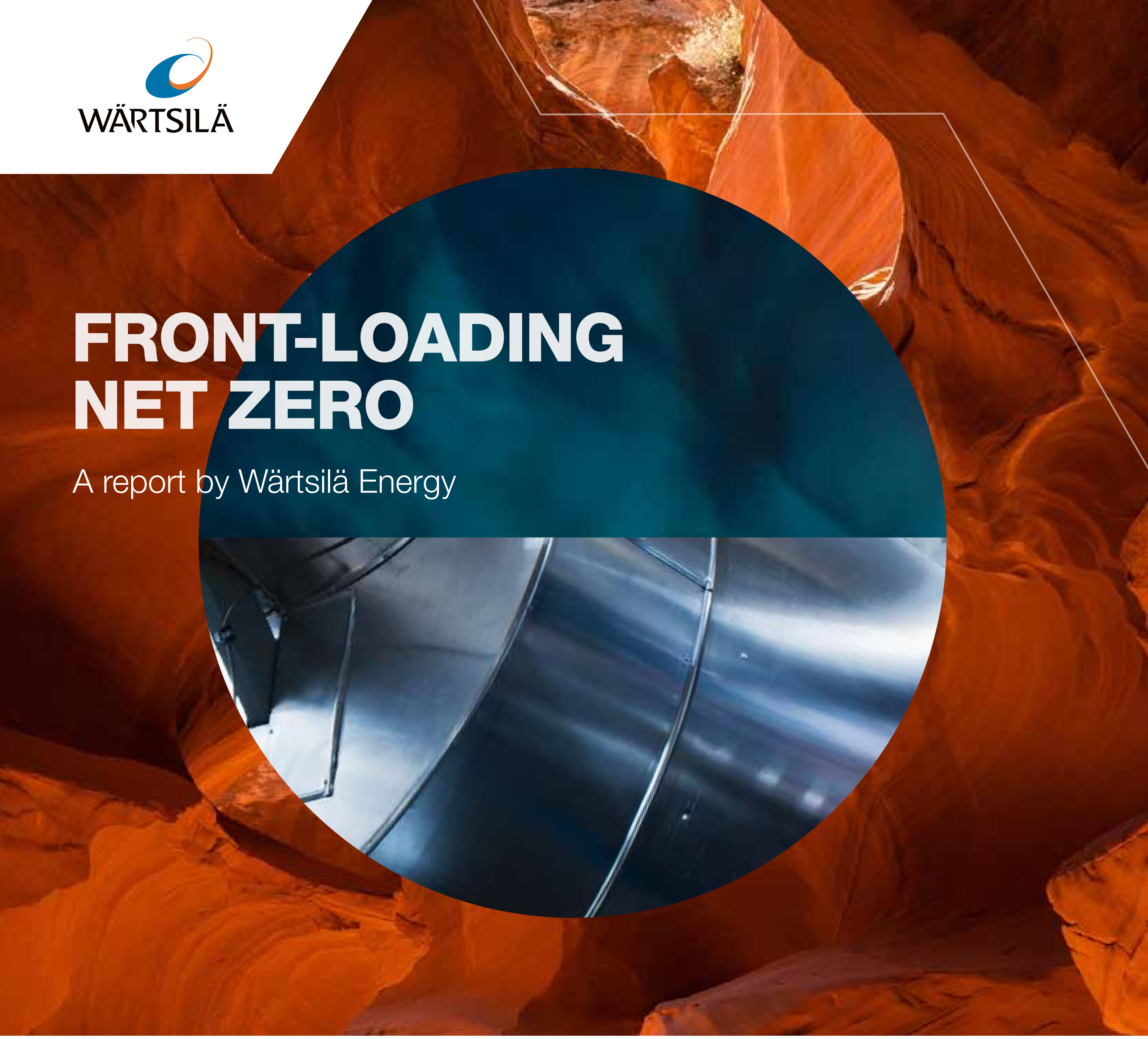


FRONT-LOADING NET ZERO

A report by Wärtsilä Energy

To illustrate the measures needed for cost-optimal paths to 100% renewable electricity, in this report Wärtsilä has modelled the transition to 100% renewable electricity generation in three key regions: California, India and Germany. They have vastly different socioeconomic dynamics, energy systems, and challenges to overcome, but they are unified in their commitment to transform.

As well as the modelling, this report also includes on-the-ground insights from Wärtsilä's experts on the risks and opportunities facing the following countries through the energy transition: Australia, Chile and UK.

CONTENT

FRONT-LOADING THE NET ZERO FUTURE WE NEED

A monumental global energy transition is underway. The powerhouses of the global economy are aligning on climate for the first time since 2015, bringing unified ambition, vision, and diplomatic weight to the COP26 table.

We have all the technologies that we need for net zero. The transition to 100% renewable energy systems is set to accelerate at an eye-popping rate. It's no longer a question of if we'll make the journey, but when we'll arrive at a decarbonised future.

The eyes of the world are now on the energy sector. Global leaders now expect power producers to deliver the lion's share of emissions cuts that are so vital for meeting national decarbonisation goals. Investment remains a key hurdle, especially in the post-COVID world. The International Energy Agency (IEA) calculates that investment in clean electricity must leap from $380bn to $1.6tn by 2030 to put us on a path to net zero by 2050. As a result, oncoming incentives and regulation are set to ensure clean power is always the most attractive option.

Sushil Purohit
President, Wärtsilä Energy and EVP, Wärtsilä

Net zero does not have to cost more

The price of electricity does not need to increase when power systems move to net zero. Utilities are shifting from a costly operational expenditure (opex) model, where capital is continually drawn into fuelling and maintaining legacy inflexible coal, oil, and gas plants – to a new model where up-front capital expenditure (capex) is invested in predictable, low maintenance, renewable energy technology. Flexibility creates the conditions where renewable energy is the most profitable way to power our grids: ensuring back-up power is available when there's insufficient wind or solar – and earning rewards from capacity mechanisms.

Investing in renewable baseload is now viewed as buying 'unlimited' power up-front, as opposed to betting against fluctuating oil prices and narrowing environmental regulation. The early leaders of the renewable transition, such as Enel, Iberdrola and Ørsted figured this out some time ago – and they are now outperforming[2] their counterparts in the fossil fuel sector. New capex is now surging in the power sector, driving the build-out of renewables at an unprecedented rate in areas of the world, such as Chile and New Mexico, that yield the highest renewable power capacity factors[3].

> Countries must front-load the transition towards net zero, taking major steps in the next five to eight years to tackle the climate crisis."

When everything is changing, standing still is the worst response

Faced with the magnitude of the transition, some power producers have stopped investing – stopped progressing. Some are waiting to see if renewable technology costs fall even further as the sector transforms in front of their eyes. However, power producers that stall their investments risk being left with portfolios that rely on legacy technologies, which can only provide diminishing returns, while the low hanging fruit for solar and wind parks is progressively being capitalised by the first movers. Delaying the transition to renewables will reduce the competitiveness of power producers, as well as putting national climate targets out of reach.

Furthermore, carbon prices are rising steadily around the world, exceeding €50 per tonne in Europe. Notably, financial analysts have calculated that carbon pricing will be enacted in more and more countries around the world, inexorably accelerating the transition to make up for the delayed response to the climate crisis. All major economies are forecast to institute carbon pricing schemes covering power and industrial emissions by 2030[4]. In the new carbon constrained world, latecomers will be penalised, and leaders rewarded, as the carbon price is ratcheted up – and investors now expect utilities to disclose detailed, costed transition plans.

Utility leaders now face two key questions: will my business survive and thrive in a transformed energy market fuelled by renewable energy? And can the energy sector decarbonise in the timeline needed to avert a far greater crisis than COVID-19 – climate breakdown?

Front-load net zero, now

The urgency of the climate crisis demands that the power sector pioneers the rapid decarbonisation of economies worldwide. Moreover, our modelling of energy systems in both advanced and developing economies, from California to India, supports the inarguable economic case for utilities to lead the transition, rather than being shaped by it. Countries must front-load the transition towards net zero, taking major steps in the next five to eight years to tackle the climate crisis.

The technology we need for net zero already exists – we just need clear transition planning to ensure investment flows to the right places at the right times.

Critically, it's not just economics that's driving the energy transition. Our leaders attending COP26 must be prepared to pledge commitments that are generous enough to avert global climate breakdown. Today's global targets for 2030 are nowhere near enough to meet the Paris targets, as the United Nations (UN) has made clear. Globally, we must halve emissions over the next decade alone. That means taking the most action in the next five to eight years. If we front-load action on emissions this decade, we increase our chances of meeting climate goals, and allow greater flexibility down the road as we decarbonise difficult-to-abate sectors, such as heavy industry and transport.

It is the job of every power company to now put strategies and capital in place to navigate to net zero and to embed flexibility at the heart of grids to unlock 100% renewable energy systems. As we emerge from the COVID-19 pandemic, we can lay the foundations for a smoother transition to a decarbonised world. To achieve this, utilities must commit to front-loading their efforts and investment strategies. Not only will this unlock a wealth of new commercial opportunities in a transformed power market, the very future of our species depends on it.

FRONT-LOADING NET ZERO – INTRODUCTION

As global leaders prepare to gather in Glasgow, UK for the COP26 climate summit, there is cause both for optimism about this – our greatest opportunity to decarbonise – as well as deep concern about whether, as a global community, we take the necessary action this decade to make a net zero future viable.

According to the IEA's landmark 2050 roadmap[5], there is a viable pathway to build a global net zero emissions energy sector by 2050, but it is narrow and calls for a transformation in how energy is produced, transported and used globally.

Fuel combustion for electricity and heating generated nearly 14 gigatonnes of CO_2 in 2018, accounting for over 40% of CO_2 emissions related to fossil fuel combustion[6] and close to 30% of the world's total greenhouse gas (GHG) emissions[7]. Coal use in power alone surpassed 10 gigatonnes of CO_2, mostly coming from Asia[8].

The economics is on our side. Power generation is undergoing fast transformation towards cleaner energy sources due to low-cost renewables. In addition, rapidly maturing energy storage technologies, together with sector coupling, are for the first time paving a route towards zero-emission electricity generation. The missing piece of the puzzle is viable long-term storage which will be needed to provide megawatts of capacity and megawatt hours of energy during long duration seasonal conditions or unexpected renewable droughts. Hydrogen-based sustainable fuels can be stored in large quantities and for extended periods at power plants for long periods of use, enabling clean capacity to be cost effectively scaled up according to the needs of grids.

The Intergovernmental Panel on Climate Change (IPCC) recommends that to limit global warming to 1.5C°, global CO_2 emissions should decline by 45% by 2030 in comparison to 2010 and reach net zero by 2050. The latest IPCC report finds that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, the opportunity to limit warming to close to 1.5°C or even 2°C will slip beyond our reach. A rapid acceleration in renewable energy output can provide the near-term emissions reductions that are crucial for holding the global temperature rise to 1.5C°, but only if pathways to 100% renewables are fully embraced by energy leaders.

To illustrate the measures needed for cost-optimal paths to 100% renewable electricity, in this report Wärtsilä has modelled the transition to 100% renewable electricity generation in three key countries and regions. They have vastly different socioeconomic dynamics, energy systems, and challenges to overcome, but they are unified in their commitment to transform.

- **California** – A global transition pioneer on a legally binding trajectory to build a 100% renewable energy system by 2045, California must rapidly accelerate its adoption of wind and solar to unlock significant savings, both in terms of energy cost and CO_2 output.
- **India** – An economy on an astonishing growth trajectory, India must align its net zero ambition with its rapidly rising demand for energy, while ensuring that coal no longer enters the power system.
- **Germany** – A country with world-leading experience of scaling up renewables and ambitious climate targets, Germany now faces the monumental challenge to phase out coal by 2030, before fully decarbonising – setting a blueprint for coal phase-outs in countries worldwide.

As well as the modelling, this report also includes on-the-ground insights from Wärtsilä's experts on the risks and opportunities facing the following countries through the energy transition:

- **Australia** – A potential renewable superpower, Australia has for the first time reached a consensus on its pathway to net zero – but to progress to a secure and clean future, fossil fuel baseload power must be left behind.
- **Chile** – An emerging leader in clean power production, Chile must capitalise on its enviable renewable power capacity factors while accelerating its coal phase-out.
- **UK** – As the COP26 host, the UK has set a world-leading target for a net zero power system by 2035 – but to realise its ambition, it must double down on wind and flexibility this decade.

Decarbonisation is feasible with current technologies – and does not cost more

The modelling results illustrate that the transition from fossil-based to 100% renewable electricity generation will not increase the cost of electricity in comparison to today. In simplified terms, the capital investments needed in new renewable generation output and balancing power to deal with its intermittency are more than offset by the savings in fossil fuel use.

Our country-level analysis clearly shows decarbonisation is not just possible – it is technically and commercially feasible with technologies that are already available at scale. These technologies include:

- Wind and solar photovoltaic (PV) as the main sources of primary energy.
- Short-duration battery energy storage.
- Flexible thermal balancing power plants to provide firm and dispatchable capacity.
- Sustainable fuels used in thermal balancing power plants, forming long-term energy storage. (Sustainable fuels include green hydrogen and hydrogen-based fuels, such as ammonia, methanol and synthetic methane produced from renewable sources).

THE KEY STEPS TO

FRONT-LOAD NET ZERO

Running hours of legacy power plants decrease.
+
Curtailment of RES increase due to system inflexibility.

Keep adding renewables supported by flexibility.

Utilise P2X and flexible thermal plants to provide carbon neutral long-term storage.

1

ADD RENEWABLES

Build conditions that enable additions of renewable electricity sources as quickly as possible.

2

ADD THERMAL BALANCING AND STORAGE

Build conditions that enable investments in energy storage and thermal balancing power plants.

3

PHASE OUT INFLEXIBLE PLANTS

Once there is sufficient renewable output, battery storage and thermal balancing power plant capacity in the system, retire legacy inflexible plants, such as coal.

4

CONVERT TO SUSTAINABLE FUELS

Leaders must create the conditions to build new Power-to-X capacity for sustainable fuel production and convert thermal balancing power plants to run on that fuel.

5

PHASE OUT FOSSIL FUELS

Phase out any remaining fossil fuel capacity.

0 – 20%

20 – 80%

80 – 100%

SHARE OF RENEWABLE ENERGY SOURCES

DEEP DIVE COUNTRY ANALYSIS

CALIFORNIA

CALIFORNIA'S CHEAPER, FASTER PATH TO 100% RENEWABLE ENERGY BY 2040

Dr. Karl Meeusen, Director, Markets, Legislative and Regulatory Policy, Wärtsilä Energy
Antti Alahäivälä, General Manager, Business Development, Wärtsilä Energy

The U.S. state of California is a global pioneer, leading the clean power transition in setting the requirement for 60% of retail power sales to be met by eligible renewable energy by 2030 and 100% by 2045[9]. California has consistently set, and met, some of the boldest environmental and energy targets in the world. In 2011, when California set a 33% Renewable Portfolio Standard (RPS) target by 2020[10], many felt that this goal was not achievable without degrading system reliability. However, the state has shown not only that 33% is achievable, but that much more, reaching 100% clean energy by 2045, is also possible.

As renewable penetration increased, so too did the stress on California's existing grid resources. Many of the existing sources are simply not equipped to provide all of the services necessary to fully complement wind and solar resources. As a result, instead of moving thermal resources to adapt to renewable output, renewable output has been forced to adapt to the inflexibility of thermal resources. This can be clearly seen through the levels of renewable curtailment in the California Independent System Operator (CAISO). The CAISO is regularly forced to curtail wind and solar as inflexible resources cannot be quickly ramped up and down.

If California's grid is properly planned it is possible to meet 100% RPS by 2040 and become fully carbon neutral by 2045 – and it will cut the cost of generating electricity.

A 100% renewable electricity system is viable – and costs less

Given the key decisions California will make in the next few years to realise California's Senate Bill 100 (SB100) to shift to 100% carbon-free electricity, Wärtsilä has conducted system modelling for California to understand the optimal pathway to transform the energy mix while protecting stability and affordability. The results show that if California's grid is properly planned it is possible to meet 100% RPS by 2040 and become fully carbon neutral by 2045 – and it will cut the cost of generating electricity.

