly evidencing the synergies and complementary roles of both technologies in meeting power demand.

85. It must be acknowledged that the flexibility provided by gas-fired plants is only possible if there is behind a robust gas infrastructure system capable of supplying the required gas, whenever and wherever is needed, in a flexible, effective and cost-efficient way.

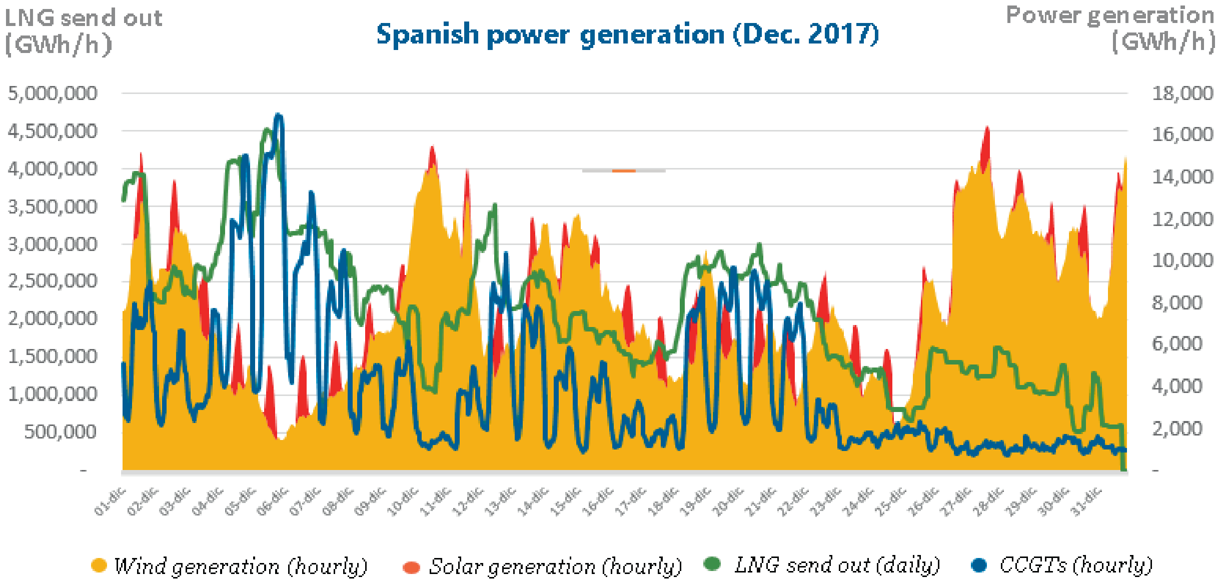
86. In this sense, the Spanish case also shows how the LNG regasification terminals have been providing a significant part of the required flexibility and have been adjusting their performance to the needs of the gas-fired power plants (see Figure 26).

Figure 25:
Evolution of the Power Generation Mix in Spain (year 2019)



Source: Enagás / REE.

Figure 26:
Power Generation in Spain produced by wind, solar and CCGTs versus LNG production (Dec. 2017)



Source: Enagás / REE.

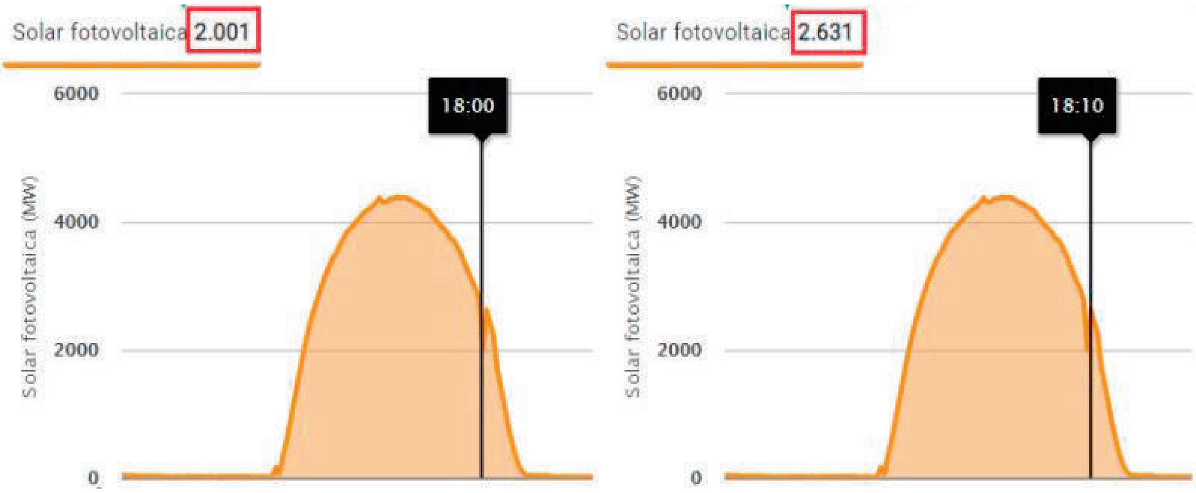
<u>What happens when a cloud passes a photovoltaic power plant in Spain?</u>

87. The Mula's solar power plant, the biggest in Spain has got an installed capacity nearing 500 MW. When a cloud passes over the solar PV plant, the plant might lose up to 400 MW of power generation capacity in 5 seconds. This capacity is equivalent to an average CCGT.

88. According to data provided by the Spanish electricity transmission system operator, REE, the Figure 27 shows significant fluctuations in power production from solar plants during a sunny day taking place within the range of a

few minutes. It is in these cases where flexible gas-based generation, together with a flexible and reliable gas infrastructure system, plays an essential role in ensuring system resilience and VRE integration.

Figure 27:
Power production (MWh) from solar power plants in Spain in two different moments of the same day



Source: REE.

Lessons learnt from the Spanish case

89. With the wide deployment of VRE in Spain, the electricity system had to learn how to provide this flexibility to successfully integrate fluctuating renewables. Based on the Spanish experience, some considerations can be drawn:

   a. Investments in technological solutions are needed to manage VRE.

   b. In a large geographical country like Spain, VRE integration challenge not only involves covering the power demand, but also dealing with a large power system, where production might substantially differ from one geographical extreme to another (e.g., north-south, west-east).

   c. The availability of hydraulic generation depends on the level of water at the reservoir.

   d. Solar Power production can be forecasted on a seasonal basis, but congestions at certain electricity nodes within the electricity transmission network have to be avoided.

   e. Wind generation can be forecasted on an annual basis and for the following day but with a certain level of uncertainty and fluctuations. Moreover, it is not possible to accurately predict the wind power production on a monthly basis.

   f. The power production with OCGT /CCGTs is predictable and it can very well compensate the VRE fluctuations thanks to:

      i. The well meshed gas and electricity networks, with a large number of CCGTs very well located across Iberia

      ii. The gas storage capacity provided by the underground gas storage facilities and the LNG regasification terminals.

      iii. LNG regasification terminals whose production can be flexibly and effectively adjusted to the flow requirements imposed by the gas-fired power plants

