# Leading the way to net-zero in Europe

## Accelerating the energy transition with the combination of renewables and gas power

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# Foreword

*Addressing climate change is an urgent global priority and one that we think we can do a better job of accelerating progress on—starting now—not decades from now. We believe there are critical and meaningful roles for both gas power and renewable sources of energy to play. Gas power is already advancing global progress with coal-to-gas switching while continuing to develop multiple pathways for low-to-zero carbon gas technologies in the future. Europe is leading the way towards a sustainable and more resilient economy, and we believe the power sector, supported by a clear, predictable and enabling policy framework, can play a key role in Europe's decarbonisation.*

**SCOTT STRAZIK** CEO, GE GAS POWER

*By using gas power and renewables alongside each other, Europe can deliver the quickest and deepest emission reduction and achieve its objective of climate neutrality by 2050 while producing the lowest possible cumulative emissions over the transition period.*

# Executive Summary

**Europe has set the objective to reach net-zero greenhouse gas (GHG) emissions by 2050.[I]**

While immensely challenging, this objective clarifies the transformational effort required to meet the objectives of the Paris Agreement and tackle climate change. While there is no single path to 2050, and approaches will vary across countries, meeting it will require flexibility and the contribution of many technologies and solutions.

Europe has achieved substantial progress already and reduced GHG emissions by ~24% from 1990 levels[II]—leading by example towards a sustainable economy. The power sector has been a core driver of Europe's decarbonisation,[III] driven by the rapid uptake of renewable energy and switch away from coal. To further step up the pace of carbon reduction and to deliver on the climate ambition, all economic sectors will need to be engaged. The power industry cannot do it alone.

All available tools and infrastructure will have to be employed to maintain reliability and affordability, while patterns of energy consumption and generation will be changing rapidly. Transparent and predictable policies will be critical. The frameworks put forward by policymakers will create the investment and policy environment and ultimately guide countries towards decarbonisation. The most efficient approach will measure and incentivise reductions in carbon intensity, delivering near-term gains while remaining on a trajectory towards net-zero emissions.

Increasingly affordable renewables will drive the decarbonisation of power generation but will not be able to achieve zero-carbon single-handedly. They will therefore need to be complemented by technologies which overcome the limitations of renewables and are compatible with Europe's 2050 net-zero ambition. Dispatchable gas power ensures the flexibility needed to make an energy system with a high share of variable wind and solar reliable. Moreover, gas turbines, installed today or in the future, can be converted to low- or near-zero-carbon generation through the application of Carbon Capture, Utilization and Storage (CCUS), or the use of low-carbon fuels, such as hydrogen, making them future-proof investments for immediate emissions reductions.

Both CCUS and hydrogen will play a crucial role in decarbonisation of not only the power sector, but of the integrated energy system and the entire economy. Developing both these technologies in industrial clusters, leveraging economies of scale, will be a viable path until cost reductions allow their wider deployment across Europe.

Gas power, with its clear pathway to low- or near-zero-carbon operation, can also facilitate accelerated coal phase-out in the countries where coal still remains an important part of power generation mix. Accelerated replacement of coal will be essential in minimising the cumulative emissions over the transition period. The decarbonisation impact of natural gas will further be augmented by targeted actions to reduce methane leakage across the entire gas supply chain.

As a technology and service provider for the full length of the energy value chain, GE has a unique perspective on the energy transition and has a suite of complementary technologies, including gas-fired power with hydrogen and CCUS capability, and solutions needed for the energy transformation. GE has also set its own goal to become carbon neutral[IV] in its facilities and operations by 2030. ■

I "Net-zero GHG emission" means that residual emissions (the ones that could not be reduced to zero) are balanced by equivalent amount of carbon removal.

II Progress achieved by 2019, before the Covid-19 pandemic.

III 'Decarbonisation' in this paper refers to the progressive lowering of the GHG intensity of the economy, through the reduction or abatement of emissions.

IV Carbon neutrality to be achieved through absolute reductions of direct emissions and energy use at more than 1000 GE facilities and operations worldwide by 2030.

# Targeting Climate Neutrality

*Europe's shared objective of climate neutrality by 2050, manifested in the European Green Deal and other aligned policy frameworks, will shape decarbonisation activities across society. There won't be a single or unique pathway applying to all countries. Meeting the target will require a flexible approach that enables many technologies to contribute.*

The European Union (EU) has set a clear objective of achieving climate neutrality by 2050, soon to be set out in the European Climate Law. European Economic Area (EEA) countries and the UK have similar objectives. This goal is fundamentally necessary for protecting the planet, our way of life and delivering the innovation and transformation needed for a decarbonised economy.

The unprecedented scope of the European Green Deal reflects this truth. Especially important is the acceleration of mid-term objectives, with an increased climate ambition for 2030 supported by a revisiting of the existing climate and energy policy framework. To achieve this, new targets for renewable energy and energy efficiency will be supported by an expansion of market-based policies like carbon trading. Together, these policies must strive towards an optimal pathway to deliver rapid decarbonisation in the most immediate term, leading to the lowest possible cumulative emissions as Europe transitions towards climate neutrality.

Other European countries who are not members of the EU have nonetheless matched its ambition. The United Kingdom was the first country in the world to put legally binding reduction commitments in place. Norway, Switzerland, Iceland and Liechtenstein (members of the European Free Trade Association) all have legally committed to reaching net-zero by 2050 or earlier. By setting these targets in legislation, governments are bound to align all future actions with the objective of climate neutrality. While they are of course not governed by the EU's specific approach, they remain closely integrated with the EU economy and energy markets, and are fundamentally aligned on the need for coordinated climate action. With this in mind, many points discussed with reference to the EU in this paper remain true for Europe as a whole, even if some divergences exist.

Europe is not alone in tackling climate change head-on. Commitment from the United States, China and other nations means that much of the world's economy could be decarbonised as early as 2050. The challenge is urgent, and the benefits to European citizens and economies can be significant if the transition can be managed effectively. It also raises the stakes for Europe's own trajectory.

## FRAMING EUROPE'S CLIMATE CHALLENGE

**Europe has made substantial progress in reducing emissions and is determined to do more. To achieve rapid advancement and minimal cumulative emissions, different decarbonisation pathways need to be considered respecting the diversity of the individual countries.**

The European Union has made substantial progress to date, reducing emissions by 24% from 1990 levels through 2019.[1] Analysis of sectoral trajectories makes it clear that this progress has been largely due to a few high-performing contributors, namely power and industry. The decarbonisation of the power sector, with almost 30% $CO_2$ emission reduction between 2010 and 2019 alone,[V] has been a key driver in the overall EU emissions reduction of nearly 17% in the same period. At the same time, other sectors have made less progress: e.g. transport emissions over the same period have increased. While this is a symptom of a more globalised world and a more integrated Europe, it may undermine climate action efforts. Under the European Green Deal, new policies will address this challenge through the development of renewable fuels and the application of carbon pricing, for example.