The following first introduces the design challenges faced in California during the transition to a 100% carbon neutral system, after which the core modelling results will be presented.

Mitigating future blackouts

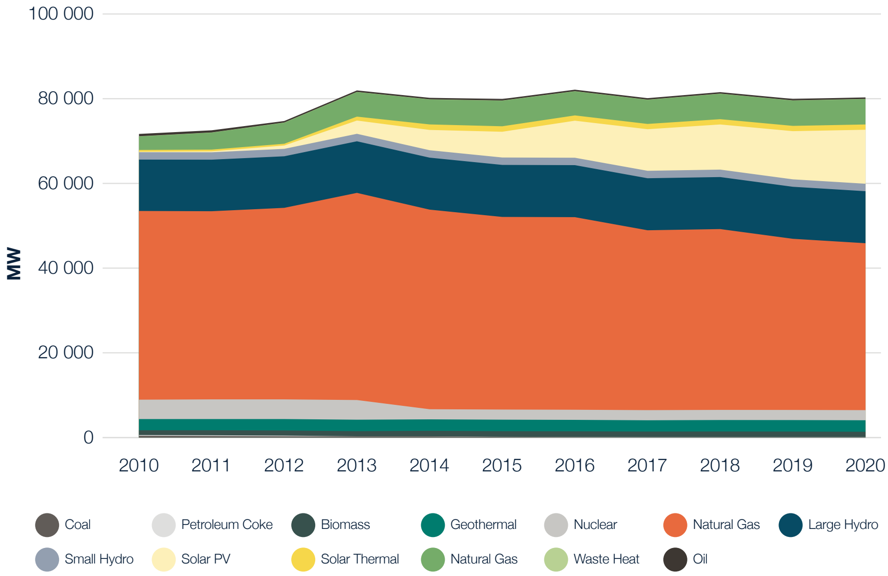
California can reach its goal of serving 100% of retail load with renewable energy. However, this cannot be achieved with its current portfolio of resources. The rolling blackouts in summer 2020 show that California needs additional resources to supplement the tools already in place. More specifically, California needs new resources that complement the wind, solar, and hydro needed for a shift to a 100% renewable electricity system. Slow ramping, long start, baseload resources must be replaced by faster, more flexible resources that are capable of running on sustainable fuels. Sustainable fuels produced by excess wind and solar energy, plus storage resources, can enable California to cleanly and reliably shift energy from low-net loads, (when power demand is low and wind and solar energy production are at their highest), to high-net loads (when renewable generation is at its lowest and demand is highest).

California must plan an integrated and complementary portfolio of resources

The key to successfully navigating California's transition is planning. It is no longer sufficient to simply create a stack of capacity, compare it to forecasted peak load, and build more if there is not enough capacity to serve that load. To realise California's transformational renewable goals, the whole system must be studied to determine that there is both enough reliable capacity to meet peak and that the resources work symbiotically to ensure adequate energy is available during all hours.

For example, just prior to the summer 2020 blackouts, the CAISO was forced to shed load – not at 2:00pm when solar power was available – but at 6:38pm, when solar generation plummets[11]. Resources that help sustain output from solar resources as the sun sets or come online quickly when outages and derates start to occur could have mitigated many of the challenges the CAISO faced on those days.

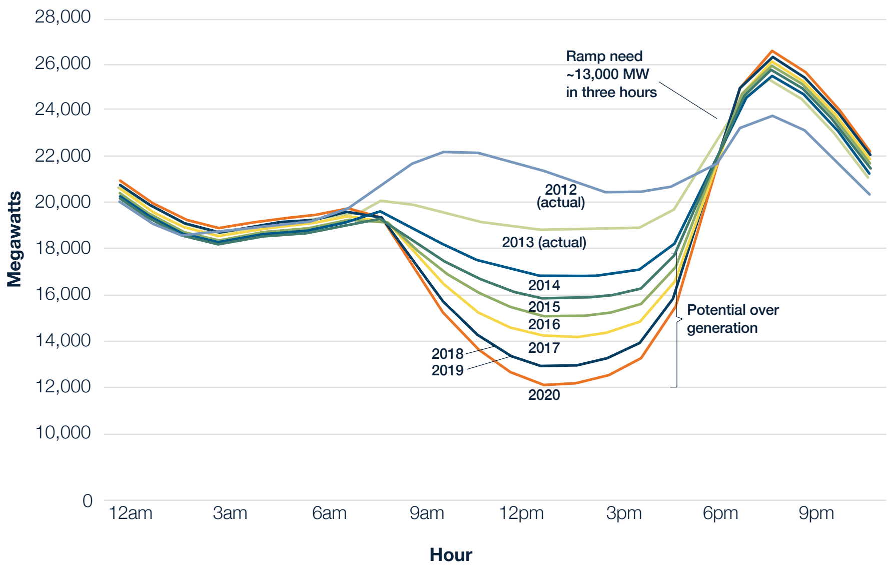
California's power systems have transformed since 2010[12]:



California's Internal Resource Mix, California's generation mix has altered radically in the last ten years, shown by this graph of installed capacity between 2010 and 2020.

Building flexibility to support the shift to renewable baseload

At current volumes, California's existing solar PV capacity has revealed numerous challenges for the future grid. The CAISO introduced the "duck curve" to the world almost ten years ago, but the state has still not completely solved the four main issues captured by this famous illustration: belly (low net-load), neck (long sustained steep ramps), head (net-load peaks after sunset), and feathers (variable output and forecast error). Overall load also varies significantly due to proliferation of behind-the-meter-solar, bringing additional grid volatility (especially between day-ahead forecast to the actual real-time load).

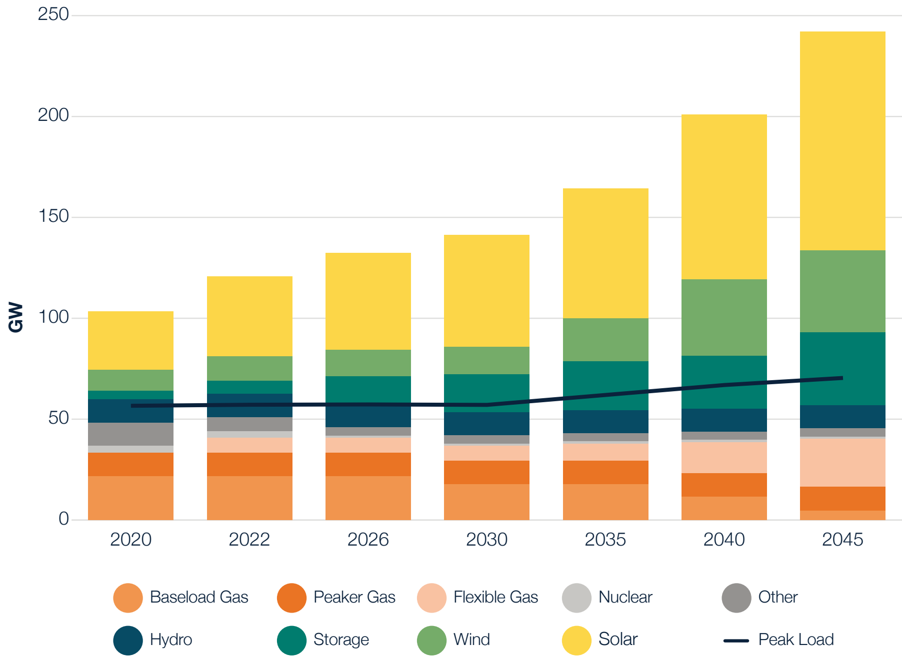


Net Load – March 31, CAISO duck curve, showing the risk of steep ramping and overgeneration[13].

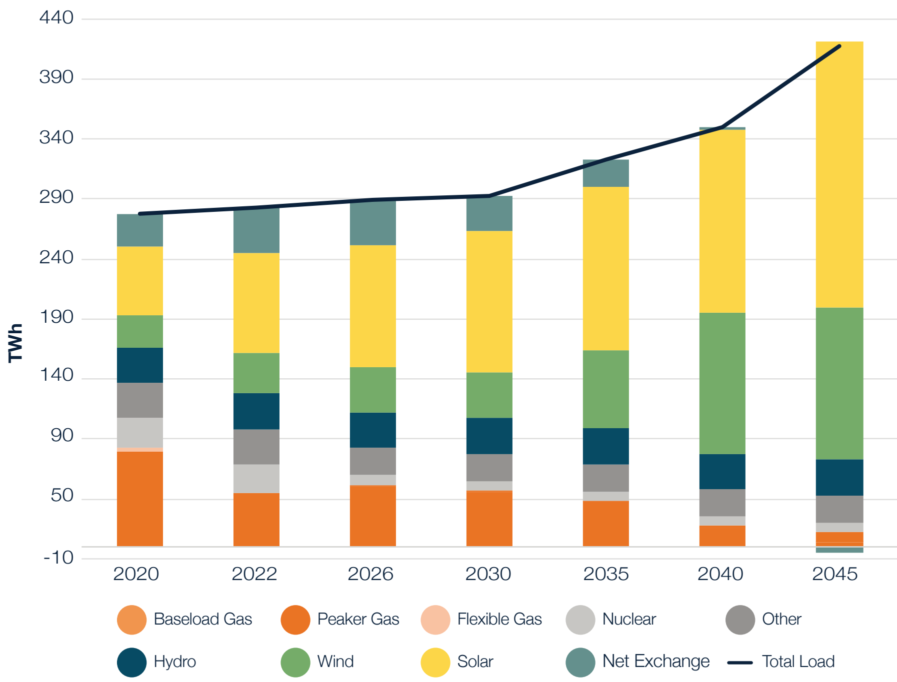
California's Senate Bill 100 demands the system plan for both MW and MWh

As Wärtsilä's modelling results in the next graph show, California's forecasted peak load is only expected to increase from 57 GW to 70 GW, a 23% increase. However, the overall TWh of consumption will increase from 280 TWh to 420 TWh by 2045, meaning a 50% increase. This growth is driven by the electrification of the society, which introduces, for example, electric vehicles and the production of sustainable fuels from wind and solar PV generation.

Installed Capacity, Optimised capacity mix to meet 60% RPS by 2030, 100% RPS by 2040 and to become fully carbon neutral by 2045.



Generation, Optimised generation mix during the transition to carbon neutrality. Total load contains customer load, electric vehicle charging, production of sustainable fuels, and losses in battery and pump storage. In the figure, Net Exchange = Import - Export



To meet its SB100 objectives, California will continue to require significant wind and solar additions. More specifically, California needs to add an average of 3.2 GW of solar PV and 1.2 GW of wind annually every year through 2045. To put this into context, the state has never built more than 2.7 GW of non-rooftop solar power or 1 GW of wind power in a single year.

To achieve this in the model, wind and solar are expanded by optimisation, from 10 GW and 29 GW, respectively, in 2020 to 40 GW and 109 GW in 2045. This wind and solar capacity will be needed not only to serve load through mid-day peaks but also to charge short and long duration storage resources to serve load during non-solar hours. Adding solar capacity and wind capacity (MWs) well in excess of forecasted peak load, when paired with storage resources, offered the lowest cost solution to 'right-sizing' the needed energy (MWhs). As a result, the model shows storage capacity increasing from four GW in 2020 to 36 GW in 2045.

California will also need to replace 11 GW of baseload and peaking gas resources with flexible, dispatchable capacity resources that are capable of frequent low-cost, low/no-emissions starts and stops[14]. Any remaining base or peaking capacity will be used extremely infrequently, typically only in the event of localised or system emergencies. Finally, the model shows that 'Power-to-Gas' is the final element needed to achieve California's goals. Power-to-Gas converts excess wind and solar energy to sustainable fuels and stores them for later use, to cover reliability needs, plus multi-day extreme weather conditions and uncertainty. Flexible thermal resources should be either running on sustainable fuels or, at a minimum, be easily convertible over time. 10 GW of Power-to-Gas capacity would be enough to produce the sustainable fuels for California's power sector's needs.

A 100% Renewable system is affordable

Decarbonising electricity generation does not need to be expensive. Wind and solar prices have declined over the past years, and they have become competitive in many parts of the world. This decline is expected to continue, which can even lead to lower electricity prices during the path to a 100% carbon neutral system.

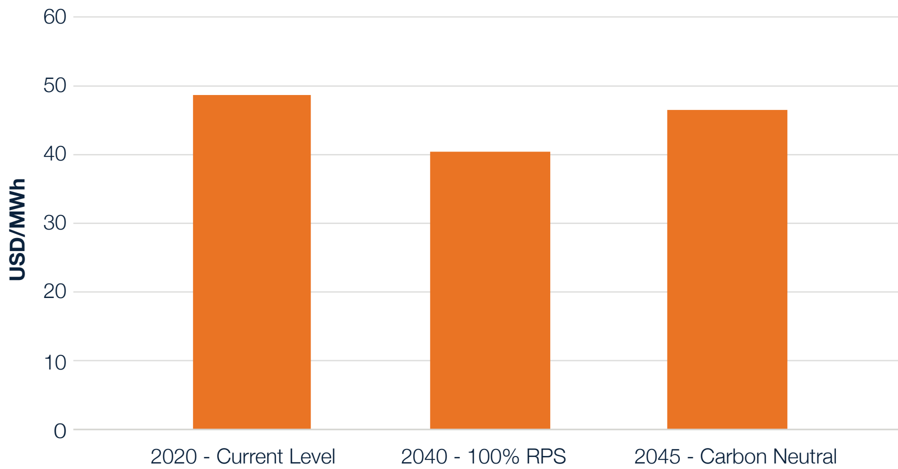
Wärtsilä's modelling plans for California's energy system to be first 100% RPS compliant in 2040, five years ahead of schedule, before becoming fully carbon neutral in 2045. The results reveal that:

- Reaching the 100% RPS target in 2040 reduces the cost of electricity by 17% compared to 2020 levels.
- Becoming fully carbon neutral in 2045 reduces the cost of electricity by four percent compared to 2020 levels.

The lower cost of the faster decarbonisation is enabled due to reductions in fossil fuels such as natural gas and coal which currently serve as baseload. During the transition to carbon neutrality, the electricity produced by these fossil sources is replaced by economic solar PV and wind generation, which are reducing in price from year to year. The affordable energy from renewables together with battery storage and long-term energy storage from sustainable fuels enable a cost optimal power system with lower generation costs.

The 100% RPS still allows the use of fossil fuels to some extent, so to ensure that the system is carbon neutral these fuels would need to be replaced by sustainable fuels. In the modelling, this is done by 2045, which slightly increases the cost of electricity but still provides lower LCOE compared to today's situation. This can be seen in the figure below.

Levelised Cost of Electricity, LCOE during the transition to a carbon neutral system. The costs include the opex and capex of generation, storage and production of sustainable fuels.



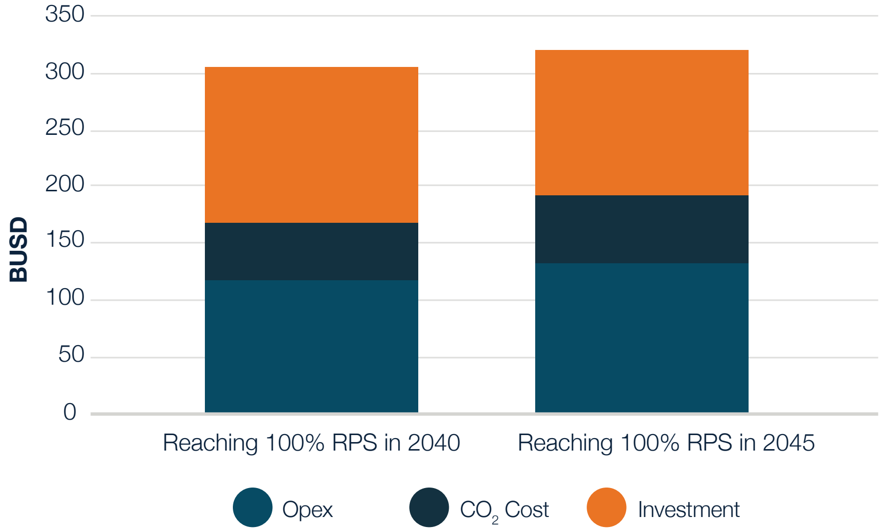
Invest or wait - limiting exposure to carbon risk and cost

The 'Inevitable Policy Response'[15] analysis forecasts that policy responses to climate change will necessarily become more forceful, due to the delay of decarbonisation. As a result, they forecast that all major economies will institute carbon pricing schemes covering power and industrial emissions by 2030, causing carbon to hit $65 USD per tonne by 2030 in the U.S. This is more than three times higher than California's current carbon price level, plus the Inevitable Policy Response forecasts that prices will increase steadily after 2030.