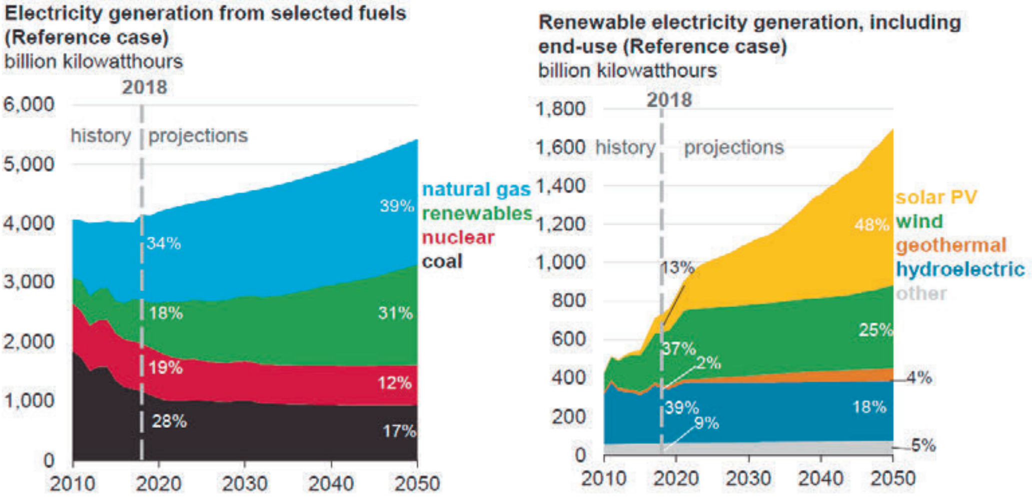
   g. The gas system provides reliable support to the electricity transmission and distribution network in these place with gas-fired (co)generation technology.

USA

90. The energy statistics are showing that, as much as wind and solar are increasing, natural gas is also increasing more. And gas will continue to grow faster than all other energy sources in the United States for some time.

91. Over the past fifteen years, coal has decreased from over 40 per cent to 28 per cent of the electricity generation and gas has increased from 17 per cent to about 35 per cent. As a result, greenhouse gas emissions in US dropped to a 25-year low two years ago, although they are now rising again with increased economic activity and an ever-increasing number of gas-guzzling Sport Utility Vehicle (SUVs). Natural gas is cheaper to build than any other generation source, and natural gas itself will be cheap for decades, so it is likely that gas will continue to be USA's top electricity producer and should reach around 40 per cent of US generation by mid-century.

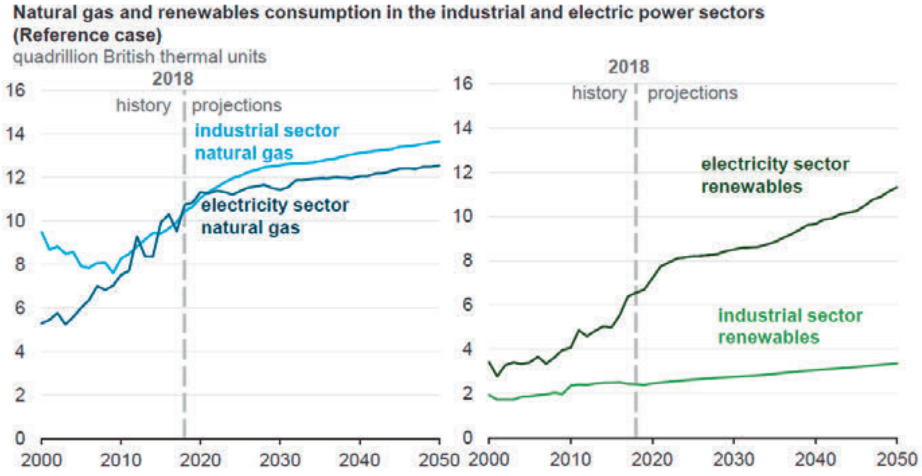
Figure 28:
Electricity generation from selected fuels and sources – projections to 2050



Source: EIA (2019).

92. The continuing decline in natural gas prices and increasing penetration of renewable electricity generation have resulted in lower wholesale electricity prices, changes in utilization rates, and operating losses for a large number of baseload coal and nuclear generators.

Figure 29:
Natural gas and renewables consumption in the US industrial and electric power sectors – projections to 2050



Source: EIA (2019).

93. According to the Annual Energy Outlook (EIA), the renewables generation increases more than 130 per cent through the end of the projection period (2050) in the Reference case, reaching nearly 31per cent of total generation mix by 2050. Increases in wind and solar generation lead the growth in renewables generation throughout the projection period across all cases, accounting for about 90per cent of total renewables growth in the Reference case.

94. Cheap natural gas, and social pressure to reduce carbon emissions, are giving gas-fired power plants and renewable energy resources a competitive advantage over traditional coal and nuclear generation. Energy storage continues to gain traction as costs decrease and technology evolves. The Figures 28 and 29 shows how electricity from VRE is expected to grow fast in the following decades. Regarding electricity produced out from natural gas, the projection to 2050 presents a clear growing trend. This trend reinforces the even stronger interrelationship between VRE and gas for the medium and long-term.

2.7 Smart Sectoral Integration and Power-to-Gas: Solutions to Integrate High Shares of VREs

95. The worldwide fight against climate change has intensified after the COP21. The energy transition in an on-going process and it is no more a matter of whether the energy system will become carbon neutral but rather when.

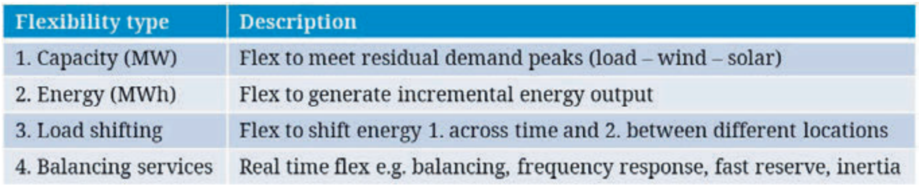
96. In this framework the energy sector should be largely decarbonized by 2050. However, the path towards this goal remains less clear as there are several technically possible pathways that could be taken. Regardless of the chosen pathway, the energy system should be undergoing a cost-efficient transition towards near full decarbonisation in 2050. A sensible assumption could be that, by the mid of this century, around 50per cent primary energy could be supplied by renewable electricity and the remaining 50per cent of the primary energy demand could be based on renewable, decarbonized, and low-carbon molecules, such as hydrogen, biomethane and other types of gaseous and liquid fuels.

97. To accomplish this energy transition, the power sector requires, among others, on one hand, decreasing the share of fossil fuels used for thermal generation, and, on the other, increasing system flexibility to continue integrating growing shares of VRE.

98. Analysis of the power market models show transformational shifts in flexibility requirements across 2020-2030. By 2030, and depending on the country, VRE could impose within-days swings between 50per cent-100per cent of power demand for those markets more advanced in VRE penetration. The occurrence of GW-scale swings may take place in the space of minutes as wind and solar conditions change.

99. Not all flexibility is created equal. Keeping the lights on will require ramping, storage, load shifting and balancing services at unprecedented scale. Table 2 summarizes the 4 different categories of flexibility required to support decarbonisation of the power sector.

Table 2:
Four types of flexibility required

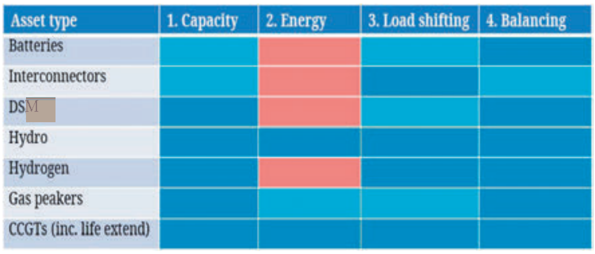


Flexibility type	Description
1. Capacity (MW)	Flex to meet residual demand peaks (load – wind – solar)
2. Energy (MWh)	Flex to generate incremental energy output
3. Load shifting	Flex to shift energy 1. across time and 2. between different locations
4. Balancing services	Real time flex e.g. balancing, frequency response, fast reserve, inertia

Source: Timera Energy.