Countries across Europe are diverse in terms of power generation carbon emissions intensities (see Figure 1 on the following page). While the EU average is around 300g$CO_2$/kWh, countries with a high share of renewables (Norway, Austria), nuclear (France) or combination of both (Sweden, Finland) reach values at or below 100g$CO_2$/kWh. On the other hand countries with a high share of coal (Greece, Poland) can be more than two times as carbon-intensive as the EU average.[2] The urgent need to reduce emissions means that the path forward for countries like Greece and Poland is necessarily different from those more advanced in the energy transition. They must prioritise rapid gains leading to lower cumulative emissions over the period to 2050. European policies should not only permit but support the rapid deployment of lower carbon generation technologies in these countries, while remaining aligned with the long-term objective of climate neutrality.

[V] Unless otherwise stated, "IEA outlook" in this paper refers to IEA State Policies Scenario in IEA World Energy Outlook (2020), which uses existing policy frameworks and announced commitments as a baseline.

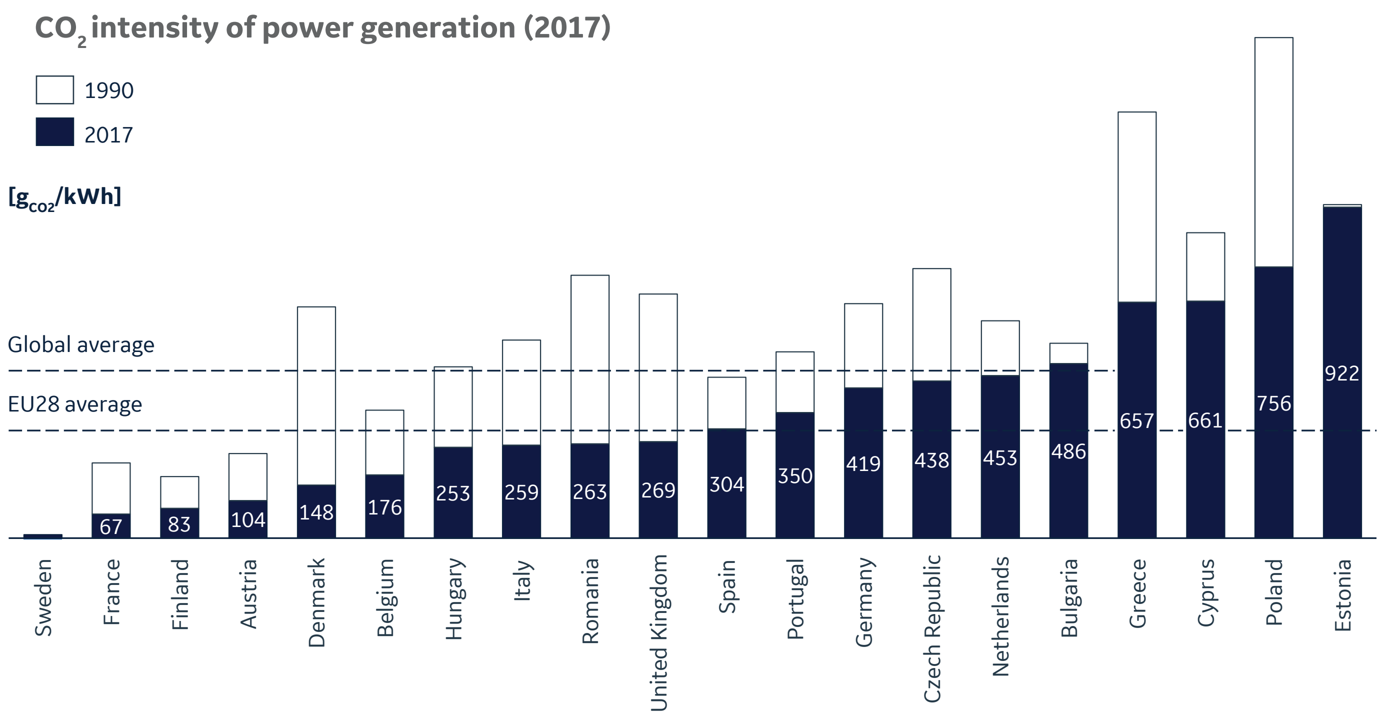



**FIGURE 1:** Countries across Europe are diverse in terms of carbon emissions intensity of power generation

*Sources: European Environment Agency (2020) https://www.eea.europa.eu/data-and-maps/data/co2-intensity-of-electricity-generation (EU values, 2017)*
*IEA (2019) https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions (global values, 2018)*
*Note: Latest values published on 2017*

The most efficient approach will measure and incentivise reductions in the carbon intensity of power systems, delivering near-term gains while remaining on a trajectory towards net-zero emissions by 2050. It will further be supported by realistic timelines for reduction efforts, which are regularly reviewed in the face of new science and technology developments.

This transition requires significant changes to Europe's energy system, technologies and fuels. It will also mean a change in the way European citizens and businesses access and consume energy. 'Efficiency First' will need to be the core principle applied to all policymaking, planning, and investment in the energy sector. For citizens especially, the climate transition can be a driver for a fairer society, or it could undermine the wellbeing of those employed and supported by affected sectors—responsible governance will be the deciding factor.

The range of activities covered by the European Green Deal and related policy programmes reflects the need to consider the energy system as a whole rather than any specific technology. Only by thinking holistically about all these elements can Europe achieve deep decarbonisation in a cost-effective way.

The next two sections of this paper will elaborate first on the evolution of the energy systems, and then on the roles different energy technologies and fuels will play in the transition.

# Energy System

THE POWER INDUSTRY CANNOT DO IT ALONE

The integration of the energy systems will be fundamental to delivering the climate transition, ensuring gains and efficiencies made in the power sector can be shared across the economy.

The power industry has been the key contributor to lowering EU's emissions with almost 500Mt$CO_2$e reduction between 1990 and 2018 out of the total ~1400 Mt$CO_2$e net GHG change. As underlined by the European Environment Agency, these reductions have been driven by the "strong uptake of renewable energy sources, the switch from coal to gas for heat and power generation and improvements to energy efficiency."[3] During this period the share of coal generation dropped approximately in half from almost 40% to 20% of generation, gas power almost tripled, from less than 7% to more than 18%, and wind and solar grew from a baseline of essentially contributing no generation to 14% of total generation. See Figure 2.