Based on this policy direction, Wärtsilä's modelling indicates that front-loading the transition and reaching the 100% RPS in 2040 is a more economic option than pursuing 100% RPS in 2045. The slower path to 100% renewables, reaching 100% RPS by 2045, would cost $14 billion USD more. This represents a 5% increase on the cost of decarbonisation.

As the next graph shows, faster decarbonisation needs marginally greater capital investment. However, these increased capital costs are more than offset by reduced operating expenses and CO_2 costs (largely due to the removal of carbon intensive fossil fuels) – leading to an overall net reduction in cost.

To reduce exposure to rising carbon prices, once again, the business case to front-load the building of renewable baseload, underpinned by flexibility, is the most economic route.



Total Cost over the Path to Carbon Neutrality, Total cost of reaching carbon neutrality in the front-loaded case (100% RPS in 2040) and in the slower case (100% RPS in 2045).

Sustainable fuels acting as long-duration storage: the missing link of SB100

A key piece of the 100% emissions-free electricity puzzle is to deploy significant amounts of long-duration energy storage, especially from 2030 onwards. The need to meet daily ramping needs and energy requirements covering a few hours, is currently driving the rapid adoption of short duration battery energy storage. As the market becomes saturated, however, the marginal value per kilowatt hour (kWh) of storage will diminish after 2030.

Following 2030, multi-day or seasonal week-long gaps between supply and demand will require larger quantities of storage capacity, with lower use rates. This is where long duration energy storage and sustainable fuels come in. California has only recently recognised the need for long-duration storage, but the state seems to still dramatically underestimate the need. The California Public Utilities Commission (PUC) recently ruled that load-serving entities must procure 11.5 GW of incremental capacity by 2026, but only one GW of this capacity must come from long-duration energy storage . This contrasts with a recent study conducted by Strategen, which forecasts that the state must deploy between 45GW - 55GW of long-duration energy storage[16].

The planning and operational needs required from long-duration resources demands detailed and thorough studies and potentially long lead times. Therefore, waiting until the transition is required means that California will have already waited too long. The planning and studies for this phase of the transition are urgently required today – with much greater focus on next generation energy storage, including clean bridging fuels.

Hydrogen-based sustainable fuels created from excess renewable energy can meet California's demand for firm, fast-starting capacity. As well as offering green, firm capacity, sustainable fuels can be stored for many months and can release megawatts of power within minutes when needed, when combusted within thermal balancing power plants.

> "Hydrogen-based renewable fuels can bridge the critical 10% – 20% gap to full decarbonisation of the electricity sector."

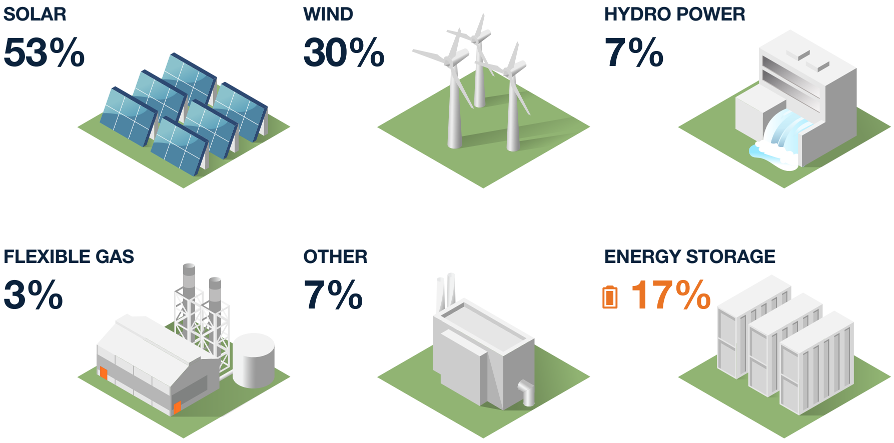
With the right planning, hydrogen-based sustainable fuels can become the missing link of the SB100, bridging the critical 10% - 20% gap to full decarbonisation of the electricity sector. Synthetic methane, for example, can be produced through Power-to-X processes and can already be used in existing energy infrastructure, plus it's easy to transport – these are all key factors in keeping with a fast Californian decarbonisation. The use of sustainable fuels, such as synthetic methane, in the mid to long-term can provide a clean transition as California explores the long-term cost effectiveness of additional infrastructure upgrades and investments needed for fuels like pure hydrogen, including investments in pipelines, storage, and hydrogen-ready generation resources.

SB100 is viable with the right planning

With strong leadership and adequate planning, California's ambitious 100% renewable energy goals are achievable. As demonstrated by the August 2020 rolling blackouts, additional resources and planning are required. However, if California sets a path today, it can not only reach its lofty renewable energy goals, but it can do so sooner and at a lower cost than if it waits until 2045. As wind and solar continue to expand, emerging storage and flexible 'green' fuel technologies will provide the most cost-effective means of storing excess renewable energy for use when and where needed to ensure reliability.

CALIFORNIA RUNNING ON 100% RENEWABLES

Share of annual electricity generation



INDIA

A NET ZERO POWER SECTOR IS THE PATHWAY OF LEAST COST AND GREATEST OPPORTUNITY FOR INDIA

Sandeep Sarin, Market Development Manager, Wärtsilä Energy

In less than a decade, the role that renewable energy plays in India's power generation mix has moved from margin to mainstream. Back in those earlier days, both global and local actors from across the utility industry dismissed discussions on increasing the share of renewable generation for meeting electricity demand as unrealistic. The concept of integrating variable sources of generation into India's legacy system, which is designed for stable operations, was thought to be far-fetched. Since then, renewable generation technologies have gained momentum, primarily because of falling costs of renewables, and enabling policies and regulatory frameworks. The recent foray by major Indian conglomerates into the renewable sector, coupled with the renewed ambition of the government to scale up renewable deployment and manufacturing of solar and batteries, are clear signals that clean energy is the future in India.

However, as world leaders prepare to discuss the actions required to address the climate emergency during the ensuing COP26 meeting in Glasgow, the international community has high expectations for India. To date, 59 countries, representing 54% of global GHG emissions, have communicated net zero emissions targets[18], including the world's two largest emitters – the

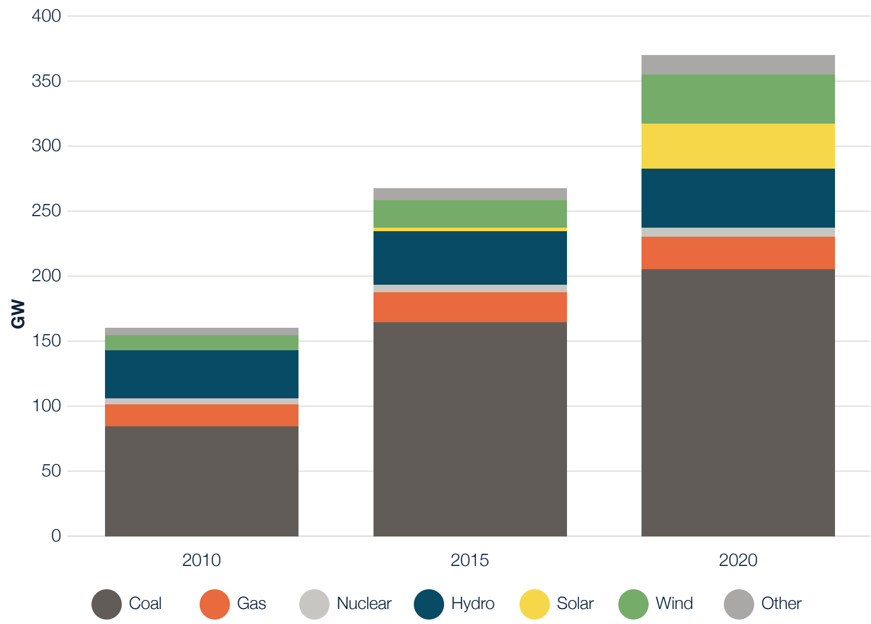
As the world's fourth-largest carbon emitter, India's ability to meet its energy demand using clean energy is essential, both to powering its rapidly expanding economy and stabilising climate change.

United States and China. The world desperately needs India to join the movement of countries committed to limiting global warming to 1.5°C by the middle of the century. As the world's fourth-largest carbon emitter, India's ability to meet its energy demand using clean energy is essential, both to powering its rapidly expanding economy and stabilising climate change.

Realigning India's ambition with global decarbonisation agenda by 2050

In the 2015 Paris Agreement, India committed to reduce its greenhouse gas (GHG) emissions intensity by 33–35% (below 2005 levels) and to produce 40% of its electricity from non-fossil sources by 2030[19]. India has taken remarkable strides in increasing the share of renewables in the electricity mix. Since 2015, 36 GW of solar and 16 GW of wind has been added to the system; increasing the share of renewables to 25% in 2021 from 14% in 2015[20].

India's installed capacity (GW).



Despite the increasing share of renewables in India's capacity mix, carbon emissions from the power sector have inched upwards by 255 million tonnes of CO_2 since 2015. The increased share of coal power generation in the electricity mix, to the tune of around 38 GW since 2015, is the crucial reason behind the relative rise in emissions. Considerable investments in coal-fired power plants commenced from 2010 to meet the shortfall in energy and peak demand in the country.

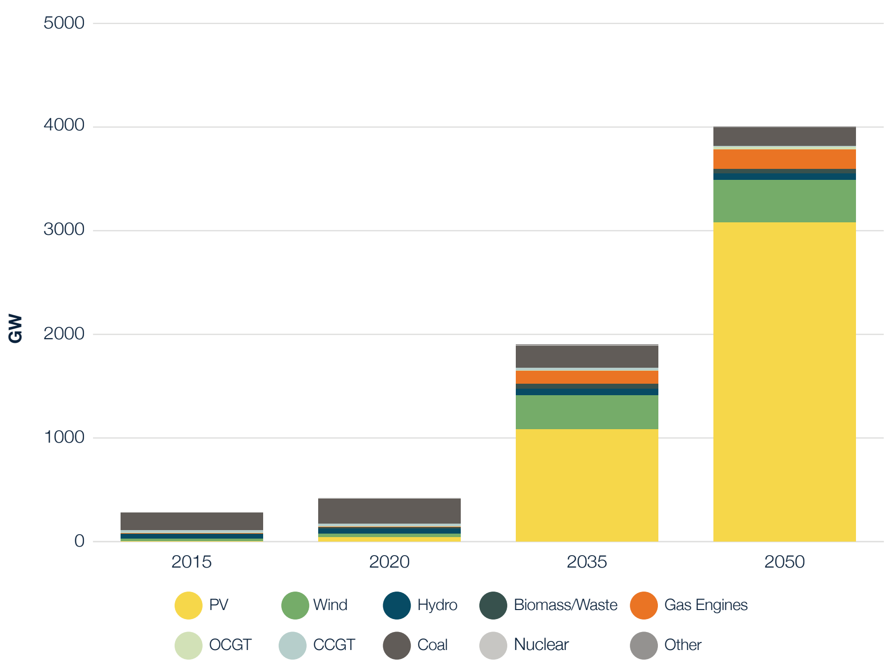
However, the improving economics of renewable power generation, both solar and wind, has brought a significant shift in capacity planning exercised at the state and the central level. A report published by Central Electricity Authority (CEA), a technical think-tank of the Ministry of Power, on Optimal Power Generation Mix 2030, reveals how renewables will become a mainstream source of power generation. The report discloses that by 2030, the share of renewables in the electricity mix will be 420 GW[21], representing around 51% of the overall projected installed capacity in the country, with no significant increase in coal capacity.

These are ambitious targets for India to achieve. However, there is a need to look beyond 2030 and set targets that are aligned to limit global temperatures to below 1.5°C by the middle of the century. The International Energy Agency (IEA)'s recent 'India Energy Outlook 2021'[22] mentions that "all roads to successful global clean energy transitions go via India", highlighting its critical contribution to global climate action and ability to show emerging and developing economies that a clean energy transition is viable.

India's clean energy transition is also the pathway of least cost

The transition away from fossil fuels is challenging and is often considered expensive. However, a power system modelling study – jointly carried out by Lappeenranta-Lahti University of Technology (LUT) and Wärtsilä to explore the feasibility of a net zero emissions power system in India by 2050 – shows that renewables, when paired with flexible generation technologies (thermal balancing power plants and energy storage) can improve the affordability of electricity while ensuring the reliability of system operations. Moreover, the study presents some interesting findings that could inform the government's choices in building a carbon neutral power system in India.

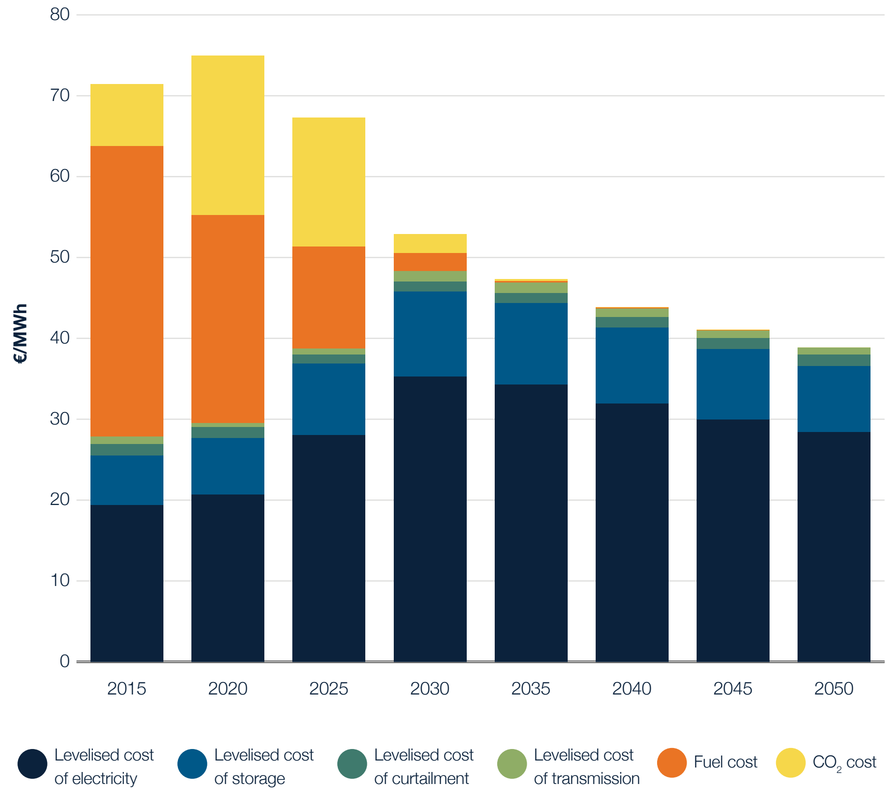
Firstly, solar dominates the energy transition. The study reveals that India would need around 4,000 GW of installed capacity, an increase of around 10-fold in comparison to 2020 capacity, to meet 5,921 TWh of electricity demand and 1,023 GW of peak demand over the next three decades up to 2050. The total solar capacity is projected to be around 3,076 GW or 76% of the total installed capacity base, in 2050. Other sources of generation such as wind, hydro and gas make up for the remaining 24% of the capacity mix. India's abundant sunshine – about 300 sunny days in a year – and falling cost of solar PV technology, makes solar generation an ideal candidate to provide renewable baseload for the country's transition to clean, affordable power.