100. No one single technology can meet these flexibility requirements. Table 2 shows a heat map view of the characteristics of different asset types in providing flexible capacity. Darker blue indicates a higher contribution to the 4 types of flex required. Red indicates a net negative energy contribution, i.e., the technology uses more energy than it generates.

Table 3:
Flex technology heat map



Source: Timera Energy.

101. The assessment made on Table 3 is based on the following assumptions:

    a. Batteries & DSM: These are two key sources of new low carbon flexibility, with a primary focus on system balancing and shifting load across intraday time windows. But both sources make a zero or net negative energy generation, as well as having practical duration limitations. This means other flexibility sources are needed, particularly to address sustained periods of energy deficit or surplus.

    b. Interconnectors: Interconnectors are important in allowing access to flexibility in neighbouring markets. Their primary role is shifting energy from lower to higher value locations, but as with batteries & DSM they do not create energy (consuming small amounts via line losses). They also have limited impact in correlated high/low solar & wind events across Europe.

    c. Hydro: Hydro scores highly on all flexibility metrics, however the scope for further hydro developments in Europe is limited by planning, geographical and cost constraints.

    d. Hydrogen: Hydrogen fired generation may provide clean and flexible back-up generation capacity, however the production of green hydrogen (via electrolysis) is a net drain on energy.

    e. Gas peakers & CCGT: That leaves gas-fired generation, which is very flexible, but has the obvious challenge of greenhouse emissions. Those emissions are relatively low for gas peakers (given their low load factors) and it will decline over time for CCGTs as load factors fall. Gas plant utilisation will be supported in the 2020s by the fact that nuclear & coal closures outpace renewables build. It is not easy to see a realistic alternative to gas, even under the most optimistic scenarios of storage, DSM & interconnector development. Gas plant load factors are set to decline in the 2030s as their role transitions towards providing backup flexibility. But according to different sources, it is difficult to construct a scenario where gas flexibility will not be required during at least the following 2-3 decades.

102. Moreover, with major decarbonisation efforts and the scaling up of renewable base generation, the widespread adoption of flexible energy storage continues to be identified as the key game changer for electricity systems.

103. Affordable and flexible storage systems are a critical missing link between variable renewable power and a 24/7 reliability for a net-zero carbon scenario. Beyond solving this salient challenge, energy storage is being increasingly considered to meet other needs such as relieving congestion or smoothing out the variations in power that occur independently of renewable-energy generation. However, as it can be observed in Figure 30, whilst there is plenty of visionary thinking, recent progress has focused on short-duration and battery-based energy storage for efficiency gains and ancillary services. There is limited progress in developing daily, weekly and even seasonal cost-effective solutions which are indispensable for a global reliance on variable renewable energy sources.

104. The electricity sector and many environmental NGOs are calling for an extensive electrification using mostly renewable electricity. Notwithstanding there are several major and unresolved technical issues, most notably the question of how and where to generate that much more renewable electricity, the long-distance transportation and the necessary (long term/seasonal) storage of electricity. Moreover, on top of the enormous difficulties to build new overhead power lines in multiple UNECE countries (e.g., Germany and others), the total system costs of a full electrification would put massive economic burdens on industry and consumers.

105. Regardless of the final level of electrification, sources of large-scale affordable flexibility will have to be found. Technical innovations, regulatory and market reforms, together with a combined use of a variety of flexibility sources are expected to tackle the VRE fluctuations.

106. In this context, in order to face a future with large amounts of VRE, the potential of gas and gas infrastructure should be fully exploited.

107. The gas infrastructure is one of the backbones of the UNECE energy system which serves to achieve the afore-mentioned goals via transporting, distributing, and storing vast amounts of energy (in gaseous form). Natural gas is currently playing an important role in the UNECE energy system, especially for heating, industrial use and power generation.

108. The obvious advantage of natural gas - besides the relatively low CO_2 emissions – is the clean combustion compared to other fossil fuels (SOx, NOx, micro-particulates emissions) which helps to improve air quality[18].

109. Additionally, there other positive aspects to be considered such as:

   a. the security of supply and quick flexibility provided by high peak capacities, storages and diverse supply routes

   b. the capacity to transport and store large amounts of energy (see Figure 31) in a very cost-efficient way[19] compared to electricity.

110. However, natural gas is often simply seen as a fossil fuel and thus contributing to global warming "in a similar way" as coal and oil.

Figure 30:
Overview of storage technologies

	ELECTRICAL		MECHANICAL			ELECTROMECHANICAL			CHEMICAL	THERMAL
	Supercapacitors	**SMES**	**PHS**	**CAES**	**Flywheels**	**Sodium Sulfur**	**Lithium Ion**	**Redox Flow**	**Hydrogen**	**Molten Salt**
Maturity	Developing	Developing	Mature	Mature	Early commercialised	Commercialised	Commercialised	Early commercialised	Demonstration	Mature
Efficiency	90-95%	95-98%	75-85%	70-89%	93-95%	80-90%	85-95%	60-85%	35-55%	80-90%
Response Time	ms	<100 ms	sec-mins	mins	ms-secs	ms	ms-secs	ms	secs	mins
Lifetime, Years	20+	20+	40-60	20-40	15+	10-15	5-15	5-10	5-30 years	30 years
Storage duration*	min - hr	ms - min	4 - 20hr	4 - 30hr	s - hr	min - 8hr	<8hr	<10hr	up to months	hr
Discharge time	ms - 60 min	ms - 8 s	1 - 24 hs+	1 - 24 hs+	ms - 15 min	s - hr	min - hr	s - hr	1 - 24 hs+	min - hr
Environmental impact	None	Moderate	Large	Large	Almost none	Moderate	Moderate	Moderate	Dependent of H2 production method	Moderate
Possible applications by technologies										
RES integration		✓			✓	✓	✓	✓	✓	

Legend: H2 = Hydrogen, RES = Renewable energy source, RE = Renewable energy, SMES = Superconducting magnetic energy storage, PHS = Pumped hydroelectric storage, CAES = Compressed-air energy storage.
Source: World Energy Council – "Five Steps to Energy Storage" (2019).

