Crossroads to net zero

Choosing the optimal path to a renewable energy future

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Summary of report

This report evaluates two commonly considered pathways to achieve net-zero emissions in the power sector at a global level. The findings indicate that combining balancing power plants with renewables and energy storage offers the most viable and cost-effective pathway to accelerate decarbonisation and achieve net zero.

Anders Lindberg
President, Wärtsilä Energy and
Executive Vice President
Wärtsilä Corporation

Optimal pathway to net zero

"
The world is on a narrowing path to achieving net-zero emissions by 2050."

The world is on a narrowing path to achieving net-zero emissions by 2050 and limiting global temperature rise to 1.5°C, as committed to by over 190 countries in the Paris Agreement.

The power sector is pivotal in global decarbonisation efforts, demanding rapid, large-scale transformation. This transformation requires that we optimise power systems to enable massive emission reductions, while maintaining energy reliability and affordability for homes, industries and businesses worldwide. To achieve this, we need multiple different energy technologies working together.

Our study demonstrates that balancing technologies are essential to achieve a rapid and cost-effective transition to 100% renewable energy. The energy transition depends on large-scale renewable energy deployment; however, power is needed even when the wind isn't blowing, or the sun isn't shining, to ensure system reliability.

This flexibility must come from multiple sources of balancing technologies, such as grid balancing engines and energy storage in the form of batteries, as these are essential components in enabling an optimal, rapid decarbonisation pathway.

Achieving the transition also requires targeted and coordinated actions from governments, regulators, utility companies and grid operators. It is crucial for the energy transition that we rapidly expand renewable capacity, redesign electricity markets for flexibility, and prepare for the future integration of sustainable fuels.

The need to scale up renewables and energy storage is well understood. However, we still need a more holistic regulatory and policy approach to create power systems that work today, set us on the path to net zero, and are ready for the decades to come. This report aims to show the optimal pathway to achieving that goal.

Net zero is at a crossroads. Decisive action is needed now to ensure we choose the optimal path.

Malin Östman
Vice President,
Strategy and Business Development

Executive summary

Given the urgency of coordinated global action to achieve net zero by 2050, achieving greater alignment on the most effective pathway to decarbonisation targets is essential for meaningful progress. To support this goal, Wärtsilä initiated a global power system modelling analysis to evaluate the impact of widely discussed decarbonisation pathways.

This report evaluates two pathways to achieve net-zero emissions in the power sector by 2050.

> **Pathway 1: Renewables and storage** relies solely on the expansion of variable renewable energy, namely solar and wind, and energy storage systems.
>
> **Pathway 2: Balanced** incorporates balancing power plants, for example flexible engine power plants, alongside renewable energy and energy storage systems.

The findings show that the Balanced pathway achieves net zero faster and more cost-effectively, with projected savings of over 42% (EUR 65 trillion), 21% lower emissions, and with half the land use for renewables from 2025 to 2050 compared to the Renewables and storage pathway. This significant cost reduction is largely due to minimised curtailment and reduced renewable energy overcapacity enabled by the use of balancing power plants, providing additional flexibility and optimising the overall system.

The study also finds that over 76% of annual emission reductions are achieved before sustainable fuels are introduced from the middle of the next decade (2035 in our model), demonstrating that we can achieve more than three-quarters of our power sector carbon goals without using scarce sustainable fuels for power generation.

The results show that including balancing power plants is crucial for a rapid and cost-effective path to net zero. While renewable energy is key to decarbonisation, system reliability depends on flexibility. Energy storage offers near-instantaneous flexibility, while balancing power plants provide critical reserves and both short- and long-term flexibility during breaks in renewable generation. Together, they support a reliable and optimised renewable energy system. Adding balancing power also reduces reliance on inflexible assets, such as coal plants, and will therefore accelerate emissions reductions.

This report underscores the need for coordinated action in renewables expansion, market reforms, and leveraging existing technologies to enable a timely and cost-effective transition to net zero.

The significant advantages of adding balancing power plants

EUR 65 trillion reduced costs: The study shows that compared to the renewables and storage only pathway, the deployment of balancing power plants reduces the total cost of future power systems by as much as 42%, approximately EUR 65 trillion.

21% reduced emissions: Adding balancing power can reduce the total cumulative power sector CO_2 emissions between now and 2050 by 21%, compared to the renewables and storage path.

88% less wasted energy: The modelling shows that the use of balancing power allows for enhanced power system optimisation, resulting in 88% less wasted energy due to renewable curtailment by 2050, compared with the other pathway. In total, 458,000 TWh of curtailments would be avoided, enough to power the whole world (based on current electricity consumption) for more than 15 years.

50% less renewable capacity and land needed: By adding balancing power plants, we can halve the total required renewable capacity and significantly reduce the land needed to build wind and solar infrastructure, which would otherwise need to cover an area comparable to the size of Europe.

> "The study shows that the deployment of balancing power plants reduces the total cost of future power systems by EUR 65 trillion."

Accelerating the global energy transition

The global energy transition continues to gain momentum, driven by targeted policy support and decreasing renewable energy costs. 2023 saw a record-breaking 565 GW of new renewable capacity - a 60% increase on 2022. Total installed renewable capacity reached 4,000 GW, supplying close to 30% of global electricity demand[1].

These milestones reflect significant progress in decarbonisation efforts, yet we are falling short of the target set at COP28 to triple renewables to 11,000 GW of renewable capacity by 2030. As of 2022, the power sector contributed approximately 40% of total energy-related CO2 emissions, underscoring the necessity of meeting these targets to achieve the climate goals set forth in the Paris Agreement[2].