Yet the power sector alone cannot deliver on Europe's climate ambition. While low-carbon power generation has become increasingly cost-effective, new constraints will limit progress. Europe's population density has made it increasingly challenging to develop renewable energy projects, which are land-intensive. Furthermore, nearly 40% of Europe's electricity is produced from nuclear and hydro; $CO_2$-free energy sources which are unlikely to grow substantially in the coming years. These factors, combined with the need to phase-out old, polluting power stations even as Europe grows overall electricity demand, mean the most challenging days of the power sector transition are ahead, not behind us.

While many sectors will rely on electrification to reduce emissions, electrification alone will not deliver on sustainability goals. Switching from combustion of fuels to electricity has clear environmental advantages at the point of use due to reduced emissions of local air pollutants. However, for electrification to be most effective at reducing $CO_2$ emissions, the power sector must transform and further reduce its carbon intensity.

*All economic sectors must step up decarbonisation efforts and develop efficient integrated energy systems to achieve net-zero carbon Europe.*

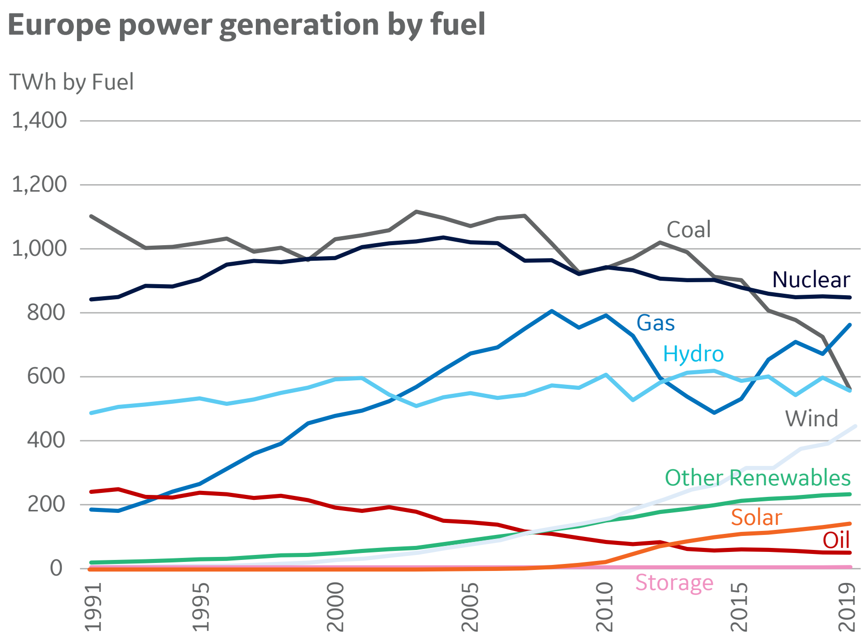



**FIGURE 2:** European power generation mix moving away from coal to lower carbon technologies

*Source: ENERDATA (2020)*

*The growth of renewable energy will lead to new challenges in delivering energy where and when it is needed. Europe's energy system must leverage all the tools and infrastructure available to maintain reliability while patterns of energy consumption and generation are changing rapidly.*

## MANAGING THE EVOLVING ENERGY SYSTEM

To understand how and why different technologies will contribute to the decarbonisation of our power system, we must first consider the specific needs of the power system itself. The path towards a carbon-neutral economy is not governed simply by the emission intensity of our generation assets, but also how they perform and their specific characteristics. Therefore, this paper will briefly discuss the primary considerations which will impact our electricity mix.

The future of the European energy system is one which is interconnected and integrated. To deliver this, policymakers and market actors must consider the energy system, across multiple energy carriers, infrastructures and consumption sectors.[4] A practical example of this is the electrification of light-duty transport. Battery-operated electric vehicles can make use of $CO_2$-free power instead of liquid fuels, and at mass scale could even provide storage for the grid —acting as both consumers and suppliers of electricity in a truly integrated way.

This will increase demand for power, and thus further strain the electricity system. Improving energy efficiency is a key way to alleviate this pressure. On the supply side, simultaneous generation of heat and electricity ('co-generation') and targeted replacement of power generation assets can ensure maximum energetic output from fuels. Complementing this, product standards and building renovations can significantly reduce energy demand.

Also, operating an electrical grid is a very complex task, as the power generated and consumed must be made equal in real time to ensure the delicate balance of frequency.

## Cogeneration system

**Cogeneration, the simultaneous production of heat and electricity, can increase energy efficiency up to about 90%, compared with 60–65% for the most advanced combined cycle power plants. Through cogeneration plants, the heat produced in the generation of electricity can be recovered and used to produce steam for industry or heat for residential or industrial buildings.**

Many EU countries have promoted cogeneration as a way to reduce $CO_2$ emissions. In Germany, a national law which targets the promotion of energy production through cogeneration has been in place since 2002. Combining incentives with a clear target, the law has successfully promoted cogeneration technologies across the economy, improving energy efficiency and lowering costs for industrial energy consumers. High-efficiency cogenerations are one of the short-term decarbonisation levers and continued support across Europe will be required.

To that end, several mechanisms are critical for grid operators to keep the lights on and maintain the power supply quality that Europeans have come to expect (and which is higher than that in other parts of the world).

The underlying requirement related to the continued ability to deal with the challenges[VI] faced by the European electrical grids is flexibility in responses and reserve capacities. As these grids were built around synchronous generation, the inertia was provided by the turbine and generator rotors of the synchronous generating units. Rapid addition of non-synchronous generation capacity, that we have been witnessing in recent years, is resulting in lower inertia in the system.

'Synthetic inertia' introduced through inverter-connected technologies like wind and solar has been providing some unique grid services tailored to specific needs. Still kinetic energy of rotating units is essential for providing grid stability. This kinetic energy, however, is being reduced with the continuing retirement of large units (nuclear and coal) and the reduction of the time when the remaining rotating capacity is in operation. This is a challenge the energy system will need to address in order to stay reliable and to avoid brown-outs, automated disconnection of some demand areas in case of frequency drop or even grid wide black-outs. The event in the UK on August 9, 2019, is a dramatic example of the consequence of a failure to balance the frequency following two consecutive faults on the system. This event led to a severe disruption of public transport in the London area and around 1.1 million customers disconnected from power supply.

[VI] These challenges include, for example: unforeseen trips of large generation units or interconnectors, rapid increases/decreases of large industrial load, variability of renewables with no rotating inertia, transmission line faults, reduction of inertia due to retirement of steam/nuclear units, or advent of electrical vehicles with fast charging.

In addition to the impact on the grid, new renewable capacity poses specific infrastructure challenges. Locations for renewable installations are often chosen on the basis of suitability over convenience. This means supply can often be distant from demand. An example of this divergence is in Germany, which produces much of its renewable electricity in the north of the country and the North Sea, where wind is plentiful and consistent. Conversely, many industrial demand centres are in the south of the country. This requires significant new infrastructure investments, with four high voltage, direct-current (HVDC) lines expected to be operational by 2030, as part of a grid development plan costed at more than €60bn.[5]

The growth of variable renewables also increases the need to fully capture the energy generated when it exceeds demand, and to deliver energy when demand exceeds supply. Increased interconnectivity, progressively affordable battery storage, demand side management and digital solutions will all contribute to the resolution of this challenge. Costs and market design will be key drivers here.