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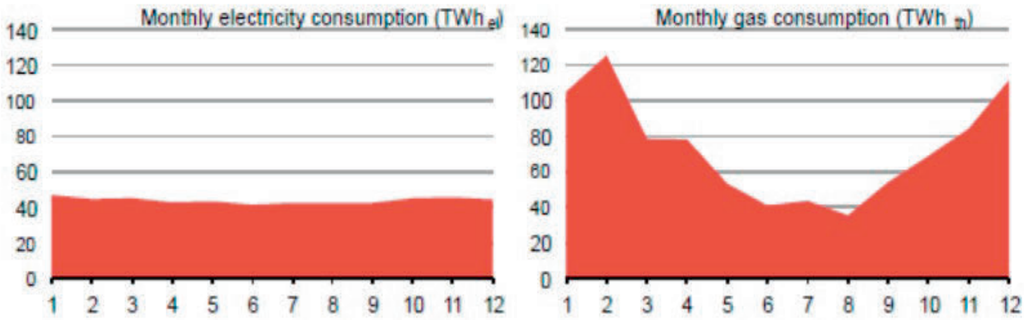
[18] An example of how natural gas can help to improve air quality is Beijing. The Chinese capital has for many years suffered from serious air pollution. Primary sources of pollutants included exhaust emission from Beijing's more than five million motor vehicles, coal burning in neighboring regions, dust storms from the north and local construction dust. A particularly severe smog engulfed the city for weeks in early 2013, elevating public awareness to unprecedented levels and prompting the government to roll out emergency measures. This pollution crisis was dubbed as "Airpocalypse". In 2013 over 50 per cent of the days were ranked as unhealthy or worse for air quality. In 2014, as the city recorded PM concentrations of 85.9 µg/m3 (almost 9 times the WHO limit), the National Government announced a "war on smog" and intensified anti-pollution policies. With this in mind Beijing adopted early targets in the government's fight against pollution. In 2015 the city implemented an aggressive coal to gas substitution policy. In 2017, PM concentrations had dropped to 58 µg/m3 – a 54 per cent decrease vs. 2016. That year over 4,450 coal-fired boilers were shut down, and 900,000 households being shifted from coal to gas since 2013.Natural gas was a decisive solution for Beijing's Government in achieving their air quality targets.

[19] For a EU citizen gas prices (€/MWh) are up to 4 times cheaper than electricity (source: GasNaturally)

Figure 31:
Comparison of the annual electricity and gas consumption in Germany



Source: Frontier Economics (2017).

111. To make further progress in the decarbonisation, the destiny of gas infrastructure needs to be detached from the natural gas' future, since gas grids can be used to transport different gases, not only natural gas but also renewable, decarbonized and low carbon gases such as hydrogen and biomethane among others.

112. UNECE Member States seek to develop flexible energy systems that would allow decarbonisation of the power generation. There is potential for an increasing interaction between renewable energy and different types of gases. In the long-term renewable, decarbonized and low-carbon gases could progressively displace natural gas leading to a carbon-neutral gas infrastructure system ready to underpin the massive penetration of VRE into the UNECE Energy Systems.

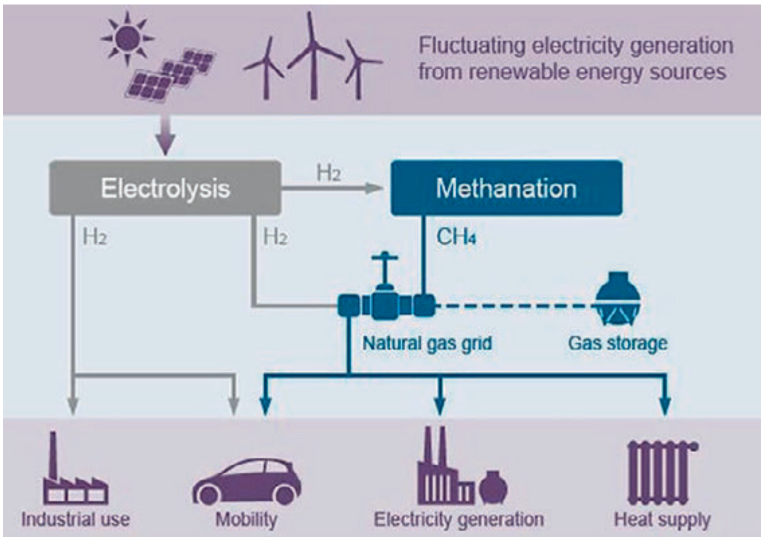
113. "Sectoral Integration" is therefore the key strategy to promote economy-wide decarbonisation and broader macro-economic efficiency. It is defined as the intelligent linkage between the power sector and other energy-consuming sectors (e.g., industry, mobility and buildings), using the interplay between the electricity and gas networks, supported by advanced sensing, communication and control, and digitalisation, among other technologies. The flexibility provided by a hybrid energy system, based on both gas and electricity networks, is the key to integrate very large shares of VRE, preserving the energy system efficiency and ensuring lower system operational costs for the society.

114. Figure 32 is one of the multiple ways to represent Power-to-Gas whilst Figure 33 is a way to represent a hybrid energy system when talking about sectoral integration and sector coupling. Compositions with additional elements and different graphic configurations are possible.

115. The Hybrid Energy System is possible thanks to different technologies connecting both grids, such as Gas-to-Power and Power-to-Gas (P2G). P2G technologies will be very much needed when renewable energy will account for higher share of power generation mix. Production of hydrogen via a P2G plant allows for its injection and storage in large quantities either into the gas infrastructure system or within a dedicated hydrogen storage system. The hydrogen produced by P2G can be stored there for long time, even on a seasonal manner, before being reutilized for power generation or alternative uses.

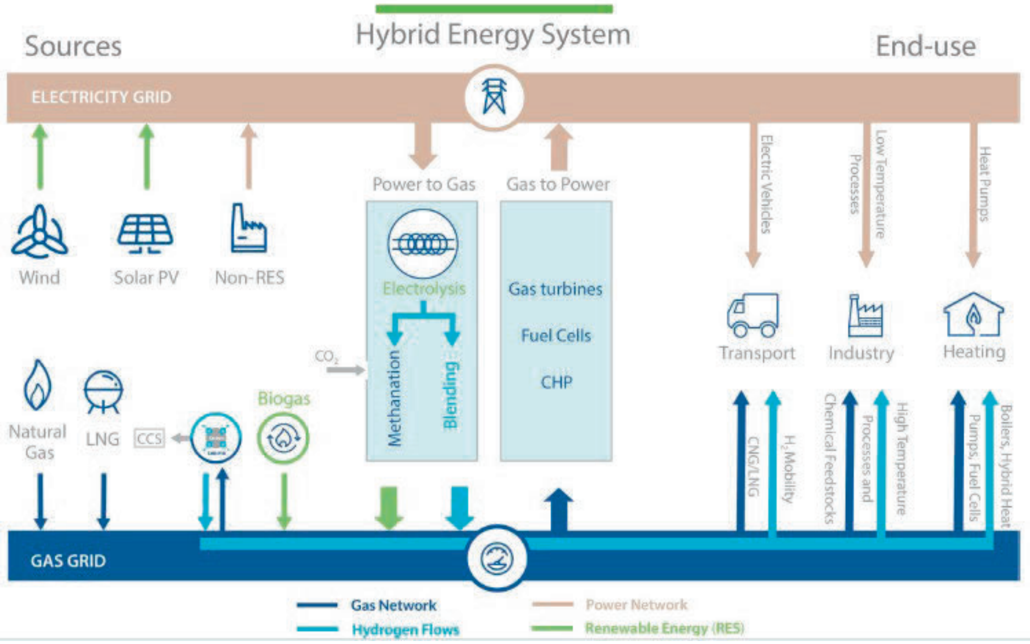
116. Hydrogen produced through VRE, together with biomethane/biogas, could be used for power generation progressively replacing natural gas power generation and enabling a decarbonized industrial-scale source of flexibility to integrate high VRE shares. Beyond its combustion to produce electricity, hydrogen can be sold as feedstock for heavy industries (e.g., refineries, chemical industry, etc.), as fuel for transport or combined with other elements to produce synthetic methane and/or other e-fuels (methanol, ammonia, etc.). Hydrogen and other decarbonized gases can be used, either directly or as a part of e-fuels, in sectors where electrification is difficult to achieve such as aircraft, ships, heavy road transportation, etc. Hydrogen is therefore the energy carrier which enables sectoral integration and offers an opportunity to introduce renewable energy in all sectors, including those difficult to electrify, by using hydrogen either as a chemical component, as fuel or as an industrial feedstock.