Installed Capacity, Projected Installed Capacity (GW).

Secondly, the study reveals that a cost-optimal carbon neutral power mix, where renewables are the mainstay of power generation, can cut the per megawatt hour cost of meeting electricity demand by 48%, from 6,000 INR/MWh ($81 USD/MWh) in 2020, to 3,120 INR/MWh ($42 USD/MWh) in 2050. This cost, also referred to as overall system cost, includes: the levelised cost of electricity generation, the cost of energy storage, transmission interconnections, as well as the costs of curtailing surplus renewable generation, which at times may not get absorbed by the system.

Levelised Cost of Electricity.



A cost-optimal carbon neutral power mix, where renewables are the mainstay of power generation, can cut the per megawatt hour cost of meeting electricity demand by 48%.

Flexibility helps bring down system-level costs

Building a power system on renewables alone is not feasible, as renewables are intermittent sources of electricity generation. This means that on cloudy, or windless days, solar and wind generate less than their installed capacity would suggest. Therefore, solar and wind need to be supplemented by other sources of flexible generation (technologies that can scale to full output in less than two minutes) such as thermal balancing power plants or battery energy storage. Together these technologies can provide more than enough electricity to support the smooth functioning of the grid, from seconds to minutes, or hours, depending upon system requirements.

The modelling also demonstrates that, by 2050, India would need some 99 TWh of storage capacity and a total of 187 GW of gas engines[23]. Storage capacity includes storage in the form of both batteries and gas storage – mainly in the form of sustainable fuels (green hydrogen, methane etc). Together, these technologies form the backbone of a reliable, cost optimal power system for India.

Energy storage, mainly battery storage, is used to shift generation when it is surplus, during the day, to a time of the day when renewables are not available, during evening or night-time. On the other hand, energy storage in the form of sustainable fuels, such as green hydrogen and methane etc., is mainly used to manage seasonal electricity demand when generation from renewables is lowest.

Contrary to shifting applications, which is where battery energy storage is useful, there are multiple time blocks throughout the year when India's power system must be balanced for a sudden surge in demand or instant drop in generation due to renewable droughts. For such applications, gas engines emerge as the most cost-optimal solution for managing the power system. For 2050, we analysed that gas engines will play a relatively small, but nevertheless crucial back-up role, providing a 1.1% share of electricity generation. Another important reason that thermal balancing power plants play a crucial role in decarbonising the power system is their ability to burn synthetic fuels to generate electricity.

Currently, Wärtsilä's engines can run on a 25% share of green hydrogen and we expect to have an engine and power plant concept capable of running on 100% hydrogen by 2025, making them an ideal candidate for decarbonising India's power system.

The benefits of the energy transition stretch well beyond a least-cost pathway for India

India has been trying to arrest its inflating fuel import bill for some time. Currently, India imports 76% of crude oil, 50% of gas, and 27% of coal to meet its energy requirements. The prices of these fuels have a significant impact on the import bill, to the tune of INR 9 trillion ($123 billion USD), which is a drag on the Treasury and India's foreign exchange reserves. In its recent report, 'The India Energy Outlook 2021', the International Energy Agency (IEA) estimates that India's import bill will likely increase to INR 17 trillion ($228 billion USD) by 2030 due to increased demand, further increasing India's current account deficit.

Converting renewable generation into synthetic fuels, is key to reducing India's dependence on imported fuels.

Converting renewable generation into synthetic fuels, mainly green hydrogen, is key to reducing India's dependence on imported fuels. Over time, as the cost of producing green hydrogen or other sustainable fuels (such as ammonia or synthetic methane) falls, these fuels can replace some of India's energy imports as a versatile energy carrier. Given India's record low solar power prices (INR 1.99 / $2.7 cents USD per KWh[24]) and the rapidly declining cost of solar generation due to technological advancement, it is feasible to displace fossil fuels with green hydrogen or other sustainable fuels.

For decarbonising the power sector alone, the modelling study, carried out by LUT and Wärtsilä, demonstrates that by 2050 India would require 142 TWh or 3.6 million tonnes of green hydrogen - also used for producing other sustainable fuels such as ammonia or synthetic methane. Investment to the tune of INR 446 billion ($6 billion USD) is needed in gas storage and electrolysers to meet the projected demand for green hydrogen over the next three decades. Expanding green hydrogen use for decarbonising the entire energy sector (power, heat, and transport) will significantly increase its demand to over 89.2 million tonnes in India by 2050. Currently, India consumes around 6.7 million tonnes of hydrogen, 5.8 percent of global consumption, for refining and ammonia manufacturing for fertilisers. Most of the hydrogen today is produced using fossil fuels - also known as 'grey hydrogen.' However, meeting the projected demand for green hydrogen will require setting up around 1,355 GW of electrolyser capacity in the country.

A clean power system can catalyse India's transformation into a clean energy powerhouse.

Domestic manufacturing of electrolysers - devices used to split water (H2O) into hydrogen (H2) and oxygen (O2) - and production of green hydrogen could create a new green technology market worth INR 3 trillion ($39.8 billion USD), considering only electrolysers and gas storage, in India by 2050. Investment of this scale will not only boost economic activity but will also create domestic jobs. Furthermore, the domestic availability of green hydrogen may attract high-value green industries, like green steel or chemicals, to the local market. India has a massive opportunity to take a leading position in exporting high-value green products or sustainable fuels to emerging demand centres globally.

Investment in India's transition is an investment in a global clean future

The modelling study demonstrates that building a net zero emissions power system by 2050 is in India's interest. A clean power system can catalyse India's transformation into a clean energy powerhouse; lifting millions from poverty, creating new jobs, insulating India from energy shocks and at the same time contributing towards the global goal of limiting the temperature rise to below 1.5°C.

KEY STEPS FOR INDIA TO DECARBONISE ITS POWER SYSTEM BY 2050

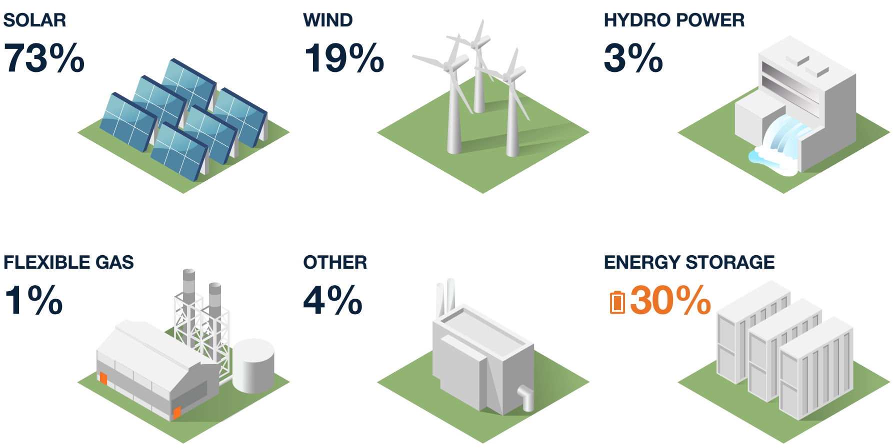
1. India should set ambitious clean energy targets over longer-term time horizons to create visibility for investors.

2. Increase regulatory pressure on companies to go green. This will include mandating consumers and load-serving entities to meet a certain percentage of their requirements from renewable sources. These targets should be aligned with the long-term vision of decarbonising the power system.

3. Strengthen supply-side flexibility by introducing market mechanisms to attract investments in flexible generation technologies, such as thermal balancing power plants and battery storage. Presently, the power market in India does not offer enough incentives for investments in such technologies. Currently, all grid reliability services are procured from inflexible legacy power plants – these plants will not be able to effectively support the grid as the share of renewables increases.

4. Launch an incentive program for production of electrolysers (as capital costs are responsible for 30% of the cost of green hydrogen), and create new demand centres equipped to cost-effectively off-take and transport green hydrogen.

The opportunities for India are immense. The modelling study demonstrates that India could cost-effectively leapfrog other developed nations into a sustainable future. As most of its infrastructure has yet to be built, India can secure its clean transition with domestically produced green energy - to power major socioeconomic benefit for its people.



INDIA CENTRAL SOUTH RUNNING ON 100 % RENEWABLES

Share of annual electricity generation

GERMANY

CROSSING THE BRIDGE TO A NET ZERO GERMAN POWER SYSTEM

Jan Andersson, European Market Development Manager, Wärtsilä Energy

Given Germany lies at the centre of a spiders' web of national interconnections, their ability to decarbonise is pivotal to the decarbonisation of Europe.

An early leader in the renewable transition

Germany's energy transition is somewhat paradoxical. On one hand, the government's progressive policies have enabled Germany to become one of the world's earliest adopters of grid-scale renewable technologies. While, at the opposite extreme, the country continues to operate Europe's largest fleet of coal power stations, with an installed capacity of close to 40 GW.

Given Germany lies at the centre of a spiders' web of national interconnections, their ability to decarbonise is pivotal to the decarbonisation of Europe, the world's third biggest emitter.

Having long recognised the environmental burden of its legacy coal assets, in 2020 Germany struck a historic deal to provide €40 billion to help its coal-producing regions to phase-out coal-fired power by 2038. Building on this action, in April 2021 Germany brought its net zero target forward – from 2050 to 2045. As a signal of intent, Germany also set carbon reduction milestones to 2045, raising its 2030 target from 55% to 65%, based on 1990 levels, while setting a target to cut CO_2 emissions by 88% by 2040.

Germany's new national targets represent a profound shift for the power sector. Utilities must decarbonise even earlier than 2045 to allow time for hard-to-abate sectors, such as heavy industry, to make the same transition.

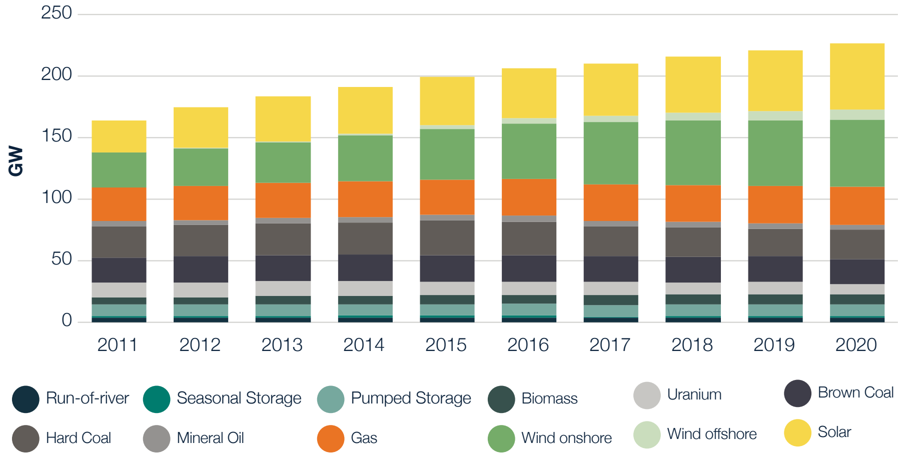
The Energiewende – pioneering, but costly for Germany's power sector

Germany first set out its historic 'Energiewende' in 2000, as a pioneering nationwide initiative to transform the country's energy system – to meet demand for both utility-scale and domestic energy via renewable energy. The policy goal to progressively raise the share of solar and wind in Germany's capacity mix has succeeded, however, hard and brown coal has persisted in the system.

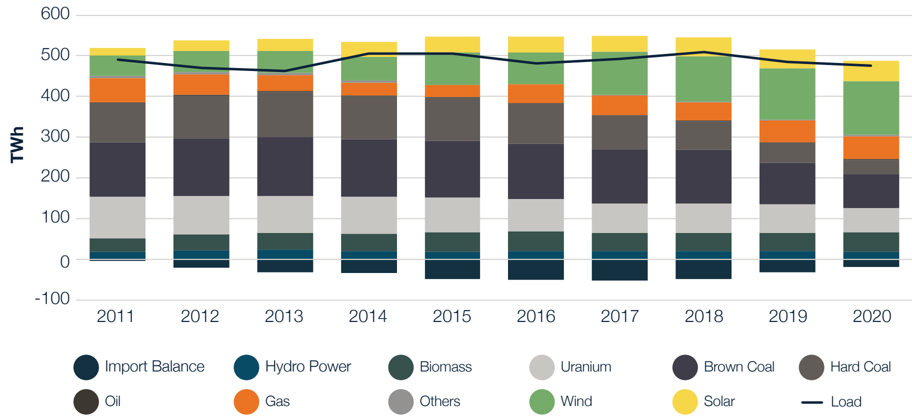
Furthermore, in the aftermath of the 2011 Fukushima disaster in Japan, the German government resolved to retire all 17 of its nuclear power plants by 2022. Replacing this coal and nuclear capacity with renewables is a massive undertaking, demanding that the energy coming from renewable sources rises from 50% of the 2020 electricity mix to 65% by 2030. In the past, high volumes of inflexible coal generation have prevented renewables from fulfilling their role as the most affordable generation source available; since a lack of system flexibility has meant that high periods of renewable energy generation have led to negative wholesale electricity prices, or heavy curtailment costs to remove power that cannot be utilised.

These factors have caused Germany's early leadership in the renewable energy race to come at a cost, with the surcharge for increasing renewable energy levelled at consumers' power bills. Even today, Germany's renewable tax[25] is around €65/MWh, around a quarter of the average household energy bill. To meet carbon targets and replace the coal capacity gap, while retaining consumer confidence, it's vital for utilities to find the most affordable pathway to net zero.

Germany capacity mix 2011–2020.



Germany energy mix 2011–2020.



Germany's headstart on renewable energy places the country in a strong position to accelerate energy independence by using low-cost renewables as baseload to allow coal to be fully replaced this decade.

When will Germany's transition headstart pay off?

To a large extent, the Energiewende paved the way for cost reductions in wind and solar energy worldwide, but what steps must Germany take to fully cross the bridge to renewable baseload, to realise its early investment in the energy transition?

To find out, Wärtsilä modelled Germany's existing capacity and predicted load, accounting for the coal phase-out, CO_2 limits and the maximum annual capacity additions of renewables. Legacy coal and gas plants continue to provide district heating for Germany, so the entire district heating sector was included in the modelling.

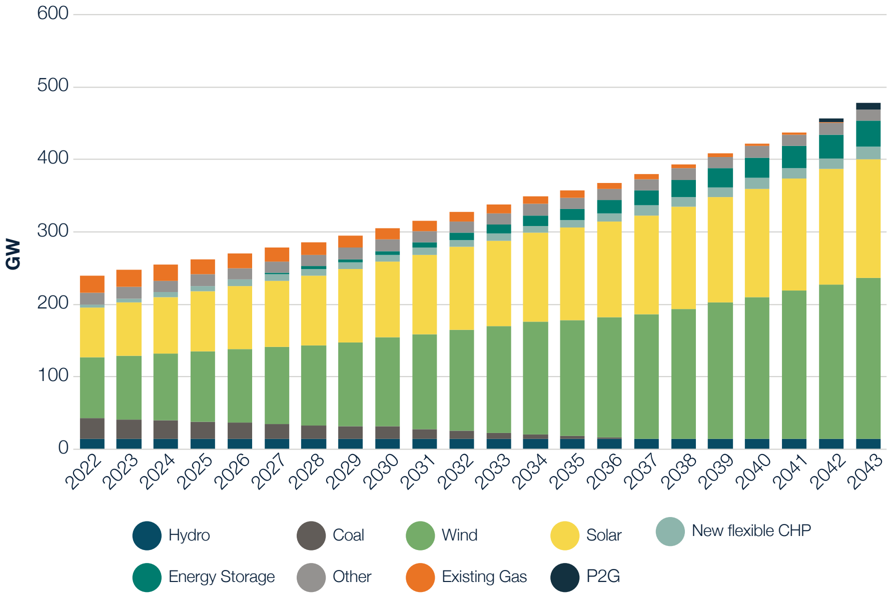
The findings are striking - showing that Germany's headstart on renewable energy places the country in a strong position to accelerate energy independence by using low-cost renewables as baseload to allow coal to be fully replaced this decade, creating myriad benefits.