When considering seasonal variations of supply and demand, more substantial solutions are required, and gas will continue to play a key role in this, providing the cornerstone of system resilience for decades to come.

## POLICY FRAMEWORKS WILL GUIDE INVESTMENTS

*While our energy system is built on infrastructure and generation, it is the framework put forward by policymakers which will ultimately guide markets towards decarbonisation.*

Energy markets across Europe are tightly regulated. These frameworks deliver competition and fairness across the energy system, and have an ambition to assign value to characteristics required for system stability and, of course, sustainability. However, they do not systematically assign clear value to, for example, flexibility or resilience, which are increasingly important. Policies must ensure energy markets are fit for purpose, can secure the investments they need and are ultimately able to deliver on Europe's 2050 objective.

Europe's energy policy framework needs to balance transparency with flexibility. GE cautions against policies which aim to predict the future, setting narrow pathways for technologies and energy sources. Carbon pricing is the central EU policy to regulate $CO_2$ emissions of the power sector by delivering price signals for market operators and investors. The upcoming revision of the EU Emissions Trading System (ETS) Directive as part of the 'Fit for 55' legislative package has to strengthen the current system to ensure it will send the right signals to markets for a cost-effective energy transition. Further measures should always be coordinated with the ETS as $CO_2$ pricing intelligently combines government regulation with innovation-friendly and cost-efficient market processes. Attempts to divide economic activities administratively into how much they contribute to the transformation could do more harm than good as innovation and economic realities are too complex and dynamic. Carbon pricing should be further complemented by policies that are technology agnostic and which emphasise both near-term actions that drive the greatest reductions sooner, and a longer-term vision of ambitious carbon reductions leading to climate neutrality by 2050. Finally, targeted initiatives to support, for example, hydrogen, CCUS and end-use sector integration will be key to the development and deployment of new technologies.

Market designs are also structured by policies and are therefore driven not by economics alone, but rather meeting the energy needs of Europe's citizens. This means the best energy is not always the cheapest or indeed lowest carbon emitting, and it is the responsibility of market participants and policymakers to prepare for the most extreme demand scenarios. Balancing these concerns with those around sustainability and affordability is often referred to as the 'Energy Trilemma'.

**Gas power can meet flexibility needs, while progressing towards carbon-neutral generation through the decarbonisation of fuels and facilities. The design of Europe's electricity markets must recognise this contribution, ensuring gas generation can continue to play this key role while being economically viable.**

The remuneration of flexible, dependable capacity through, for example, capacity—or better, "capability"—mechanisms is thus a vital element of a stable and sustainable energy system.

The policy frameworks must further ensure the energy system can secure the substantial investments needed to decarbonise. While estimates can vary significantly, the European Commission predicts that annual investments exceeding €500 billion are needed to achieve climate neutrality by 2050.

Private financing can and should deliver the largest portion of investments into decarbonisation. These investments will be driven by market forces, recognizing the economic opportunities that the energy transition provides. Public financing will have a very important role in supporting nascent technologies, complementing private sector investments where market forces are not sufficient, and ensuring a Just Transition.[VII]

When considering public steps to either invest directly or mobilize private sector investments, it is crucially important that the investment environment works with the energy system Europe has today, not the one it hopes for in 2050. This means financing should be directed to where it can make maximum reductions in the near and medium terms, while still being compatible with the long-term objective of climate neutrality.

The intangible framework of policies, markets and investments will be the most important factor in Europe's success. How they interact and affect each other is challenging, if not impossible, to predict precisely. With this in mind, policymakers must avoid narrow frameworks. Instead, markets can be guided by the right incentives, like carbon pricing, to innovate and experiment their way to a carbon neutral future.

[VII] A Just Transition is a transition which protects the wellbeing of citizens, especially those in deeply affected regions which are reliant on industries incompatible with a decarbonised economy, like coal mining.

## Carbon price floor

**The application of a carbon price floor can be very successful and has been leveraged by different jurisdictions within and outside of Europe in delivering a rapid phase-out of coal in their power system. Price floors can ensure the harmful impacts of carbon-intensive power generation are adequately factored into the lifecycle economics of a plant.**

The introduction of such a tool brings also more certainty for investors, by providing a guarantee that the price of carbon cannot go below a certain defined price. In April 2013, the UK government decided to introduce a carbon price floor (CPF) with the goal of supporting the EU Emissions Trading System. The CPF has supported the price for carbon, reduced the revenue uncertainty due to carbon price fluctuation, and improved the economics for investments in low-carbon generation. Since the introduction of this policy tool, the UK has seen a significant fall in coal electricity generation. The share of coal on the total power generation declined from ~36% in 2013 to ~2% in 2019. Additionally, since 2017 the UK is experiencing periods without any coal power generation. During 2020 the UK experienced a record-breaking period without coal generation using coal-fired electricity on only one day between April 10 and August 12—the longest such period since the time Great Britain introduced coal-power electricity generation in the 1880s. Outside of the EU ETS the German government has also decided to put a minimum price on GHG emissions in both the transport and building sector from 2021. Berlin intends to keep increasing the price every year, until allowances are auctioned from 2026 onwards.

# Technology and Fuels

RENEWABLES AND GAS TOGETHER CAN FACILITATE EUROPE'S ENERGY TRANSITION

*Increasingly affordable renewables will drive the decarbonisation of power generation but will not be able to achieve zero-carbon single-handedly.*

Renewable energy, especially wind and solar photovoltaic (PV), is a $CO_2$-free, infinite source of power that is not subject to fuel price fluctuation and thus allows the production of electricity at a very low cost. The deployment of these technologies is key to tackling climate change, while developing innovative and high-value industries around the manufacturing and operation of renewables. The rapid increase of renewable electricity production in Europe has been mostly driven by reductions in cost, technology advancements improving capacity factors, favourable policies, and positive public sentiment around zero-carbon energy.

GE strongly supports the continued advancement in cost-effective renewable energy technologies. Our Paris-head-quartered renewable energy division is a leading provider of wind turbines and hydropower equipment.

Cost has been a crucial driver in this transition. In Europe, renewable technologies often compete with thermal generation in open tenders for new capacity. Between 2010 and 2019, the EU installed capacity of solar PV and wind turbines grew from approximately 110 GW to 285 GW.[6] Within that period, the cost of electricity produced from those sources fell by 82% and 40%,[7] respectively, a key driver of this extraordinary growth. This fall was mainly due to the capital costs reduction, supply chain improvements and support schemes. Wind turbines are also getting more efficient at low wind speeds. The towers are getting taller and blade diameters larger, enabling them to produce more energy from a given piece of land.