Figure 32:
Power to Gas technology



Source: Infinity FCH, 2019.

Figure 33:
Hybrid Energy System – Enabling VRE through Sectoral Integration/Sector Coupling

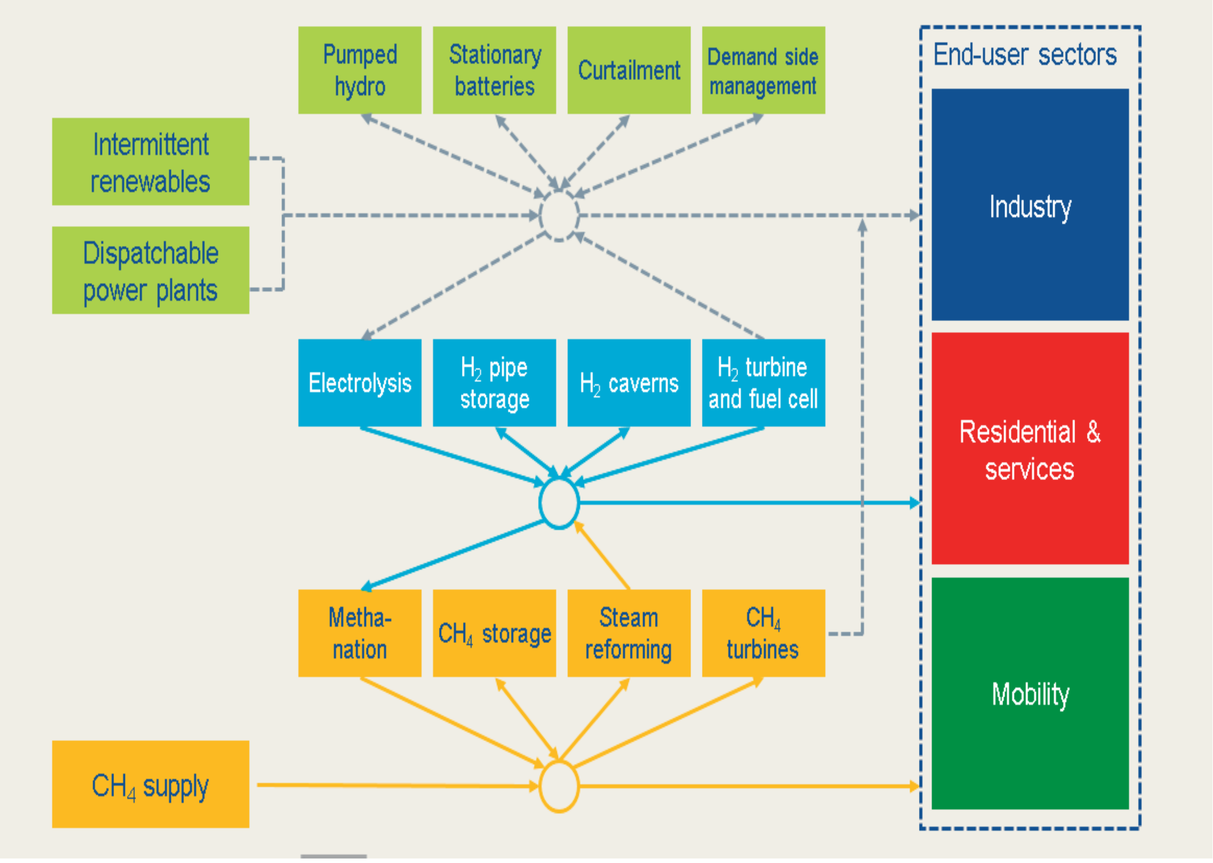


Source: ENTSOG.

117. The use of P2G technology and hydrogen injection into the gas grids should comply with the technical specifications. The natural gas grids can accept certain level of hydrogen concentration. This maximum concentration varies from one country to another. Depending on the amount of hydrogen to be injected, the gas grids might require investments in refurbishment and adaptation for the use of admixtures based in methane and hydrogen. When the hydrogen volumes are big enough, the use of dedicated hydrogen lines can be an option. These hydrogen lines can be newly built or could come from the conversion of natural gas grids into pure hydrogen pipelines. The use of different networks to enable the sectoral integration is represented in Figure 34.

118. The Pan-European trade or the different gases (renewable, decarbonized and low carbon) does not only require a well-interconnected and integrated market able to move molecules across borders, but also the development of a certificate and guarantees of origin (GOs) system to document and trade the "climate value" from production and/or import to consumption and across borders. It should be also possible to trade and track GOs/certificates across different energy carriers, e.g. when converting green electrons in green molecules via Power-to-Gas, so that full interoperability and exchangibiliy between GOs/certificats for electricity and the different gases should be ensured. The architecutre required to underpin a GOs/certificate schemes should be provided by the establishment of national registers, as well as with the existence of a supranational system which allows the trade of GOs/certificates between these registers.

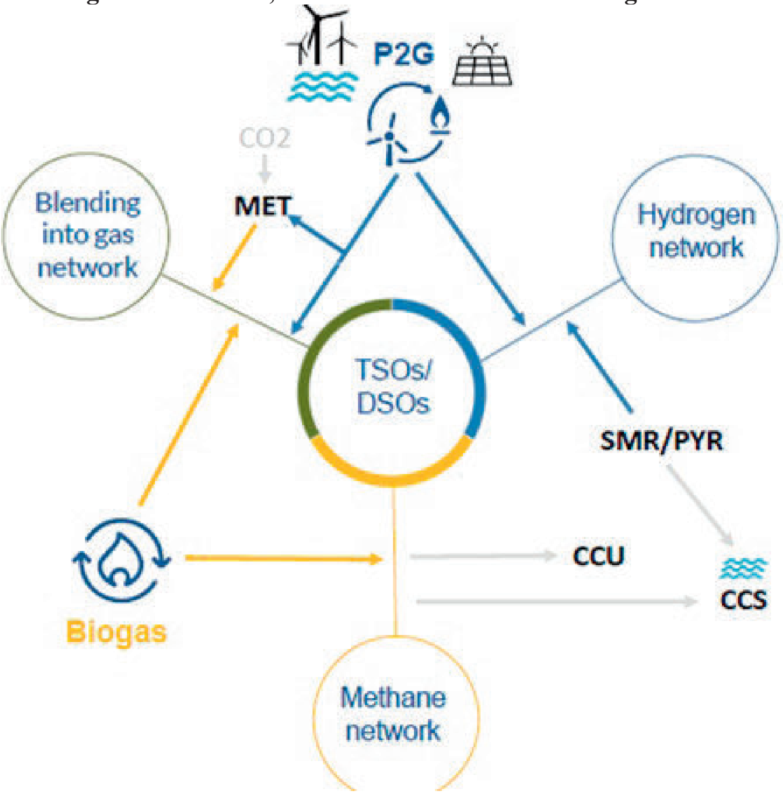
Figure 34:
Impact of the Use of biomethane and hydrogen on trans- European Infrastructure



Source: Trinomics, LBST (2019).

119. Through hydrogen, the existing gas infrastructure system can enable the energy system integration of very large shares of VRE, and the transition to a low emission economy as it can deliver high storage and transmission capacity in an efficient and cost-effective way. In this sense, gas infrastructure positions itself as the backbone of the future energy system. From an energy perspective, gas and electricity grids will be complementary assets.