Two paths to net zero - by 2040, or 2045

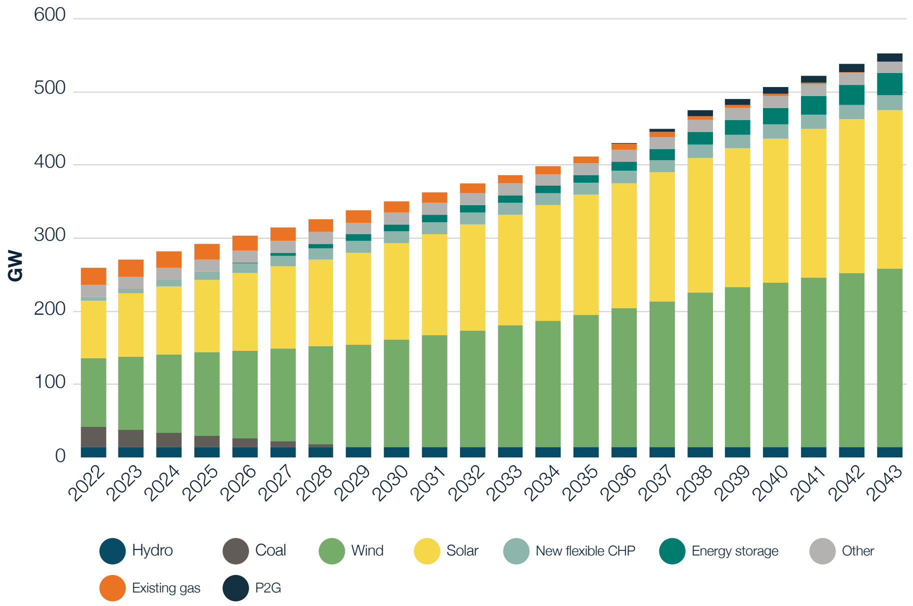
To show the most cost optimal path to net zero, Wärtsilä modelled two key scenarios. Firstly, in the "Baseline 2045" net zero scenario, Germany executes its current plan to phase-out coal in 2038. To replace coal, up to 13.5 GW of renewable sources are added annually until the power sector reaches net zero by 2045[26].

In our second "Supercharged 2040" net zero scenario, Germany phases out coal by 2030, in line with the G20's recent commitment to accelerate away from unabated coal capacity[27]. To do so, renewable electricity is built-out at an increased rate of up to 19.5 GW annually, enabling a net zero power system to be brought forward - to 2040.

Wärtsilä modelled Germany's existing capacity and predicted load. The findings are striking.



Baseline 2045 Net Zero.

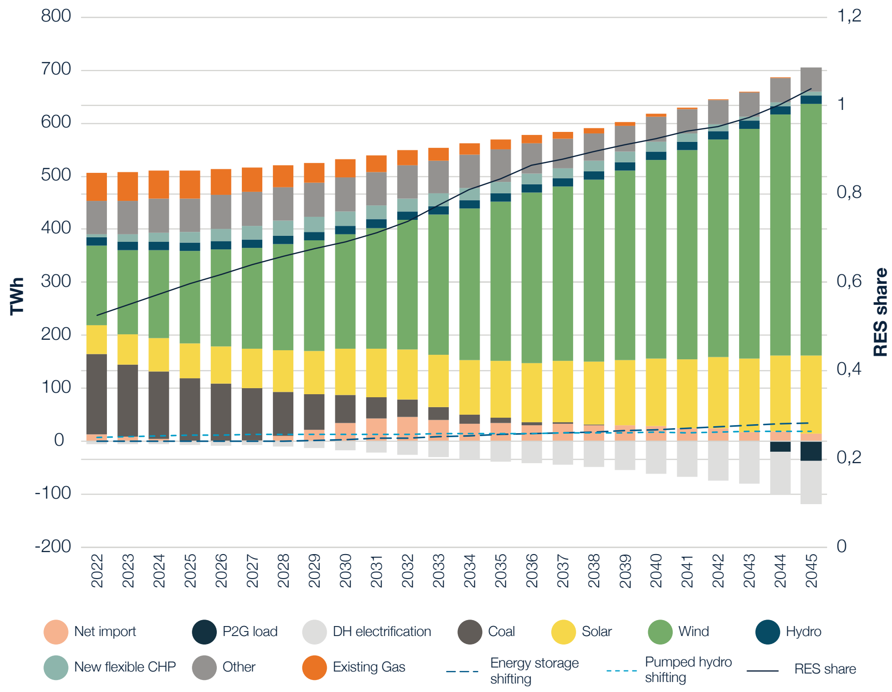


Supercharged 2040 Net Zero.

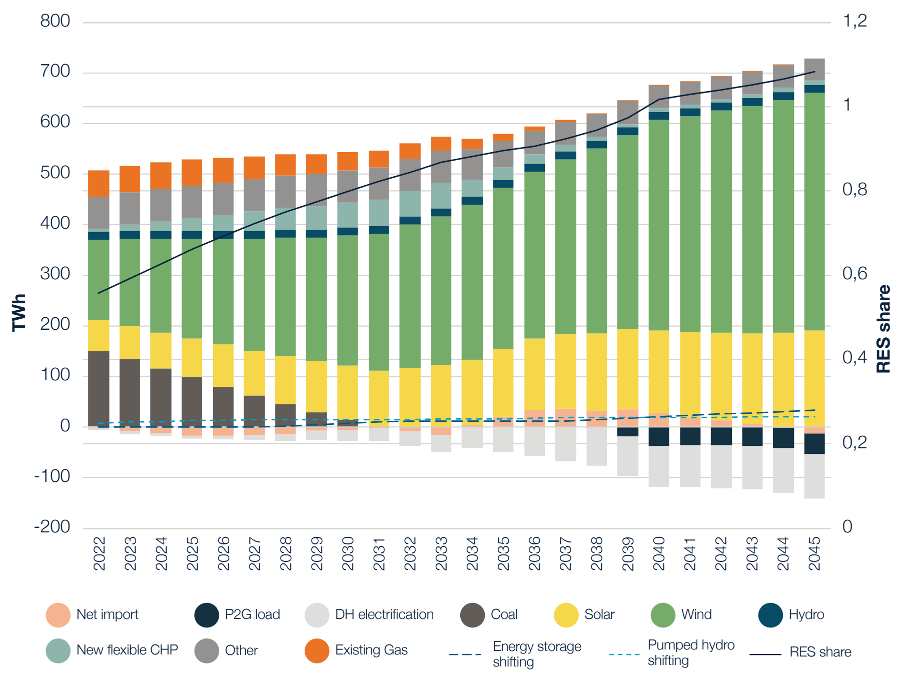
Both scenarios show there are two distinct phases that Germany's energy system must undergo to transition to net zero at the lowest possible cost:

1. The coal phase-out – which is critical to cut Germany's near-term emissions – must be enabled using flexible gas capacity as a bridge.
2. Electrification of district heating and the phase-out of the gas bridge, to fully rely on renewable baseload and sustainable fuels providing long-term storage.

Germany's energy mix in the Baseline 2045 Net Zero scenario.



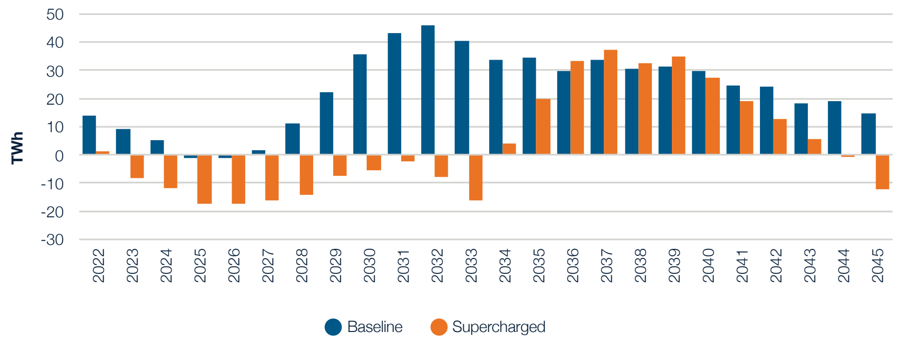
Germany's energy mix in the Supercharged 2040 Net Zero scenario.



Phase 1: The coal phase-out must be underpinned by new gas-fuelled combined heat and power (CHP) plants

The modelling shows that in a cost optimal, coal-free system, renewable energy coming from wind and solar PV should be expanded by 125% (based on 2020 levels) in the Baseline 2045 scenario by 2039. In the Supercharged 2040 scenario, the same amount of renewables is reached by 2035, with coal having been gone from the system for five years already. The new renewables should be supported by firm, dispatchable capacity from flexible Combined Heat and Power (CHP) plants. To phase-out coal by either 2038, or 2030 - around 5-6 GW of new flexible gas-fired CHP capacity is urgently needed in the next five years.

To fully offset energy away from coal during the phase-out process, as well as to provide balancing capacity for the adoption of variable renewable energy generation in a baseload role, around 15 GW of new flexible CHP capacity is needed - in both scenarios - to operate the system completely without coal.



Annual net imports of electricity to Germany.

Phase 2: Electrification

The second stage of Germany's pronounced decarbonisation begins when coal is almost removed. In both scenarios, under a cost optimal system, district heating switches from coal to electrification, with the use of large-scale heat pumps to provide heat production. In the Baseline 2045 scenario there is a gradual shift towards electrification of district heating, with gas still playing a major role. In the Supercharged 2040 scenario, the shift towards renewable baseload and electrification is much more pronounced, beginning in 2033.

The reason for this spike lies in the amount of renewable energy in the system. In the Baseline scenario, electrification is partly dependent on electricity imports, while in the Supercharged scenario there is sufficient domestic renewable production to meet the increased electricity demand.

The key differentiator between the scenarios is that in the Baseline 2045 scenario, electrification is powered to a large extent by electricity from coal, producing 152 million tonnes of emissions in total following 2030, while in the Supercharged 2040 scenario, electrification is powered mostly by renewable energy coming from wind and solar PV. The declining prices of energy storage and the shift to renewable baseload in the early 2030s also paves the way for the rapid expansion of short-term storage. Both scenarios show more than 30 GW of short-term storage at the end of the modelling horizon.

Germany is on an energy import / export knife-edge

The modelling shows that the timing of Germany's coal phase-out – either 2030, or 2038 - determines whether they need to ramp up power imports (racking up cost and carbon) to replace the gap left by coal, or they become a net exporter of clean power.

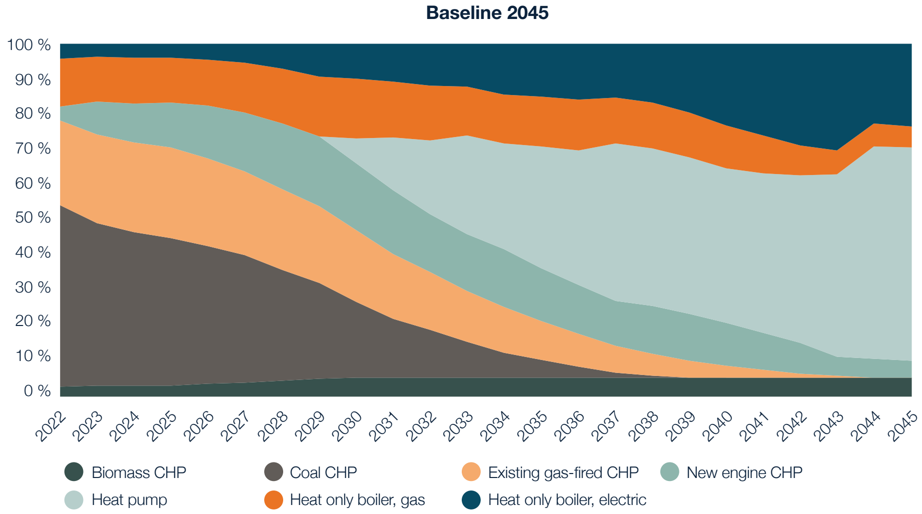
The coal phase-out reduces Germany's potential to export electricity on a net basis, as the country needs the electricity for its own use. However, in the Supercharged 2040 scenario, additional renewable capacity makes Germany less dependent on imports during the coal phase-out period. In both scenarios, it is noteworthy that the absolute energy flow through the cross-border transmission lines remains at the same level, or even higher, meaning that electricity is actively traded with neighbouring countries, even when the annual net flow is close to zero.

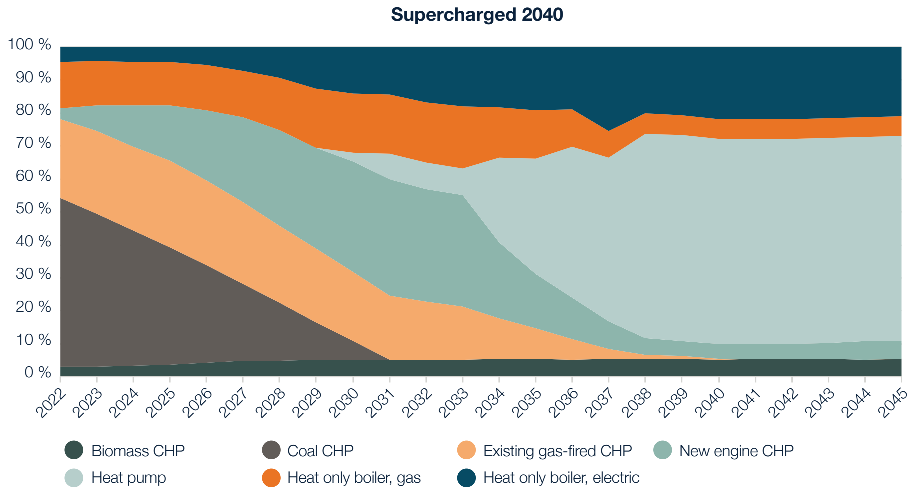
In the Baseline 2045 scenario – a slower coal phase-out forces Germany to become a net importer in the next five years, leading to total net energy imports of 550 TWh, 500% more than speeding up the coal phase-out to 2030. Taking into account the annual emission intensities of the neighbouring countries, this also results in an additional 77 million tonnes of CO_2 being emitted outside Germany by 2045. Also, as the hydrogen economy develops, an alternative option to electricity imports would be to import sustainable fuels.

New CHP – A reduced, but vital, ongoing role

New CHP is a crucial enabler for Germany's coal phase-out. However, the role for flexible CHP technology changes throughout its lifetime, according to system requirements. In Phase 1 (above), the primary role of the new CHP is delivering electricity and heating in a flexible manner, while balancing renewable electricity. However, in Phase 2, CHP has a different, but nevertheless vital role, operating with less running hours, while providing ongoing grid support, reliability and security of supply.

In both scenarios, when reaching net zero, the district heating production mix is the same: most district heating (84%) will be produced by electricity, a small amount (11%) will be produced most cleanly and affordably by sustainable fuels and biofuels will provide the rest. The modelling shows that once Germany's grid is predominantly powered by renewables, it is more efficient to turn excess electricity directly into heat. However, sustainable fuels providing long-term storage are still needed to cover times when insufficient renewable energy is available. In both scenarios, around 18 GW of flexible CHP plants are needed to cover the heat and flexibility demand in the net zero system.





District heating sector in Germany in Baseline 2045 and Supercharged 2040 scenarios.

Sustainable fuels and the final push to net zero

In both scenarios, it is evident that Power-to-X-to-Power, i.e., hydrogen-based sustainable fuels, will play a vital role in reaching full decarbonisation of Germany's energy sector. Some sustainable fuels (hydrogen, synthetic methane, etc) will become more dominant over coming decades. Ultimately, the use of sustainable fuels will depend on cost and technological maturity. Hydrogen is cheaper to make but requires expensive new infrastructure to be transported and used safely, whereas synthetic methane is currently more expensive to make, but can already be used within existing infrastructure and thermal balancing power plants. Wärtsilä, for example, is testing its grid balancing engines using 100% hydrogen and expects to have an engine and power plant concept capable of using the fuel by 2025. Lastly, it's key to note that, regardless of the dominant synthetic fuel type(s), the energy sector will only use sustainable fuels for the final push to 100% from 2039 onwards.