With the starting points and also physical constraints being very different across Europe, the optimal pathway to achieve lowest possible carbon emissions will be different for every country.

**A combination of renewables and gas will for many countries be the fastest and most cost effective pathway to decarbonisation. Furthermore, the transition from coal to lower emitting sources can lead to lower cumulative emissions over the transition period.**

As discussed previously in this paper, our existing electricity system is limited in its ability to transmit and store renewable electricity. This in turn means either a slower transition or a significant increase in investment costs, with little advantages over a transition which also leverages gaseous fuels.

**The rapid deployment of renewables should therefore be complemented by technologies which overcome possible limitations, while being compatible with Europe's 2050 ambition.**

## GAS TURBINES HAVE A PATHWAY TO LOW- OR NEAR-ZERO-CARBON EMISSIONS

Gas power is the technology that can complement variable renewables and make the energy system with a high share of wind and solar reliable and ready to meet the needs of the European economy. By leveraging Europe's robust gas transport and storage infrastructure, gas power generation can safeguard the transition to a carbon-neutral power system, ensuring security of supply while cost effectively delivering deep decarbonisation.

Natural gas-fired combined cycle power plants (CCPP) are the lowest emitting dispatchable power plants, whether measured based on $CO_2$, $SO_X$, $NO_X$, particulate matter, or mercury emissions. Going forward, however, there will be a need to reduce $CO_2$ emissions further and there is a misconception that deploying new gas generation capacity will "lock in" $CO_2$ emissions for the lifetime of the power plant. Gas turbines currently in operation, or yet to be deployed, have a pathway to enabling decarbonisation and avoiding lock-in of $CO_2$ emissions through utilisation of carbon capture technologies or low-carbon fuels, e.g. low- or zero-carbon hydrogen, or biofuels.

Furthermore, significantly less space is required for gas-fired generation than for renewable energy, enabling natural gas power plants to be deployed closer to demand centres and possibly avoiding the need for an investment in transmission infrastructure. A CCPP requires almost 400 times less land than a solar PV and 4000 times less than an onshore wind farm of comparable capacity[8] would need.

GE firmly believes that the technologies we deploy today must be compatible with Europe's long-term climate objectives, even as they reduce emissions and support grid stability in the short term. Gaseous fuels, and thermal generation, are an essential component of all electricity systems even in a fully decarbonised economy. See Figure 3.

*Through hydrogen and CCUS, gas turbines installed today can be converted to low- and near-zero-carbon generation, delivering immediate emissions reductions while cementing the trajectory to net-zero emissions.*

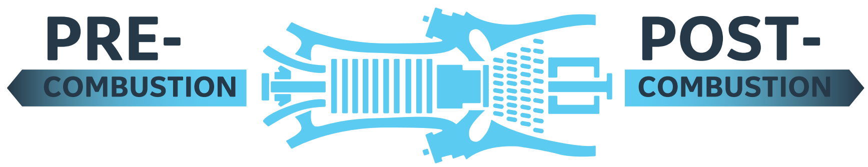



**FIGURE 3:** Means to decarbonising a gas turbines – two technology pathways to low- or near-zero-carbon gas generation: pre-combustion and post-combustion

There are two key technology pathways towards low- or near-zero-carbon gas generation—post-combustion and pre-combustion. Carbon capture, utilisation and storage (CCUS) and hydrogen are the two commonly accepted options representing post- and pre-combustion approaches. Where and how each technology is implemented will depend substantially on factors related to cost, policy environments, geography, public perception and existing infrastructure. For this reason, it is vitally important that the European policy environment allows operators in the energy market to choose the technology pathway which best fits their specific needs. In this way, Europe can move towards our shared objective of a $CO_2$-free power system in the fastest, most cost-efficient way.

## CARBON CAPTURE, UTILIZATION AND STORAGE WILL ENABLE DECARBONISATION ACROSS THE ECONOMY

**CCUS is an available technology which can be used to decarbonise power plants almost fully. It can be deployed in clusters, leveraging economies of scale to support low-carbon industries.**

CCUS involves capturing and storing $CO_2$ emissions before they are emitted into the atmosphere. As discussed above, this process can be applied 'pre-combustion', that is converting natural gas to hydrogen. It can also be applied 'post-combustion', which means capturing and sequestering the emissions from natural gas-fired power plants. These emissions can then be stored underground, in suitable saline aquifers, depleted gas fields, or used in other industrial processes. Through these processes, upward of 90% of power plant $CO_2$ emissions can be eliminated.

While significantly reducing emissions, CCUS impacts the economics of a power plant. Factoring in the additional cost and reduced efficiency results in an increase in Levelized Cost of Energy (LCOE) of 30% to 50% depending on expected level of carbon captured.[9] Furthermore, the addition of CCUS facilities can grow the footprint of power plants. Efforts are underway to optimise the power plant and CCUS thermal needs such that the impact on efficiency is reduced.

Merely separating $CO_2$ is insufficient to reach deep decarbonisation goals. It must be stored safely and permanently. Public perception that captured $CO_2$ cannot be sequestered permanently is one of the biggest impediments to CCUS today. Drawing on parallels to fossil fuel extraction technologies, scientists believe that the Earth has the capacity to store more $CO_2$ than humans can produce, and there is very strong evidence that $CO_2$ can be stored safely underground for hundreds of millions of years. Public perception and political sentiment are real, however, and need to be addressed before carbon sequestration is employed on a large scale.

CCUS facilities have been operational in Europe since the mid-1990s. Just one, the Sleipner gas field in Norway, has sequestered more than 20 million tonnes of $CO_2$ to date in depleted gas fields. This has demonstrated the effectiveness of the technology, permanence of the storage and scale at which CCUS can be deployed around Europe.

Furthermore, it is not just the energy sector investing in CCUS. The technology is an essential component of the decarbonisation trajectory of many industrial sectors; cement and chemicals manufacturing for example. The development of CCUS in industrial hubs can create economies of scale, delivering low-carbon clusters of complementary industrial and power generation facilities.