Figure 35:
Pathways to integrate renewable, low carbon and decarbonized gases



Legend:
MET = Methanisation; P2G = Power to Gas; SMR = Steam Methane Reforming, PYR = Pyrolisis; CCS = Carbon Capture and Storage; CCU = Carbon Capture and Utilisation

Source: ENTSOG.

Flexibility options in a VRE world: costs and challenges

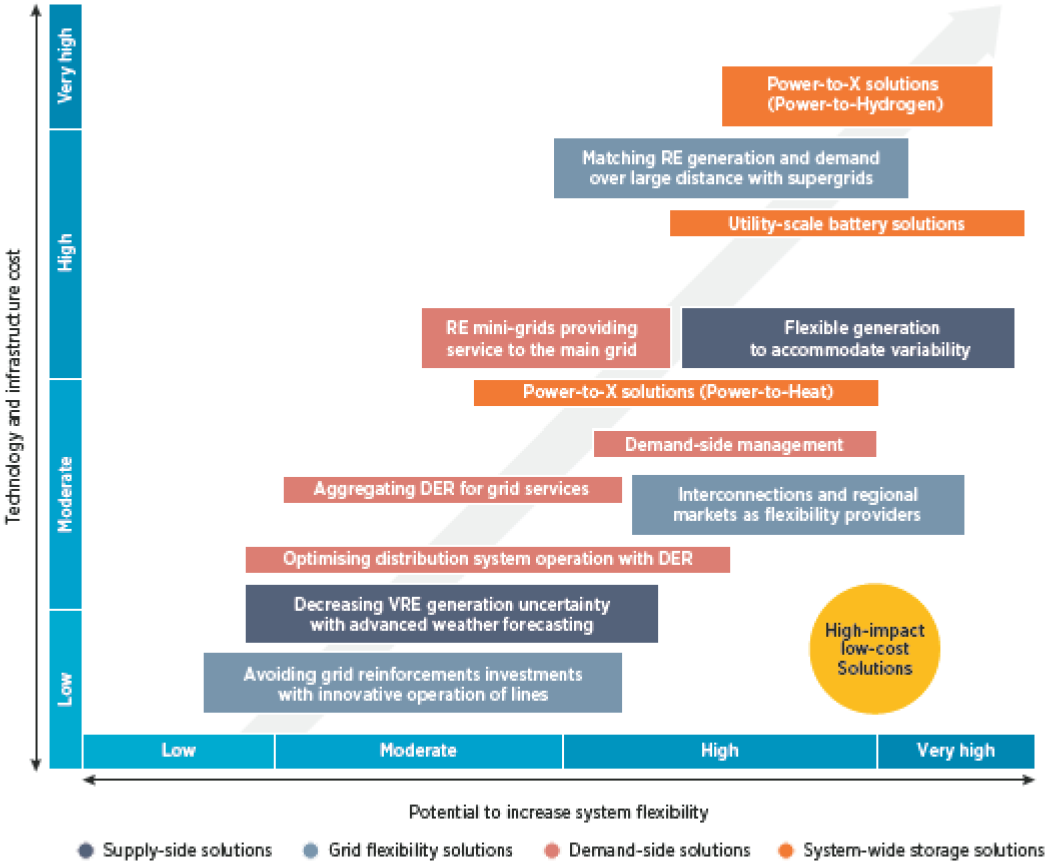
120. Figure 36 shows a high correlation between the technology and infrastructure costs associated to each solution and their potential impact to increase system flexibility. Large-scale batteries, super grids and the electrolyser for power-to-hydrogen applications are costly technologies and are part of solutions with high and very-high flexibility impact. However, many other solutions offer significant flexibility to unlock at lower costs. Each system needs to assess the level of flexibility needed and the synergies that can be created within its own context.

121. Importantly, potential synergies exist among the solutions, which would result in lower investments when implementing them together. For example, investments in digital technologies to enable distributed energy resources to provide services to the grid would help at the same time for demand-side management purposes. Moreover, an important variable in this assessment is given by the system context and set-up. For example, if the system is well interconnected, better regulation and operation of the interconnections would enable regional markets with no significant investment in infrastructure. However, if interconnections are not in place, the costs could significantly increase. The same applies when a system has already in its capacity mix flexible power plants, such as large hydro reservoirs or flexible gas-fired plants: it is needed to harness their full flexibility potential. Otherwise, more costly options would be needed.

122. Apart from costs, there are other elements to be considered in relation with the potential flexibility unlocked by the various energy solutions. Regulatory changes required are an important aspect considered, with a lot of weight in some cases such as the utility-scale battery to accommodate variable generation. In this context, regulation and market design are important to send the right incentives for flexible operation of the energy resources. On top of regulatory changes, another important aspect that makes the solution more challenging to implement is the changing roles and responsibilities of actors involved. For example, power-to-gas plants involve the development of a new

framework. For integration of power-to-gas facilities and allowing them to provide services to the system and the grid, changes in the role of the grid system operators, in gas and electricity, are required so that investment can be realized. Changing the roles of actors is a significant challenge, as the right incentives and business models are needed to justify the shift. Moreover, a sound regulatory framework has to be put in place to facilitate the investment in P2G plants and their operation.

Figure 36:
Solutions' flexibility potential versus technology costs needed



Source: IRENA.

3. Conclusions and Recommendations

3.1 Conclusions on which the Recommendations (3.2.) are based

123. The strong business case for VRE technologies such as wind and solar PV has positioned these technologies at the core of the energy transition.

124. There is ample evidence that VRE and fast-reacting generation technologies, such as natural gas, appear as highly complementary and that they should be jointly installed to meet the goals of cutting emissions and ensuring a stable and resilient power supply.

125. Gas-fired power generation has enabled VRE diffusion by providing reliable and dispatchable capacity to hedge against variability of renewable supply.

126. The flexibility of the overall power system will need to be increased as the share of VRE reaches higher levels.

127. Innovations being trialled in front-running countries show that power systems can be operated with very high shares of VRE in a secure and economical way.

128. Flexibility can be provided through a number of technological options; the least-cost options available to individual grids depend on the overall flexibility of the grid because of the generation mix (including the renewable energy penetration), regulatory structure, presence or absence of markets, operational practices, level of interconnectivity and institutional structures. A better understanding of the least-cost mix of generation sources is needed for identifying and evaluating the available solutions to deal with higher levels of wind and solar energy. Certain generation technologies are inherently more flexible than others; gas-fired generation is the main option that provides large amount of cost-efficient flexibility among all the available of technologies.

129. Sector coupling and Sectoral Integration can offer important added value in the decarbonisation process of the EU energy system, by contributing to the increasing flexibility needs and to the reliability of the energy system, and by reducing the global costs of the energy transition.

130. The role of new gases will be crucial in integrating VRE while advancing in the decarbonisation process. The renewable, low-carbon and decarbonized gases will enable the decarbonisation of difficult-to-electrify sectors.

3.2 General Recommendations from the GEG and GERE to the ECE member States, energy industry, and other stakeholders

131. In developing these recommendations, the Group of Experts on Gas worked under the auspices of the Committee on Sustainable Energy, in close collaboration with the Group of Experts on Renewable Energy through a joint task force co-chaired by representatives of the two groups. The Group of Experts on Cleaner Electricity Systems also provided significant contribution.