The value of coal has been eroded by low-cost renewable baseload and carbon regulation.
The most significant impact that Germany can make on global carbon emissions is by accelerating its coal phase-out to 2030, which equates to a difference of 422 million tonnes of CO_2. Forecasted rises to the cost of carbon will also have a major impact on the levelised cost of energy production in both the Supercharged and Baseline scenarios. Based on the current carbon price, around €55 per ton of CO_2, the cumulative carbon costs of phasing out coal by 2038, under the Baseline transition scenario, are €137 billion, compared with €114 billion if coal is phased out in 2030, creating annual savings of €0.9 billion on average. Notably, the above figure is conservative, given the carbon price in Germany has been forecast to exceed €62 by 2030[28].

Leaving aside coal's damaging carbon footprint, the influx of renewable energy onto grids plus financial support to shut down German coal is accelerating the phase-out. European prices for coal-fired power have more than doubled in 2020/21, reaching 75 €/MWh, mostly due to higher EU Emissions Trading Scheme (ETS) prices, as well as increased fuel costs. The lower cost of renewable baseload has simply eroded the value of coal past the point of no return.

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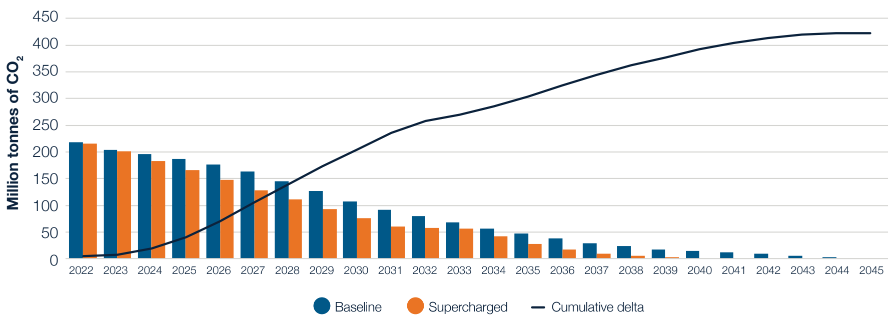


Annual energy sector CO2 emissions and the cumulative difference between the Baseline 2045 Net Zero scenario and Supercharge 2040 Net Zero scenario.

The faster the transition, the lower the total cost of energy – key takeaways:

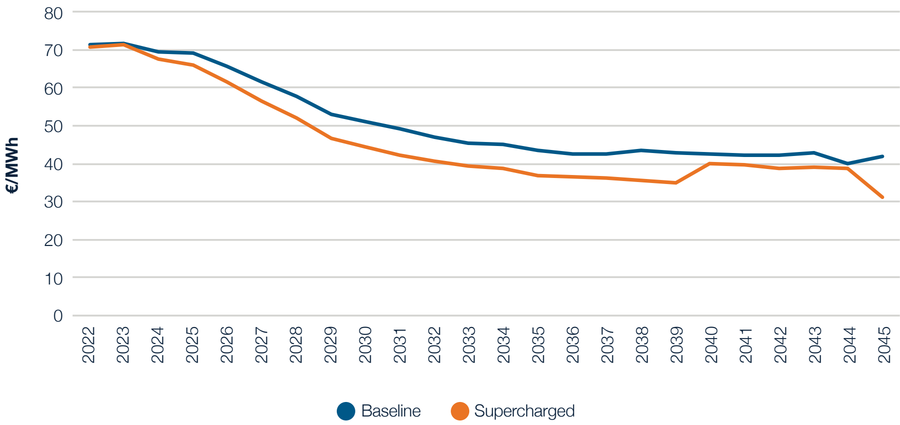
- A faster coal phase-out enabled by more renewables, storage and flexible gas CHP does not cost more.
- Capital expenditure needed to accelerate Germany's transition to a 100% renewable energy by 2040 is offset by operational expenditure savings from a slower pathway to reach net zero in 2045.
- Over the whole modelling horizon, the supercharged scenario is 8% cheaper (in total)
  - Calculated with CO_2 price of €55 per ton of CO_2.
  - With a higher CO_2 price the difference increases.

Levelling up renewable power across Germany

The conclusions from our modelling are clear: accelerating Germany's coal phase-out to 2030 and building a net zero power sector by 2040 unlocks myriad system-level benefits for Germany, from cutting power production costs; supporting energy independence; to producing sustainable fuels to decarbonise other sectors, namely district heating. Flexibility is key to "levelling up" variable renewables to fulfil a baseload role to realise these benefits.

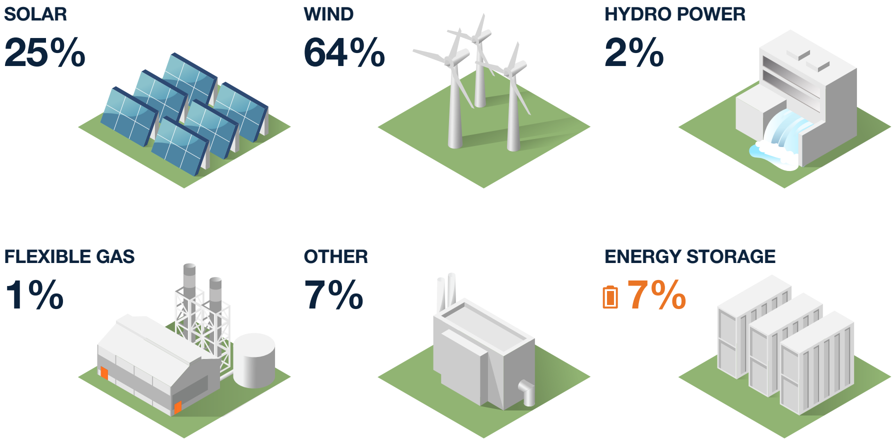
The world's eyes are on Germany, if it can shift a third of her energy generation away from coal within ten years and replace it with clean renewable baseload, other coal-reliant countries can also do the same.

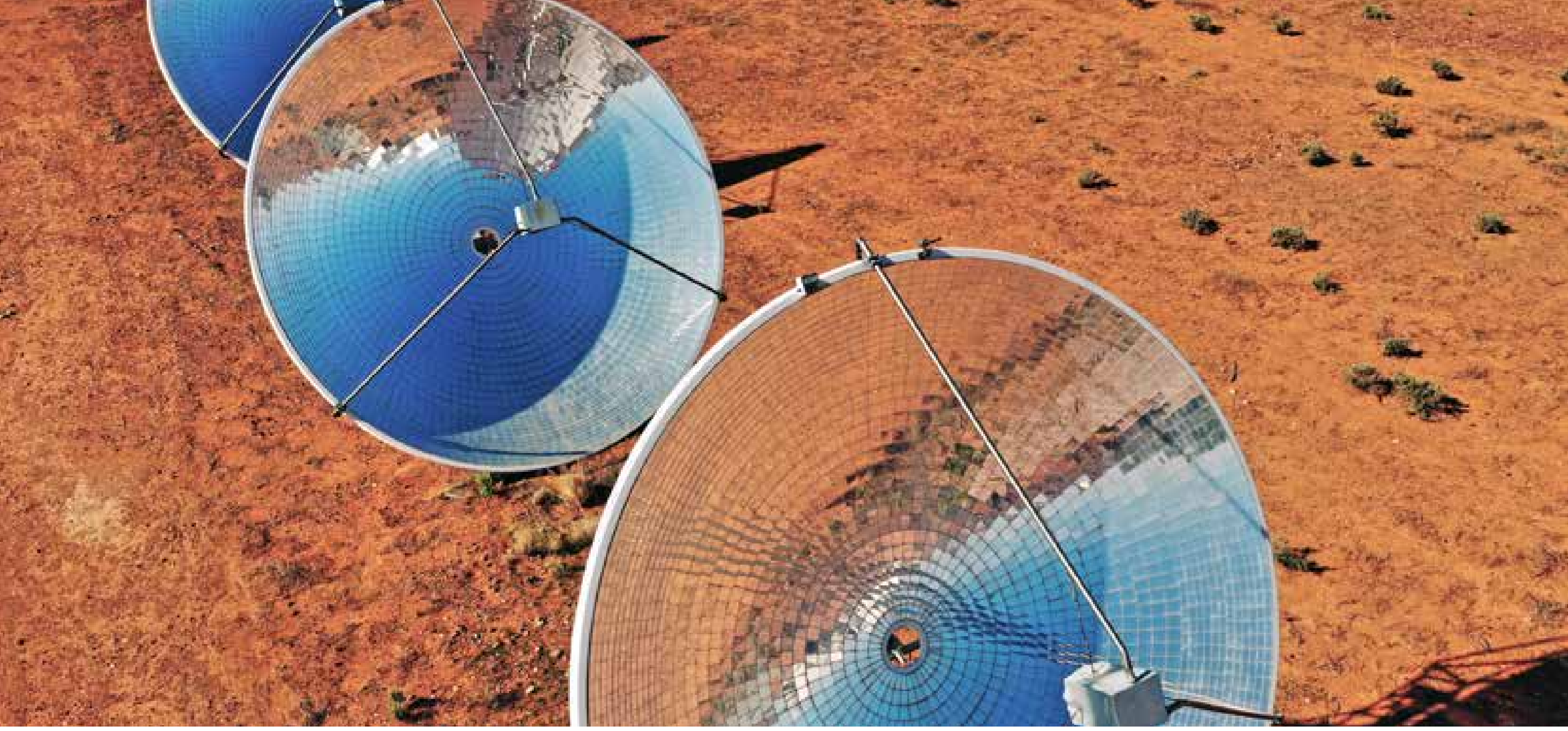
Cost to serve load (€/MWh).



GERMANY RUNNING ON 100 % RENEWABLES

Share of annual electricity generation





AUSTRALIA

BALANCING AUSTRALIA'S PATH TO NET ZERO WITH AMBITION AND ECONOMICS

Kari Punnonen, Energy Business Director at Wärtsilä Energy

A potential renewable superpower

With its unparalleled renewable energy resources, Australia has a unique opportunity to swiftly decarbonise and transition to a fully renewable power system. Given its relatively small population and vast landmass, Australia holds huge potential to meet its demand with affordable renewable power.

However, implementing policies to prepare Australia's grid for the transition to clean energy has demonstrably been very challenging. Yet, as we approach COP26, there is now consensus among the major federal political parties, plus all state and territory governments on the economy-wide path to net zero. While attending U.S. President Biden's virtual climate summit this spring, Prime Minister Scott Morrison acknowledged that "Australia is on the pathway to net zero", giving new certainty to utilities of the coming energy transition.

Aligning with the world's arrival at net zero

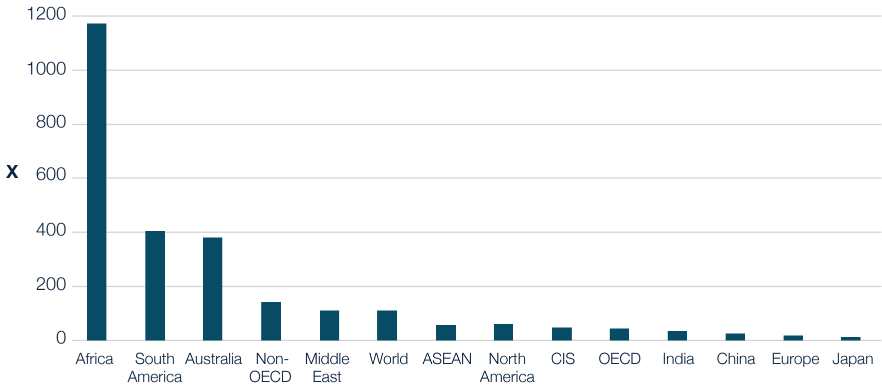
Australia's time of arrival at net zero has not been set, but the International Energy Agency (IEA) has been very clear – advanced economies, such as Australia, must build a net zero grid by 2035 to stay within the Paris targets.

The value of the conventional power sector has been clearly eroded by low-cost renewables. Moreover, a report by EY on opportunities to grow Australia's economy post COVID-19 found that every dollar of stimulus spent on renewables projects generates nearly three times as many jobs per dollar than investment in fossil fuel projects[29].

Given the inevitable shift, what are the key steps the power sector must take to fast-track the benefits of a clean, secure and affordable power system by 2035?

It's clear that Australia has a massive head start; its levels of renewable energy potential per person are amongst the world's highest at over 10,000 MWh per person per annum[30]. As a result, rooftop solar PV is Australia's renewable success story; one in four homes use it and an extra 24 GW of rooftop solar is expected by 2030[31].

Solar and Wind Potential as Multiple of Total Energy Demand, Source: Carbon Tracker Sky's the Limit Report 2021.



A flexible grid that can smooth out peaks in supply and demand is key to enabling rooftop solar plus the country's grid-scale renewables to perform a baseload role. Flexible resources enable renewables to effectively be "levelled-up" to achieve their full energy production potential, while simultaneously acting as an insurance policy to protect grid uptime.

Protecting stability through the coal phase-out

Replacing Australia's aging coal power stations with variable renewable energy will dramatically reduce the country's emissions at the lowest cost. However, to protect reliability, it's vital that the system is balanced to withstand disturbances, such as grid outages, as well as to offset periods of low renewable generation.

A report released by the Energy Security Board (ESB)[32] in early 2021 revealed that the Australian Energy Market Operator (AEMO) was forced to intervene to keep the grid stable more than 250 times in the 2019/20 financial year, compared to fewer than 20 times three years earlier.

Piecemeal additions of renewables to Australia's centralised, fossil-fuel based electricity system have undoubtedly created challenges for grid stability. Plus, the 2016 South Australian blackout starkly shows the vulnerability of Australia's grid to widespread power outages when extreme weather hits electricity transmission infrastructure. Accordingly, the ESB has stated that security of electricity supply is the most urgent issue currently facing the National Electricity Market (NEM).

Flexibility – a low carbon insurance policy for Australia's energy transition

Renewables can certainly provide the firm baseload energy that Australia needs for a highly affordable net zero power system, but only when coupled with a combination of flexible capacity technologies, both energy storage and thermal balancing power plants, to balance renewable variability in a real-time system.

It would of course be technically feasible to run Australian energy system purely with green electricity, using very large amounts of solar PV generation and storage capacity, however, most of the renewables would then be excess to requirements most of the time, adding cost to the system. To realise net zero this decade, the energy transition can only happen if the path to net zero is underpinned by sound economic decision-making.

When planning Australia's cost optimal system, it is crucial to remember that energy storage and thermal balancing power plants are not competing technologies, rather they are complementary solutions for improving grid reliability and resilience. AGL, for example, has since 2019 used 12 Wärtsilä dual-fuel engines, providing 211 MW of capacity, at the Barker Inlet Power Station, Torrens Island, to balance the supply of energy from renewable sources in South Australia. Recently, AGL also announced that, by 2023, a Wärtsilä 250 MW / 250 MWh battery energy storage system will reinforce the balancing capabilities of the same island power plant – forming a hybrid combination of thermal balancing power plants and battery storage.

Such hybrid systems, that combine back-up generation with storage, demand close consideration as variable renewable electricity generation increases in Australia's generation mix.

Leading with the economics, not technology

To achieve the optimum economics for the transition, flexibility solutions must be implemented objectively, based on the unique environmental conditions of the renewables they support. As a global provider of flexible technology solutions, we know that the efficiency of technology varies significantly across the energy mix and the geography of the installation.

Traditional pumped hydro provides a relatively slow release of power over a day, but it is vulnerable to seasonal variations, especially Australia's worsening droughts. Battery energy storage can respond in milliseconds to solve multiple problems, including smoothing output, storing excess energy and re-dispatching power. However, given battery resources only last for a period of hours, they work most efficiently when they are set-up to 'tag team' with thermal balancing power plants during 'renewable droughts'; or periods (varying in time and severity), when wind and solar generation can decline over several days, to several months. Thermal balancing power plants can ramp up to full

Hybrid systems, that combine back-up generation with storage, demand close consideration as variable renewable electricity generation increases in Australia's generation mix.

load in two minutes – bringing major system benefits when providing a bridge to renewable baseload. Both solutions are needed in their own way and must be approached objectively, with the right data and the right vision to realise 100% renewable energy.