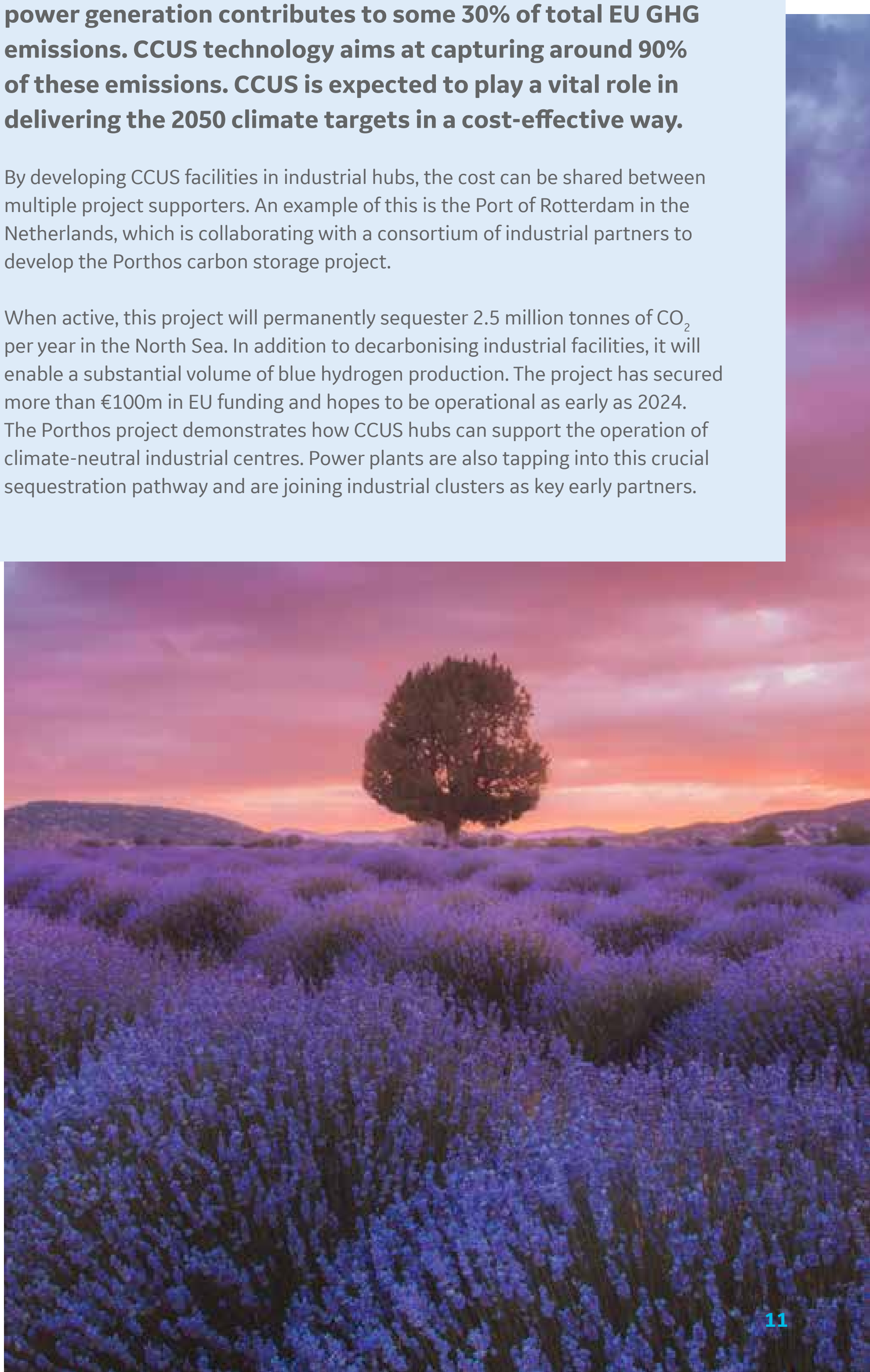
Currently, carbon pricing is applied to power plants and other industrial facilities under the EU ETS and the corresponding UK ETS. According to analysis performed by GE, and available upon request, the trade-off between paying a carbon tax on emissions versus paying to capture and sequester the carbon tips in favour of installing post-combustion carbon capture in certain conditions starting as low at ~€29–~€41 per metric ton of sustained $CO_2$ pricing. This is further supported by the EU ETS' Innovation Fund, which will provide around €10bn of support between 2020–2030 for the commercial demonstration of innovative low-carbon technologies. Combined, these policies could deliver reduced costs and widespread deployment of CCUS technologies.

## Deploying CCUS in industrial clusters

**Although the EU is planning an important shift to renewable sources in the power generation sector, fossil fuels are still expected to play a significant role in the short and medium-term. $CO_2$ emitted from the combustion of fossil fuels in power generation contributes to some 30% of total EU GHG emissions. CCUS technology aims at capturing around 90% of these emissions. CCUS is expected to play a vital role in delivering the 2050 climate targets in a cost-effective way.**

By developing CCUS facilities in industrial hubs, the cost can be shared between multiple project supporters. An example of this is the Port of Rotterdam in the Netherlands, which is collaborating with a consortium of industrial partners to develop the Porthos carbon storage project.

When active, this project will permanently sequester 2.5 million tonnes of $CO_2$ per year in the North Sea. In addition to decarbonising industrial facilities, it will enable a substantial volume of blue hydrogen production. The project has secured more than €100m in EU funding and hopes to be operational as early as 2024. The Porthos project demonstrates how CCUS hubs can support the operation of climate-neutral industrial centres. Power plants are also tapping into this crucial sequestration pathway and are joining industrial clusters as key early partners.



## EUROPE IS IN THE LEAD OF THE GLOBAL MOVEMENT TOWARDS GREEN HYDROGEN

Hydrogen will play a crucial role in the future economy both as energy carrier and industrial feedstock. Produced largely through natural gas reforming today, the application of CCUS in the near future and the growth of hydrogen produced from renewable electricity in the longer-term future will open up new opportunities.

The European Commission has been clear on the critical role hydrogen will play in Europe's economy. In its landmark Hydrogen Strategy, published in summer 2020, the European Commission projects that hydrogen will represent around 14% of the EU's energy mix by 2050, and will be supported by investments of up to €470bn. This marks a significant increase from today, when hydrogen represents less than 2% of EU energy consumption. This share is growing however, and turbines supplied by GE are already operating on hydrogen blends and variants.

The cost of low carbon and renewable hydrogen has been falling, with the EU estimating electrolyser costs have gone down 60% in the last ten years.[10] This downward trend is expected to continue, although there are always uncertainties about the long-term price trajectory of a rapidly evolving technology area. The scale of government support, development of end markets and potential for new processes together will determine the final cost curve.

While in the near future hydrogen application in electricity generation most likely will be limited to demonstration pilot projects, it can play a key role in storing excess renewable electricity and providing balancing where needed in the longer term. It could then enable near-zero-carbon generation at the power plant level in the same way as wind and solar do today. GE is ready for this future. The gas turbines that we deliver today, or upgraded existing units, will be able to operate on the low carbon fuels with appropriate consideration to the combustion system, fuel accessories, emissions, and plant systems. GE has extensive experience in this area and GE gas turbines have been operating with hydrogen fuel blends in a variety of industrial applications over the last 30+ years. GE is also continuing to develop its gas turbines' hydrogen capabilities.