132. The recommendations outlined below are based on the belief that a successful transition to an affordable and clean energy system of the future will require that both traditional (in this case natural gas) and emerging (renewable energy) sectors fulfil their decarbonisation potential. The recommendations take a wider perspective on how gas could improve the energy efficiency of the energy system. They highlight the comparative advantages of gas in terms of flexibility and efficiency and identify its optimal combination with renewable energy, from the perspective of enhancing energy efficiency and decreasing emissions and energy industry's carbon footprint.

a. **Recognize the value of the flexibility provided by gas-fired power plants:** In some countries with low demand growth, the shift to high shares of VRE has led to a considerable reduction in the utilization of conventional power capacity. When VRE plants are generating electricity, conventional plants (mostly gas-fired because of their flexibility) are forced to reduce output and move into a load-following mode. In some countries, the loss of revenues for gas-fired power plants has led to write-downs and, ultimately, to the decommissioning of some plants, as well as lack of appetite for new investment. This negative impact on existing gas-fired generation has potential implications for longer term adequacy and stability of the power grid as a consequence of the reduced investment in dispatchable and flexible plants. Solutions to remedy this situation should be proposed and could be applied by authorities in countries at the beginning of a planned VRE scale up. The underlying concept is that certain services—such as firm capacity and flexibility—are essential in a system with high VRE penetration, and the value of these services should be recognized and compensated. The value of flexibility in the system should be recognized through policy and regulation, and remuneration mechanisms for flexible capacity. For the most part, flexibility requirements should be technology agnostic in the absence of a strong reason to use a specific technology. The close link between scale-up of VRE and natural gas-fired power generation in many countries may lead to additional gas supply flexibility requirements. Policy makers, planners, and system operators must coordinate closely to achieve security of gas and electricity supplies.

b. **Take into account the impact of variability from VRE on natural gas demand:** the variability in gas-fired power generation associated with an increasing share of VRE can have implications on the gas demand and on the gas infrastructure system. The close link between a scale up of VRE and the use of gas-fired power generation to provide power system flexibility may imply the need for additional flexibility on the gas supply side. Policy makers, planners, and system operators in the electricity and gas sectors need to consider the impact on the natural gas sector of high levels of VRE, and coordinate closely on planning, infrastructure investments, and operating rules, to achieve security of gas and electricity supplies.

c. **Get ready in advance for short-term imbalances:** A comprehensive approach to planning can help to minimize VRE integration costs for the power system. The growing share of VRE must be taken in account in system planning to make sure that development plans and specifications for both VRE and flexible conventional generation are aimed at achieving the least cost for the overall power system functioning. The performance of a power system is modelled at timescales, ranging from years to fractions of a second, and across spatial regions, from a local area to the whole system. Some of the potential issues associated with VRE variability and limited predictability occur at timescales that are typically assessed in short-term simulations.

d. **Be flexible in the planning process:** Planning for flexibility is a complex multi-step process that needs to account for a variety of factors that, together, form a complex mathematical problem that can only be solved using appropriate tools. Assessment of current flexibility is key as it creates the foundations for a least-cost, long-term pathway for a flexible power system that is ready to incorporate significant shares of VRE.

e. **Take advantage of the existing gas flexibility:** Countries should anticipate future power system needs. Ensuring cost-effective integration of VRE at large scale requires balancing present needs (a focus on deployment of renewable generation technologies) with future needs (a focus on integrating high shares of VRE). Difficult trade-offs exist between quick wins and long-term strategies. In targeting high levels of renewable deployment and integration, policy makers should not focus on quick wins alone. They need to look ahead to a time when renewable energy deployment is already ubiquitous and design the markets and systems around this future. Unlocking existing flexibility provided by gas-fired plants is the first action to be taken; the restructuring of markets and operations is key. Regulation can be a barrier and requires attention.

f. **Widen the concept of "Renewable Energy":** this requires a change of mind-set. The "renewable energy" concept should no longer be commonly identified with variable renewable electricity (basically solar and wind) but it should be enlarged to commonly cover both electric and non-electric renewable energy (such as biomethane and hydrogen). This is more importantly now that these renewable gases will be expanding an occupying a significant place in the future energy mix.

g. **Implement an adequate regulatory framework for VRE integration:** Finding the optimal VRE integration approach requires designing the regulatory interventions in order to minimize overall system costs subject to meeting performance targets, rather than minimizing the costs of VRE generation alone.

h. **Set up a policy and regulatory framework to enable a Hybrid Energy System:** Ensure a strong cooperation between gas and electricity grid operators to increase the visibility of the new flexibility resources that could provide services to the system, including power-to-gas. Further progress towards integrated planning of gas and electricity networks would be advisable. Some degree of regulatory alignment between gas and electricity would be also appropriate. When planning new large energy infrastructures (gas and electricity) they should be future-proof and consider interlinkages between gas and electricity.

i. **Promote Sectoral Integration:** couple the electricity, gas and end-use sectors. Create synergies between renewable power supply, the electricity grid, the gas grid, the electric mobility, heating and cooling, intensive industry, etc. Valuable synergies exist between these different sectors that must be harnessed with the aim of wider societal changes and lower costs while reducing emissions. Make further progress towards integrated planning and operation of different parts of the energy system.

j. **Foster Research, Development and Innovation** since they are needed to develop the existing technologies and facilitate pilot projects. The concept of "regulatory sandbox" could be applied to support scalability. "Regulatory sandboxes" will allow actors to experiment and test innovations without being restricted by the regulatory environment. Innovation needs to engage different actors from both the public and private sectors and across developed and developing countries. Knowledge and experience should be shared more widely. There is ample opportunity to learn more from other sectors and from different players. Interplay with industrial segments that are not considered part of the energy sector could bring great opportunities to harness synergies

k. **Establish principles for how to transport new gases (hydrogen, biomethane and others) whilst maintaining a non-fragmented market where all gases can be traded:** it will be necessary to set the right regulatory framework which allows for construction of new hydrogen pipelines, the conversion of existing gas pipelines into pure hydrogen pipelines, the injection of hydrogen (up to certain levels), biomethane and other new gases into the existing natural gas pipelines, and the integration of existing hydrogen pipelines into the gas system to avoid fragmentation in the new gases market.

l. **Clarify market access and grid access rules** for renewable, decarbonized and low carbon gases to the gas grid, as well as technical rules for their injection and blending with natural gas. Set up the national legislation and technical rules to facilitate the connection of new gases plants (e.g. biomethane, P2G) to the gas grid

m. **Implement standardized GOs/certificate frameworks across the UNECE region for renewable, decarbonized and low-carbon gases**. Ensure the transferability of GO/Certificates from one energy carrier to another (molecules and electrons). Make GO/Certificate framework for gas compatible with the existing regulations in every country.

n. **Support the development of a hydrogen market** which will be needed to ensure sufficient cost-reductions for hydrogen to play a significant role in the future energy system.

o. **Manage gas quality in a proper way:** with the penetration of new gases, a coordinated approach for managing the changes and possibly fluctuating gas compositions would be appropriate. Measures need to be adopted to avoid market fragmentation and technical barriers. Technical and regulatory coordination is necessary to facilitate cross-border gas. Precise and quick exchange of gas quality data will be crucial – applicable for guarantees of origin and certificates for the various types of gases, operating the gas systems, providing information to end-user appliances as well as for ensuring fair and transparent billing processes. In

p. **Enable synthetic methane to be classified as a renewable energy**. However, guidance is needed to avoid double counting of CO_2 reduction between the provider and the user of CO_2.