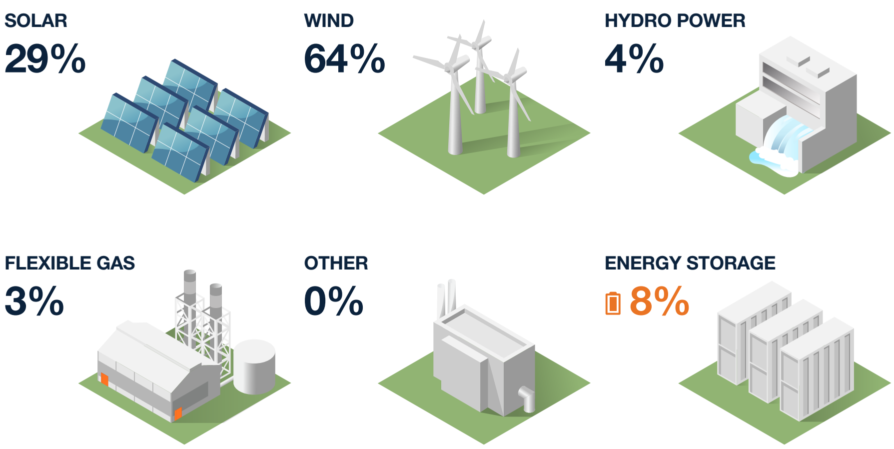
To illustrate how the flexibility technology landscape is evolving, our Atlas of 100% Renewable Energy models a 'greenfield' 100% renewable energy system end-state in East and West Australia, based on the cost optimal energy mix if the system was built from scratch. In this renewable energy mix, both East and West Australia would use battery energy storage for 8% of their capacity. To avoid carbon exposure from fossil fuels, the system shown in the Atlas of 100% also includes carbon neutral sustainable fuels, in this case synthetic methane (which our engines are already capable of using), which can be produced with excess renewable electricity with Power-to-X. Using this technology, West Australia's system would run with 5% of synthetic gas per annum, while East Australia's optimal greenfield energy system would rely on 3% synthetic gas per annum.

These and many other system benefits from the coming hydrogen economy can result from a clear plan to massively scale-up Australia's share of renewable capacity at an unprecedented rate to well beyond a 70% share of the energy mix.

Now that Australia's net zero destination is set – her time of arrival will be determined by the ability of power producers and government to work together to level-up the country's enviable renewable potential. To capitalise on renewable baseload – major increases in all forms of flexibility are needed, and they must work together to balance the path to net zero.

AUSTRALIA EAST RUNNING ON 100 % RENEWABLES

Share of annual electricity generation



CHILE

HARNESSING CHILE'S WORLD-LEADING RENEWABLE CAPACITY

Alejandro McDonough, Executive Managing Director at Wärtsilä

Chile has begun to flourish as one of Latin America's leaders in renewable energy in recent years. Its remarkable geographical make up – spanning well over half of the South American continent – provides access to world-leading renewable energy resources. From the Atacama Desert in the sunny north, which has amongst the highest levels of solar radiation in the world, to Chile's 6,435 kilometre coastline, these unique conditions are ideal for renewable energy production.

Driven by increasingly ambitious targets and innovative policy, Chile is transitioning away from its legacy coal-fired baseload. However, to decarbonise in line with climate science, while protecting energy security and affordability, Chile must complete its rapid shift to renewable energy by 2030.

Underpinning climate ambition with innovative policy

Following the 2015 Paris climate summit, Chile set itself the unconditional target of reducing GHG emissions intensity by 30% below the 2007 level by 2030. Subsequently, in 2019, President Sebastián Piñera Echenique committed to carbon neutrality by 2050[33]. To achieve this, Chile's Nationally Determined Contribution (NDC) (updated in 2020) sets out a carbon budget of 1,100 million tonnes CO_2eq between 2020 and 2030, with emissions to peak in 2025. To stay on track, by 2030, Chile must keep its GHG emissions below 95 million tonnes CO_2e.

Chile has sought to underpin its ambitious targets by capitalising on its extremely high renewable energy capacity factors and the government has piloted a range of innovative energy policy frameworks to scale-up renewables. In 2017, Chile became the first South American country to introduce a carbon tax, initially to the electricity sector, starting at CLP 4,708 ($5 USD) per ton of CO_2, which is expected to increase progressively[34]. Chile has also introduced a number of other innovative policies, including hourly blocks in energy auctions to accommodate fluctuations in renewable energy supply.

Chile's updated NDC means the country is now compatible with a 2°C pathway. While its goals exceed Latin America's other largest economies in ambition[35], Chile has also actively advocated for the decarbonisation of the region as a whole. For example, as a leader of the Renewable Energy for Latin America and the Caribbean (RELAC) Initiative at COP25, Chile committed to closing 28 coal-fired power plants by 2040[36].

Accelerating the coal phase-out

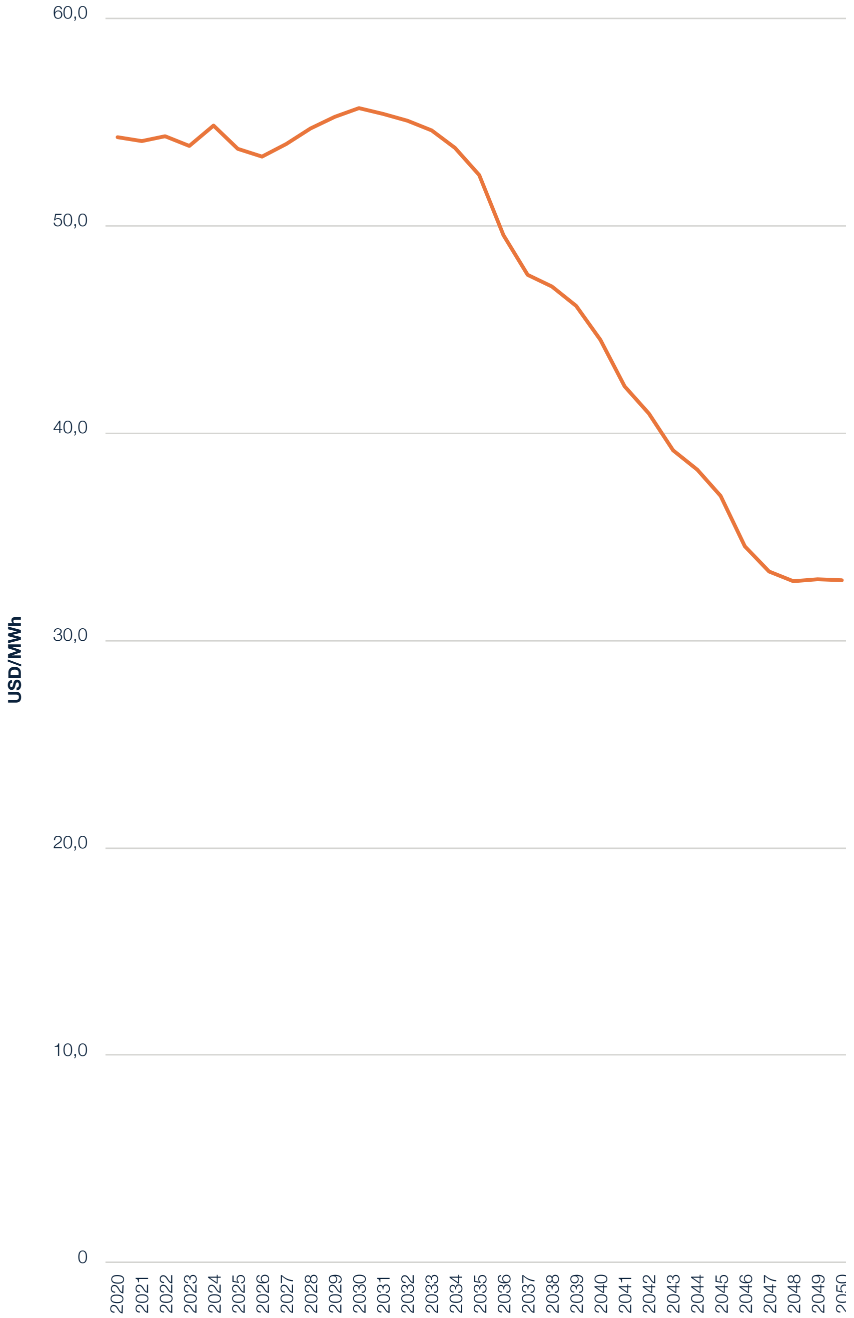
Despite strong movement towards renewable energy, Chile's fossil fuel fleet still makes up over half of the current capacity mix. Chile has a number of inflexible coal units (around 35% of total energy generated in 2020), plus numerous large legacy Combined Cycle Gas Turbines (CCGT), technologies which Wärtsilä's independent power system modelling has found to be ineffective and costly as balancing solutions for renewable energy[37]. Large legacy power plants simply cannot be quickly shut down and ramped up when renewables come on and off-line. This inherent inflexibility means large volumes of fuel are burnt during high renewables periods – when cheap solar and wind are available.

The continued presence of inflexible coal in Chile's capacity mix is entirely incompatible with adding renewable energy at scale. This was clearly indicated by Enel, the largest power company in Chile by installed capacity, which committed in January 2021 to shut down its entire Chilean coal fleet by 2023[38]. ENGIE and AES have also committed to accelerating the phase out of coal.

To bridge the capacity gap created by phasing out coal, Chile must be ambitious with its targets for new renewable energy infrastructure, adding capacity quickly and ensuring it is interconnected to the grid this decade. Modelling by Wärtsilä shows that 15 GW of solar PV and 5.2 GW of wind capacity must be added if Chile is to successfully replace coal by 2030.

Increasing the share of wind and solar PV generation also requires flexibility from thermal balancing power plants and battery energy storage, which coal power plants cannot provide cost effectively. To phase out coal by 2030, Wärtsilä's modelling shows the need for 9.5 GW of flexible capacity, provided by both battery storage and thermal balancing power plants, to realise Chile's transition to renewables, while protecting security of supply. To support this, a new regulatory framework is needed to properly reward flexible generation and to ensure that battery storage is installed in large enough quantities to support the intermittency of renewable energy.

Crucially, phasing out coal by 2030 would lead to a dramatic reduction in carbon emissions, falling from around 24 million tonnes of CO_2 in 2021 to four million tonnes of CO_2 in 2030. Further, this CO_2 reduction is possible without impacting the Levelised Cost of Electricity (LCOE) in the long run. New independent modelling, commissioned by Wärtsilä, demonstrates that a rapid acceleration of renewable capacity to replace legacy coal power, as well as diesel-burning engines, would only increase the cost of energy by around CLP 784 ($1 USD) per MWh to 2030. Following this period of renewable build-out, the LCOE would then fall dramatically to less than CLP 25,885 ($32 USD) per MWh by 2053[39], almost half the current price of CLP 42,371 ($54 USD) per MWh.



Decreasing Levelised Cost of Electricity, (LCOE) in Chile (2020-2050).

> In order for the world to meet its climate goals, international collaboration is essential. Finland has worked in partnership with countries such as Chile to develop ambitious climate policies and to co-create and scale up world-class solutions.”
>
> “Wärtsilä is a fine example of a Finnish company developing globally-significant solutions to the climate crisis and creating a vision for our 100% renewable energy future.”

Eija Rotinen, the Finnish Ambassador to Chile

Unlocking Chile’s hydrogen economy

Due to its abundance of renewable resources, the cost of green hydrogen can decrease significantly in Chile by 2030, as the excess electricity from variable renewables provides the raw ingredient for hydrogen production. In November 2020, President Piñera announced an ambitious National Green Hydrogen Strategy[40], setting out its plans to have five gigawatt of electrolysis capacity under development by 2025, and to increase electrolysis capacity to 25 GW by 2030. Under the National Green Hydrogen Strategy, Chile has the potential to drive the final stages of the decarbonisation of its power sector, as well as to provide carbon-neutral fuels for other sectors, such as mobility and industry.

Chile is currently only a minor producer of fossil fuels and is therefore heavily dependent on energy imports[41]. Its natural gas imports reached 4,952 million cubic metres in December 2019, the highest yearly level recorded[42]. In the same year, Chile also imported 11,491 short tonnes of coal[43]. By replacing coal capacity with renewable baseload, supported by flexible capacity, Chile has the potential to shift from being an importer to an exporter of electrons, as well as green hydrogen, creating a new relevance for itself in the Americas.

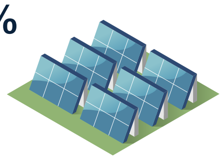
Becoming a world leader in the net zero global economy

Chile has made an excellent head start in its global transition from fossil fuel to renewable baseload. Now, to unleash the full potential of its strong renewable resources, Chile not only needs to massively expand its build-out of wind and solar power, but it must also ensure that the necessary energy storage and balancing functions are constructed, along with those renewables, to allow them to perform to their maximum efficiency and to avoid heavy curtailment costs. This will drive greater affordability, energy independence and clean energy export revenues. In this way, Chile can go beyond its leadership of Latin America to become a world-leader in the energy transition.

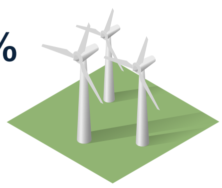
CHILE
RUNNING ON 100 % RENEWABLES

Share of annual electricity generation

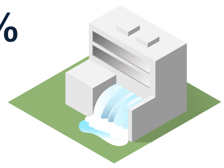
SOLAR
46%



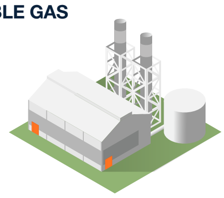
WIND
31%



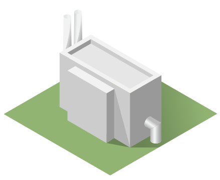
HYDRO POWER
12%



FLEXIBLE GAS
8%



OTHER
2%



ENERGY STORAGE
23%

UK

THE UK CAN UNLOCK A NET ZERO POWER SYSTEM BY 2035, BUT IT MUST DOUBLE DOWN ON WIND AND FLEXIBILITY

Tony Meski, Senior Market Development Analyst, Wärtsilä Energy

As the COP26 host, the UK government has a clear responsibility to unite the globe behind urgent decarbonisation. Setting the tone of its ambition, the UK was the first country to enshrine a net zero target in 2019 – plus earlier this year, Prime Minister Boris Johnson set a world-leading new decarbonisation target for the country to reduce its carbon emissions by 78% by 2035.

Moving from a decade of deliberation to the decade of action

The power sector provides the “low hanging fruit” for achieving the UK’s emissions reductions – and utilities have made great strides in deploying the UK’s richest energy asset – its abundant offshore wind resources. Renewables already contribute over 40% of UK energy generation, but the latest emission reduction target - 78% by 2035 compared to 1990 levels - will require the power sector to reach net zero by 2035, setting the country a monumental challenge to build a 100% renewable power system in the next 14 years.