Our whitepaper on using Hydrogen in Gas Turbines addresses related technical questions in more detail.[11] See Figure 4 on the following page.

*Hydrogen has an essential role in the decarbonisation of different sectors of the economy and enabling low-carbon flexible thermal generation.*

## The role of hydrogen in decarbonisation

**To become climate-neutral by 2050, the EU intends to transform its economy, especially its energy system, which accounts for 75% of the EU's total GHG emissions. In this context, Brussels carved out a significant role for hydrogen. In its Hydrogen Strategy, published in July 2020, the EU is projecting to increase the share of hydrogen in Europe's energy mix to 14% by 2050.[10]**

The deployment of hydrogen in the EU economy is meant to power those sectors that are not suitable for electrification and to provide storage to balance the production variability of renewable sources. The Strategy aims at boosting $CO_2$-free hydrogen production all across the EU, and aims to attract some €550 billion in the coming years.

A number of EU Member States have already identified low-carbon hydrogen as a fundamental element of their National Energy and Climate Plans. In this regard, Germany strongly believes in the potential for hydrogen to deliver deep decarbonisation across its economy, and in July 2020 published an ambitious National Hydrogen Strategy. By scaling up low-carbon hydrogen in the near term while trending towards fully renewable hydrogen by 2050, Germany hopes to secure global leadership in hydrogen technologies.

The German government sees hydrogen as an important tool for reaching the 2050 targets and promotes rapid scale-up to 5GW hydrogen generation capacity by 2030. This hydrogen will be used across the economy, decarbonising challenging industrial sectors, such as steel and chemicals, as a priority. Together with the increase of hydrogen production, there will be a deeper integration with the neighbouring countries developing hydrogen markets and projects.

To deliver on this ambition, Germany has actively promoted an "Important Project of Common European Interest" (IPCEI) scheme to be established for hydrogen, which will unlock substantial funding. Berlin further hopes to allocate more than €7 billion to speed up the market rollout of hydrogen technology in Germany, and another €2 billion for fostering international partnerships.

Other European countries, including France, the Netherlands, Norway, Portugal, and Spain, have revealed their hydrogen strategies and also are planning multi-billion euro investments in this area.

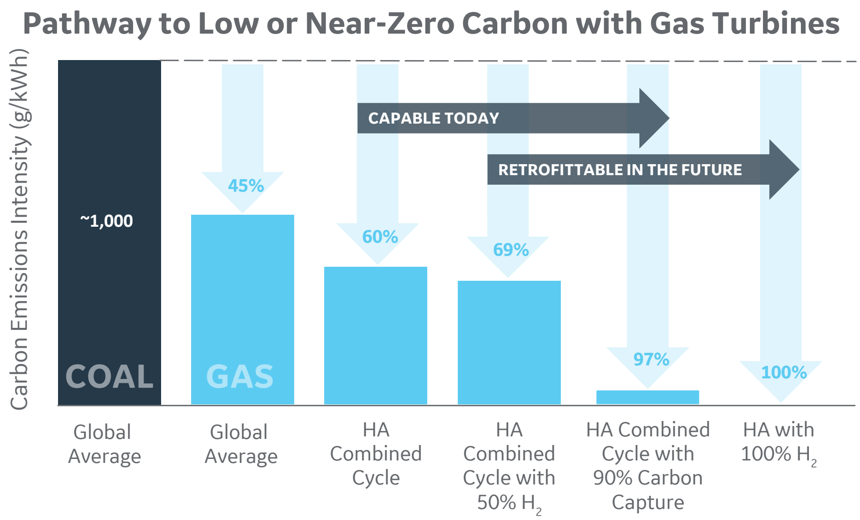



**FIGURE 4:** Gas turbine decarbonisation opportunity

*Source: IEA WEO 2020, GE analysis*

## PHASING OUT COAL WILL BRING US CLOSER TO EUROPE'S DECARBONISED ENERGY FUTURE

**Despite progress towards phase-out, coal is still a substantial element of the energy system and further action is needed.**

While trending downward, coal still accounted for around 17% of electricity production in the EU in 2019. Although the EU has not defined its phase-out date, power generation from coal has declined by around 37% between 2010 and 2019.[6] Yet coal generation is not evenly distributed across Europe, and is heavily relied upon in some power systems across Central and South-eastern Europe and will remain so for years to come. Accelerated phase-out of coal as a power generation source is essential if Europe is to minimise total emissions as it moves towards climate neutrality.

The complete coal phase out must be addressed with a firm commitment across Europe, at a pace much faster than today. The elimination of state subsidies for coal generation as well as the introduction of reverse auctions for capacity phase-out can be important first steps. Private actors have a role here too, and GE has committed to exit the new-build coal power market. With cost-effective, reliable, and sustainable technologies available today, there is little reason not to eliminate coal from the power energy sector urgently. As coal-fired generation declines, it must be replaced with lower carbon choices—renewables supported by gas.

## A RESPONSIBLE APPROACH TO METHANE EMISSIONS

*While significant progress has been made, it is important that methane emissions are addressed across the energy value chain, especially at the points of production and transmission.*

A concern often raised about natural gas power generation is that it is responsible for a significant increase in global methane (natural gas or CH4) emissions. Although it does not remain in the atmosphere as long as $CO_2$, methane has a global warming potential 28 times greater than $CO_2$ on a kilogram-for-kilogram basis,[VIII] and accounted for 10% of total GHG emissions in Europe in 2018.[12]

In the energy sector, more than three quarters of methane emissions result from upstream operations—at the point of production and transportation rather than use in a power plant. The IEA estimated that in 2020, around 10% of leaks could be avoided at no net cost considering the balance between the value of the captured methane and the costs of abatement actions. According to the IEA, the cost is smaller than 2019 due to the low gas price in 2020. The figure is expected to increase in 2021 because gas prices are expected to rise as the impact of the pandemic lessens.[13]

GE supports policies which obligate the power and oil and gas sectors to implement cost-effective available methane abatement technologies and practices. On our side, we are seeking to reduce methane leakage from the GE products as an important goal, however targeting leaks that are orders of magnitude smaller than those upstream. We further call on all producers and users of methane to employ the best available technology to measure and capture methane emissions.

[VIII] Over 100 years period as per IPPC AR5 Synthesis report (2014)

GAS AND RENEWABLES COMPLEMENT EACH OTHER AND TOGETHER DRIVE ELECTRICITY SYSTEM DECARBONISATION

**By using gas and renewables alongside each other, Europe can deliver the quickest and deepest emissions reductions. In this way, the EU can achieve its objective of climate neutrality by 2050 while producing the lowest possible cumulative emissions over the transition period.**

Given the needs of our energy system, and the technologies available to us today, the complementary role of gas and renewables stands out as a path towards decarbonisation. By creating the appropriate investment environment and policy framework, and factoring in considerations like methane leakage and land use, Europe can build an efficient, balanced and sustainable power sector.