q. **Introduce a "new gases" terminology:** introduce the terms renewable, decarbonized and low-carbon gases in legal texts and include them as part of the solutions to achieve the Climate and Energy goals. See Figure 37 for more details.

r. **Deploy a digitalization environment:** managing properly this element is an essential task to achieve the accomplishment of a Hybrid Energy System (gas and electricity)

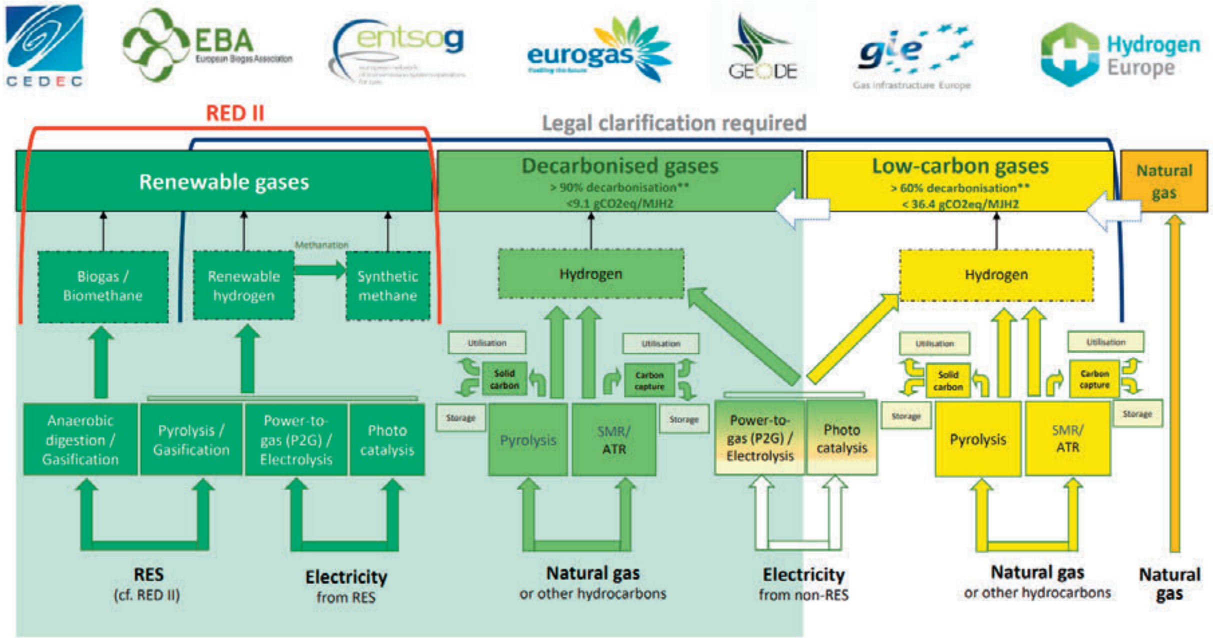
s. **Share knowledge and experiences across the UNECE region**: Countries beginning to deploy VRE should implement well-established best practices to avoid integration challenges, especially when moving beyond VRE specific shares (> 10per cent) of annual VRE generation.

A. Glossary and Definitions

1. BESS: Battery Energy Storage Systems
2. CCGT: Combines Cycle Gas Turbines
3. CCS: Carbon Capture and Storage
4. CECRE: Renewable Energy Power Control Centre in Spain managed by the electricity TSO
5. DER: Distributed Energy Resources
6. DLR: Dynamic Line Rating refers to the activity of dynamically adjusting current capacity of transmission lines based on environmental conditions such as local temperature, solar irradiation and wind speed and direction. As a general illustration, line capacities tend to be higher under low-temperature environments and decrease as temperature increases. It opposes static line rating in which the capacity to transmit energy is based on average-static environmental conditions and remains flat irrespective of current weather conditions. This approach is largely considered when setting line parameters.
7. DSM: Demand Side Management
8. EIA: US Energy Information Agency
9. ETS: Emission Trading Scheme for CO_2
10. EV: Electric Vehicle
11. GEG: Group of Experts on Gas within UNECE
12. GERE: Group of Experts on Renewable Energy
13. GHG: Green House Gas Emissions
14. GOs: Guarantees of Origin

15. IEA: International Energy Agency
16. LCA: life-cycle analysis of GHG emissions
17. LNG: Liquefied Natural Gas
18. NDC: Nationally Determined Contributions. NDC is also a Scenario used in the UNECE Pathways for Sustainable Energy
19. New gases: for the purpose of this report this concept cover renewable, decarbonized, and low-carbon gases
    a. Renewable gases: gases produced by using renewable energy (e.g., hydrogen through power-to-gas) or by using biomass. See Figure 37 for additional information.
    b. Decarbonized gases: gases produced through different technologies with very low carbon emissions. See Figure 37 for additional information.
    c. Low-carbon gases: gases produced through different technologies with low carbon emissions. See Figure 37 for additional information.

Figure 37:
New Gases Terminology proposed by the New Gases Network to the EU Madrid Forum on Gas Regulation (2019)



Disclaimer: (1) this overview is based on existing processes and known technologies and evidently does not preclude any other existing process or new technological developments, (2) the GHG reduction is calculated on the BAT 91 gCO2/MJH_2 derived from CertifHy and could be replaced by a comparable threshold pending confirmation of the methodological basis for CertifHy.
Source: New Gases Network (2019).

20. OCGT: Open Cycle Gas Turbine
21. P2C: Paris Agreement to 2º C Scenario used in the UNECE Pathways for Sustainable Energy
22. PSH: Pumped Storage Hydropower
23. P2G: Power to Gas
24. PV: Solar Photovoltaic
25. REF: Reference Scenario used in the UNECE Pathways for Sustainable Energy
26. Renewable Energy: in the short-term is understood as renewable electricity produced out of wind and sun. In the medium and long-term, the concept of Renewable Energy is extended to cover, not only solar and wind electricity, but also non-electric renewable energy, mainly renewable gases, such as hydrogen and biomethane among others.

Nonetheless, liquid biofuels are not considered under the concept of Renewable Energy for the purpose of this document.

27. SUV: Sport Utility Vehicle is a powerful vehicle with four-wheel drive that can be driven over rough ground
28. UPSE: UNECE Pathways for Sustainable Energy
29. VRE: variable renewable energy sources in the power sector produced with solar and wind.

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Carbon neutrality through synergies between gas and renewable energy

The United Nations Economic Commission for Europe's (ECE) Group of Experts on Gas teamed with the Group of Experts on Renewable Energy to identify and explore synergies between variable renewable energy (VRE) sources and natural gas. These synergies could provide the required affordably and flexibility needed to integrate an ever-increasing share of VRE in the energy mix.

This publication distinguishes two phases. The first phase, which focuses on the short term, shows how to use flexible, cost-competitive, and agile natural gas-fired generation as an enabler of VRE integration.

The second phase, which spans over the medium and long-term, enlarges the scope of the renewable energy concept to cover not only renewable electricity, but also renewable gases. The second phase is based on the hybrid energy system concept which envisages the use of new gases (renewable, decarbonised, and low carbon), together with the sectoral integration concept, as drivers to advance VRE penetration and thus reduce greenhouse gas emissions.

This publication provides several recommendations to ECE member States in developing coherent policy and regulatory frameworks for renewable energy – including renewable gases – across the ECE region.

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