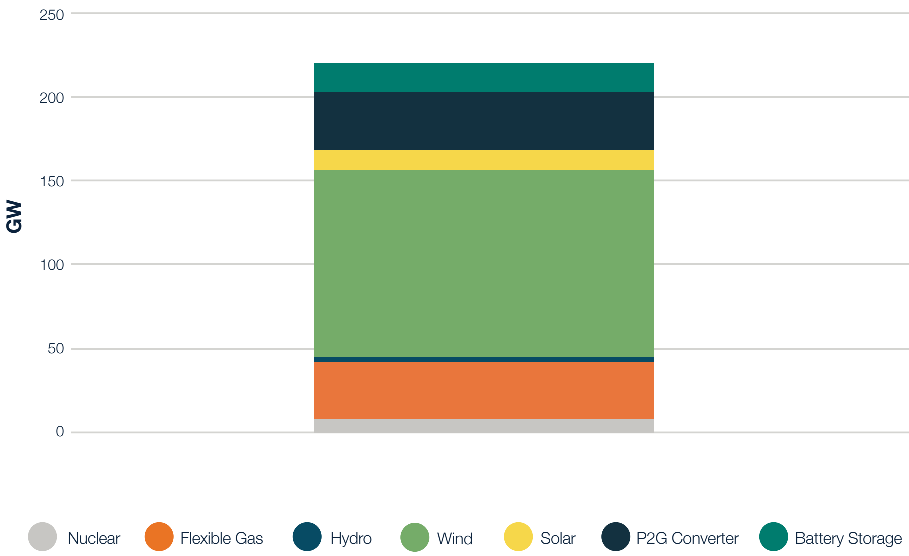
We set out to understand what a 100% carbon neutral future looks like for the UK's energy grid using our 'Atlas of 100% Renewable Energy', an open data resource showing the cost-optimal capacity mix for 100% renewable electricity systems in 145 countries and regions around the world.

The Atlas modelling shows how all renewable technologies (including flexibility solutions such as energy storage and thermal balancing power plants) can be employed in a future capacity mix. The Atlas models energy systems from a hypothetical fresh start, or 'greenfield state', to illustrate the ideal renewable energy scenario. However, to reflect the UK's current energy outlook, the following bespoke modelling of the UK also includes 7.6 GW of nuclear power that is expected in the power system in 2035[44].

The modelling highlights that the UK is facing a significant, but not insurmountable challenge. The UK's total energy capacity needs to more than double from 110 GW to over 220 GW to match the increasing electrification of the grid, the influx of electric cars, plus expected population increases by 2035[45]. Notably, even though the generation capacity needs to double, the peak demand is only increasing from 59 GW to 66 GW. The nature of fully renewable systems demands that power producers 'overbuild' capacity since it is not always available, unlike traditional capacity which can be matched with peak demand.

To be cost optimal, the UK's new capacity needs to be met by wind energy, with 112 GW needed by 2035, which (including necessary battery storage and thermal balancing), would cover 77% of the annual power demand in the UK.

The UK capacity 2035 (GW).



To be the Saudi Arabia of wind, UK must double down

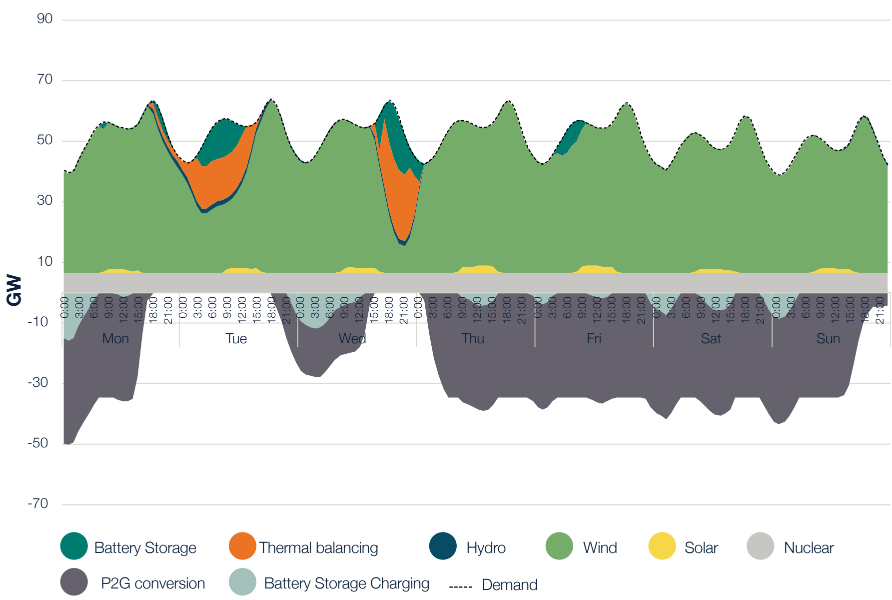
With just 14 years to meet the target, we calculate that over 6 GW of new wind energy must be installed annually.

That is almost three times the current pace of 2.1 GW per year and a significant increase on the UK's existing plans to install 40 GW of offshore wind by 2030. It is achievable for the UK to become the 'Saudi Arabia of wind', however, the shift cannot happen at the flip of a switch. New offshore wind can only grow as fast as the infrastructure that's built to harness its power.

A flexible future

The UK must now dramatically accelerate its focus on flexibility to manage the huge increase in variable renewables over coming decades.

Our modelling shows that the UK needs to install 18 GW of energy storage to affordably manage short-term fluctuations – plus almost 35 GW of thermal balancing power plant capacity and Power to Gas converters, to store renewable energy and manage longer-term peaks and troughs of supply and demand. To illustrate the role of Power to Gas, the graph on the next page shows how, in an expected wintry January week in 2035, the fluctuations of generation can be balanced in the most cost effective and sustainable way.



The UK dispatch in a week in January 2035.
Excess wind is utilised for charging battery storage and power-to-gas conversion.

The 35 GW of thermal balancing capacity that is needed signals a need for new carbon neutral fuel innovation. While this capacity will come from natural gas for at least the next decade or so, sustainable fuels, such as synthetic methane, are already technically available (green hydrogen blends are already in use in our grid balancing engines) and will provide a cleaner alternative over the long term.

The production costs of sustainable fuels will come down as renewables scale up; providing excess renewable electricity as the raw material for mass-scale hydrogen production, so that eventually the 35 GW of thermal balancing capacity will emit zero emissions.

Enabling wind to do the heavy lifting of the UK's decarbonisation

By deploying renewables and flexibility solutions at scale, the UK could essentially become one of the world's largest islanded grids, capable of powering itself on 100% renewable energy, as well as creating opportunities to export clean power to the continent via the UK's interconnections to neighbours, such as Germany.

A microcosm of the UK's increased integration of wind power onto the power system can be seen in the Shetland Islands, where Wärtsilä will this year complete an energy storage system and an engine installation, to keep SSE's Lerwick Power Station in balance with the local loads. The energy storage solution will support the power station's spinning reserve functionality and is able to provide black start back-up as needed. To underpin the energy storage system, our GEMS Digital Energy Platform will integrate multiple generation sources seamlessly, to reduce costs and protect stability.

By fully utilising the UK's world-leading wind power capacity factors, the UK can not only meet its climate targets, but also follow the most affordable route to decarbonisation.

Innovative projects like Energy Superhub Oxford, which combines EV charging with the world's biggest hybrid battery are leading the way in optimally absorbing green energy, and we're delighted to collaborate with Pivot Power, part of EDF Renewables, on that initiative.

The shift to real-time power

To fully capitalise on offshore wind, all available resources must be ready to adapt to evolving conditions in real-time, from smart metering to advanced grid management and network regulation.

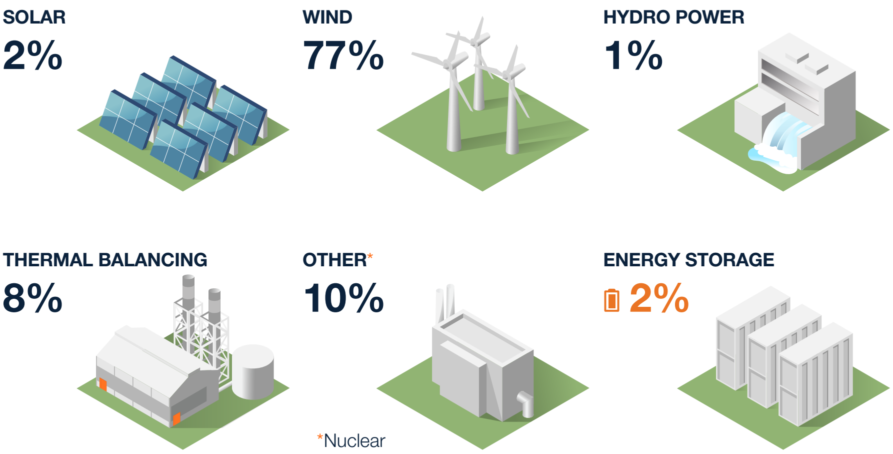
Real-time ancillary services, underpinned by flexibility solutions, now make the difference between profitability, or exposure to technical failure from rising extreme weather. For example, smart electric vehicle (EV) charging and other flexibility services reportedly could have saved British ratepayers £133 million in curtailment fees in summer 2020[46], and these numbers will only increase as more renewables are added to the grid. Innovative projects like the Energy Superhub Oxford, which combines EV charging with the world's biggest hybrid battery are leading the way in optimally absorbing green energy, and we're delighted to collaborate with Pivot Power, part of EDF Renewables, on that initiative.

Gaining competitive advantage in a decarbonised power system

With the UK's clear policy framework in support of renewable baseload power, it's clear that those power producers that act now will seize competitive advantage, but to do so requires a new mindset.

Although traditionally conventional power assets were tendered over numerous years, the UK's clear decarbonisation trajectory justifies increased up-front capex on renewables and flexibility to provide the clean power that's needed.

The UK has made striking progress in decarbonising its energy grid over the past decade. Now, it's vital that the government works closely with the power sector to scale-up its ambition to build and integrate renewable baseload, to meet its ambitious targets; setting a blueprint for other countries to follow.



UNITED KINGDOM RUNNING ON 100 % RENEWABLES

Share of annual electricity generation

FRONT-LOADING NET ZERO - CONCLUSION

It's vital to understand that the transition from fossil-based to 100% renewable electricity generation will not increase the cost of electricity in comparison to today.

The feasibility of the green transition shown in these pages should act as a wake-up call for leaders of countries and electricity utilities alike, to prioritise the building of net zero energy systems today.

This summer's floods, fires and extreme heat, in areas from Greece and Turkey - to Siberia and British Columbia, are reminders that the climate crisis is a global issue that is rapidly worsening. However, the clear potential to address the crisis shown in the IPCC's latest report provides hope. We are close to 1.5C° of warming and will reach it by mid-century. However, the IPCC has also provided greater certainty than before – that if we reach net zero CO_2 – our contributions to further warming are likely to stop. If we act now, we can halt and even reverse some of the damage.

As energy leaders take stock post-COVID and restructure their models, now is a key moment to set clear frameworks for achieving net zero. For most, it's not about starting from scratch, but understanding where and how to invest to drive future resilience and profit. No matter the region, this report demonstrates emphatically that shifting rapidly towards 100% renewable energy systems brings colossal benefit to society – both economically and in terms of the climate.

It's vital to understand that the transition from fossil-based to 100% renewable electricity generation will not increase the cost of electricity in comparison to today. The transition provides a unique opportunity to transform the profitability and relevance of the power sector – placing abundant, clean power at the centre of the world's recovery from the global pandemic.

FRONT-LOADING NET ZERO – KEY MILESTONES:

1. Build conditions that enable additions of renewable electricity sources as quickly as possible. As the investments start to flow in, power producers will see the running hours of their inflexible, legacy power plants decrease.

2. Build conditions that enable investments in energy storage and thermal balancing power plants; plants that can quickly start up and shut down as needed to balance renewable energy output efficiently. As utilities do this, the mindset of energy leaders will change. The role of fuel-burning power plants will change from 'baseload' to balancing, while renewables and energy storage become the primary sources of output to the system.

3. Once there is sufficient renewable output, battery storage and thermal balancing power plant capacity in the system, retire legacy inflexible plants, such as coal. It is crucial to have the capacity online before the retirements to ensure reliability and to avoid blackouts once the legacy plants leave the system. Utilities should keep repeating steps 1 - 3 until their systems run on 80 – 90% renewables.

4. To reach a 100% share of renewable power, leaders must create the conditions to build new Power-to-X capacity for sustainable fuel production and convert thermal balancing power plants to run on that fuel. This provides economic long-term energy storage, ensuring security of supply even during extreme weather conditions.

5. Remaining fossil fuel capacity can then be rapidly phased-out, if it has not already been retired.

Practically, what should countries do to build their paths to 100% renewable electricity systems? Based on our modelling and on-the-ground experience, the ingredients in the recipe are similar everywhere.

Overall, our analysis shows that the key is to start now. Power producers and policymakers must work together to front-load capex on renewable capacity - and ratchet up over time. Momentum is key for countries to meet national climate targets and for utilities to survive and thrive in the transformed power sector of the near future.

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METHODOLOGY

Each of the deep-dive article analyses are based on techno-economic optimisation of the studied systems. The optimisation finds the least-cost capacity mix to meet electricity demand in the future while respecting political constraints, such as emission limits. Conventional power plants are included with their technical properties and fuels to model their carbon emissions and ability to balance variable renewable generation. Wind and solar PV are modelled with their hourly generation profiles based on the weather conditions in the studied area.

The detailed optimisation modelling uses a chronological approach, i.e., the variability and seasonality of renewable generation and load need to be balanced hour-by-hour in the model. Thus, the modelling accurately dimensions the required flexibility and storage capacity in the studied power system.

To meet the future demand and political targets cost optimally, the optimisation adds required technologies to the system. The available options include different renewable sources, such as wind, solar PV and geothermal, thermal technologies from gas engines and turbine power plants - to nuclear power, storage technologies, such as battery and pump storage, and technologies to produce sustainable fuels.

Key inputs used in the modelling come from:

- Bloomberg New Energy Finance in the Germany and California modelling.
- California Public Utility Commission (CPUC) and California Independent System Operator (CAISO) in California modelling
- European Network of Transmission System Operators (ENTSO-E) in Germany modelling
- Lappeenranta-Lahti University of Technology (LUT) in India modelling

The focus countries were selected due to their vastly different socioeconomic dynamics, energy systems, and challenges to overcome. However, they are unified in their commitment to transform.

California

- A global transition pioneer on a legally binding trajectory to build a 100% renewable energy system by 2045.
- Must rapidly accelerate its adoption of wind and solar to unlock significant savings both in terms of energy cost and CO_2 output.
- California's significant inter-dependence with other energy networks in the United States provides a blueprint for other sub-states.

India

- An astonishing trajectory for economic growth with a rapidly rising demand for energy.

- Existing legacy coal-fired power plants in the power system provide a hurdle for renewable energy, but India has some of the lowest solar generation costs in the world.
- India's decarbonisation can provide a pathway for other developing and emerging economies.

Germany

- Lies at the centre of a spiders' web of national interconnections. Germany's ability to decarbonise is pivotal to the decarbonisation of Europe.
- World-leading experience of scaling up renewables and ambitious climate targets.
- Faces the monumental challenge to phase out coal by 2030, before fully decarbonising.
- Germany's coal phase-out will provide a blueprint for coal phase-outs in countries worldwide.

Australia

- A potential renewable superpower, Australia has for the first time reached a consensus on its pathway to net zero.
- Progress towards 100% renewable energy must be supported by flexibility solutions such as batteries and thermal balancing power plants. Australia provides an insight into how these technologies can be deployed at scale.

Chile

- An emerging leader in clean power production with remarkable natural resources.
- Ambitious policymaking has provided a path to 100% renewable energy.
- However, Chile must capitalise on this foundation while accelerating coal phase-out.

UK

- As the COP26 host, the UK has set a world-leading target for a net zero power system by 2035.
- However, to realise its ambition, it must double down on wind and flexibility this decade.

References

BNEF: https://about.bnef.com/

CPUC: California Public Utilities Commission (CPUC). (2019a). Inputs & Assumptions: 2019-2020 Integrated Resource Planning.

CAISO: https://www.caiso.com/

ENTSO-E: https://www.entsoe.eu/

LUT: https://www.lut.fi/web/en

WÄRTSILÄ ENERGY IN BRIEF

Wärtsilä Energy leads the transition towards a 100% renewable energy future. We help our customers in decarbonisation by developing market-leading technologies. These cover future-fuel enabled balancing power plants, hybrid solutions, energy storage and optimisation technology, including the GEMS energy management platform. Wärtsilä Energy's lifecycle services are designed to increase efficiency, promote reliability and guarantee operational performance. Our track record comprises 74 GW of power plant capacity and more than 80 energy storage systems delivered to 180 countries around the world.

https://www.wartsila.com/energy