Natural gas-fired power generation is flexible and dispatchable. Plants can come on- and offline quickly, adjust power output levels, and turn down to a very low output level to balance supply and demand as needed. They can deliver more or less power as supply and demand for electricity vary throughout the day, over the course of a week or a month, and seasonally—whenever required. This flexibility is especially important to maintain grid stability as more wind and solar resources are deployed.

Gas-fired power plants are available regardless of the time of day or weather conditions, providing dependable capacity when needed, whether for minutes, hours, days or weeks at a time. Wind and solar power are available only when the wind is blowing or the sun is shining. The availability of the wind and solar resources does not always coincide with demand. Because electricity supply and demand must always be in balance, renewables require dispatchable backup power such as natural gas power plants or batteries to ensure system reliability.

Gas power is affordable due to its low CAPEX requirements and the availability of cost-competitive natural gas. In fact, with the typical CAPEX cost in the range of ~$700–$1200/kW a combined cycle gas plant is currently the lowest cost generation technology on a €/kW basis,[14] compared with ~$1500/kW for onshore wind or ~$1250 for solar PV. This is especially important when access to capital is constrained or project financing is required.

**As underlined previously, investing in gas generation is a future-proof option, with clear technology pathways towards full decarbonisation. Whether through hydrogen or CCUS, a combination of gas and renewables can deliver carbon-neutral electricity sustainably, securely and affordably. By urgently investing in a combination of wind, solar, batteries and gas-fired power at scale, market operators can firmly set Europe on a course for net-zero emissions. See Figure 5.**

### Replacing coal with a combination of variable renewables and batteries plus dispatchable gas yields greater carbon reduction than renewables alone

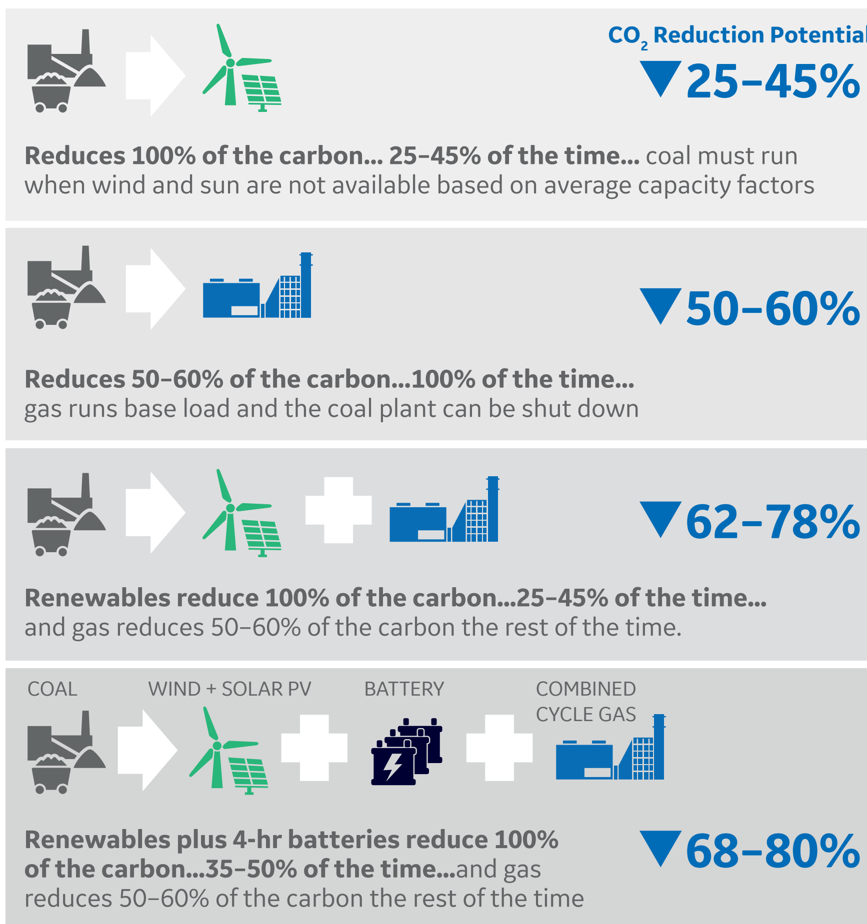



**FIGURE 5:** GE analysis considering the real-time balancing of power supply and demand using a hypothetical base loaded coal plant. Note that CAPEX and required land are not addressed in the above analysis. *Source: GE analysis available on request*


*GE factory in Birr, Switzerland*

# Conclusion

## Addressing climate change must be an urgent global priority, requiring global action, national commitments, and consistent policy and regulatory frameworks.

In this context, Europe has a global leadership position in tackling climate action, and as stated by the European Council, the EU will exploit its leading role in Climate Diplomacy to get other major economies in line with the EU climate ambitions.

Solving the climate change challenge requires cross-European cooperation that encompasses all the sectors of the economy and all the political forces around the EU27 bloc and beyond. As stated by Fatih Birol, Executive Director of the International Energy Agency, it calls for a "grand coalition encompassing governments, investors, companies and everyone else who is committed to tackling climate change."

The most immediate challenge is the accelerated phase-out of coal from Europe's power system. According to the latest EEA report,[15] among the 16 power generation methods studied by the agency, coal is still by far the most polluting power source with the highest impact on the environment. Switching from coal to gas in power generation would represent a crucial step toward the continent's 2050 net-zero economy goal. A multi-pronged approach to decarbonisation with renewables and natural gas power at its core is therefore required to take significant steps to quickly reduce GHG emissions in the sector.

Where coal is removed from the system, renewables and gas power have the capacity to quickly reduce GHG emissions related to power generation, while maximising the potential of the energy system as a whole. Natural gas-fired combined cycle power plants have the lowest emissions impact compared to other fossil fuels power plants. Their deployment, accompanied by CCUS and/or hydrogen, would represent a meaningful and long-lasting reduction of $CO_2$ emissions. Their development must be accelerated to meet the climate targets and to avoid raising average global temperatures by 2° C over pre-industrial levels as outlined in the COP 21 Paris Agreement.

**Addressing climate change will require government and consumer action. GE as a company is uniquely positioned to play a key role through its scale, breadth, and technological depth.**

We have been a key player in the power industry since its inception more than a century ago and have a suite of complementary technology including gas-fired power, onshore and offshore wind, hydro, small modular reactors, battery storage, hybrids and grid solutions needed for the energy transformation. More importantly, we believe it is our responsibility to support this transition through our relationships with customers, policymakers and consumers, collaborating to build an energy system that works for everyone.

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