To stay on the narrowing path towards net-zero emissions, we need to urgently enter an ‘era of implementation’. Concrete actions and supportive policies are needed to drive the essential investments required for power sector transformation. It is crucial to ensure that our actions are guided by clear data, enabling the fastest transition to a sustainable energy system at the lowest cost.

Determining the optimal pathways to net zero

A broad consensus has emerged on the importance of rapid decarbonisation, yet perspectives differ markedly on the most effective pathway to achieving net-zero emissions in the power sector.

Some advocate for an approach centred exclusively on variable renewable energy sources, such as wind and solar, supported by energy storage systems like battery energy storage. Others argue that, while renewables and energy storage systems are essential, additional forms of flexibility are critical to ensuring a reliable and cost-effective power supply.

Given the urgency of coordinated global action, Wärtsilä initiated this global power system modelling analysis to evaluate the viability and optimality of widely discussed decarbonisation pathways.

Power system modelling expertise

Wärtsilä helps its customers to accelerate their decarbonisation journeys through market-leading technologies and power system expertise. Using PLEXOS® software, Wärtsilä has completed more than 200 country and power system analyses globally, identifying the optimal power system designs to support the integration of renewables and reduce system operational costs and emissions.

Contrasting choice of net-zero pathways

In this study, we define two contrasting pathways between the period 2025-2050 to achieve net-zero power systems, with an end goal to better understand the options and approaches for viable decarbonisation.

Pathway 1: Renewables and storage

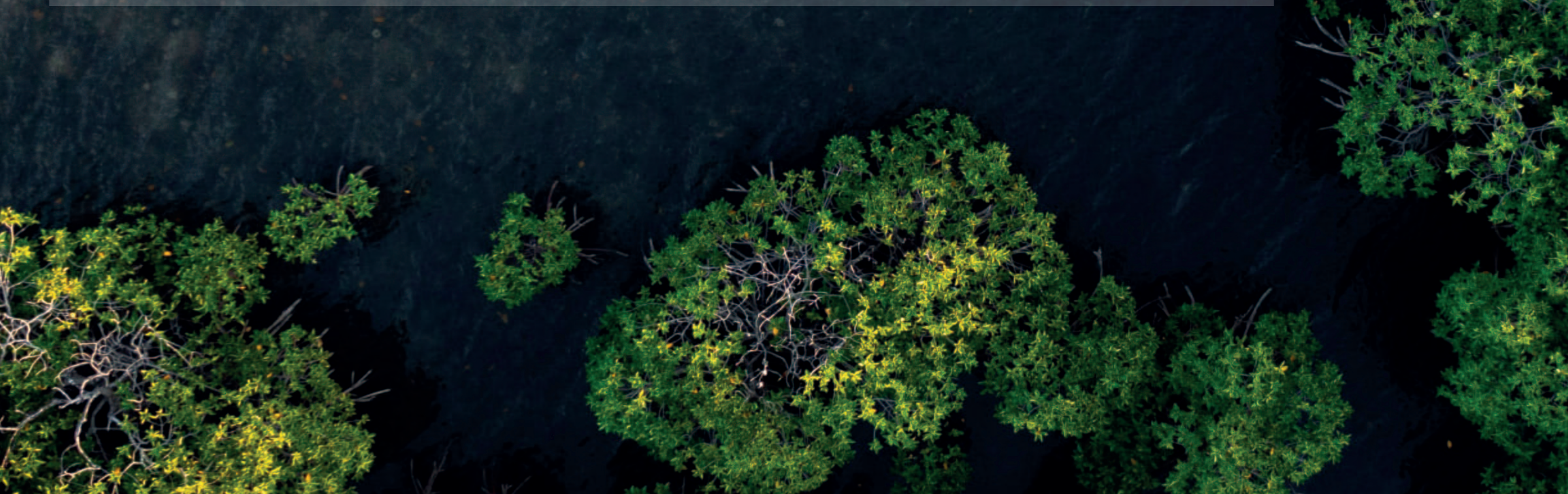
In the Renewables and storage pathway, power sector expansion relies exclusively on variable renewable energy (VRE) and energy storage systems (ESS). Existing power plants are gradually decommissioned by 2040 but are allowed to operate within emission limits until retirement. No new power generation capacity except for renewables and energy storage systems is introduced during the modelling horizon.

Pathway 2: Balanced

In the Balanced pathway, expansion is also led by renewable energy and energy storage systems, but with the addition of balancing power plants that provide additional flexibility and enhance system performance. These are enabled for sustainable fuels that are expected to become more widely available in the 2030s. Existing inflexible power plants are gradually replaced with new capacity upon retirement. Capacity additions for nuclear, biofuels, and coal and gas plants with carbon capture and storage (CCS), follow conservative projections from publicly available sources, such as International Energy Agency (IEA) and International Atomic Energy Agency (IAEA).

At the COP28 climate summit in 2023, governments committed to the global tripling of renewable capacity by 2030, expanding to 11 TW this decade. This target capacity is deployed in the model and in both pathways. From 2025, the system optimises capacity expansion and generation based on defined constraints and the unique technologies available in each pathway. The objective of this optimisation is to minimise total system costs while meeting constraints for availability, reliability, and carbon limits necessary to achieve the Paris Agreement targets.

To reduce computational demands, the global power system is modelled as a single, aggregated system using data from multiple independent research and data providers. This approach necessitates some simplifications to smooth out regional differences and produce an averaged view of the global power system. Both pathways apply consistent assumptions for key variables, including technology costs, fuel prices, renewable energy profiles, annual emission limits, hydrogen demand outside the power sector, and load profiles (excluding electrolyser demand). The model's results are broadly aligned with those of major energy institutions, such as Bloomberg New Energy Finance (BNEF), International Energy Agency (IEA), and International Renewable Energy Agency (IRENA), which employ more detailed, bottom-up, and sector-specific approaches.

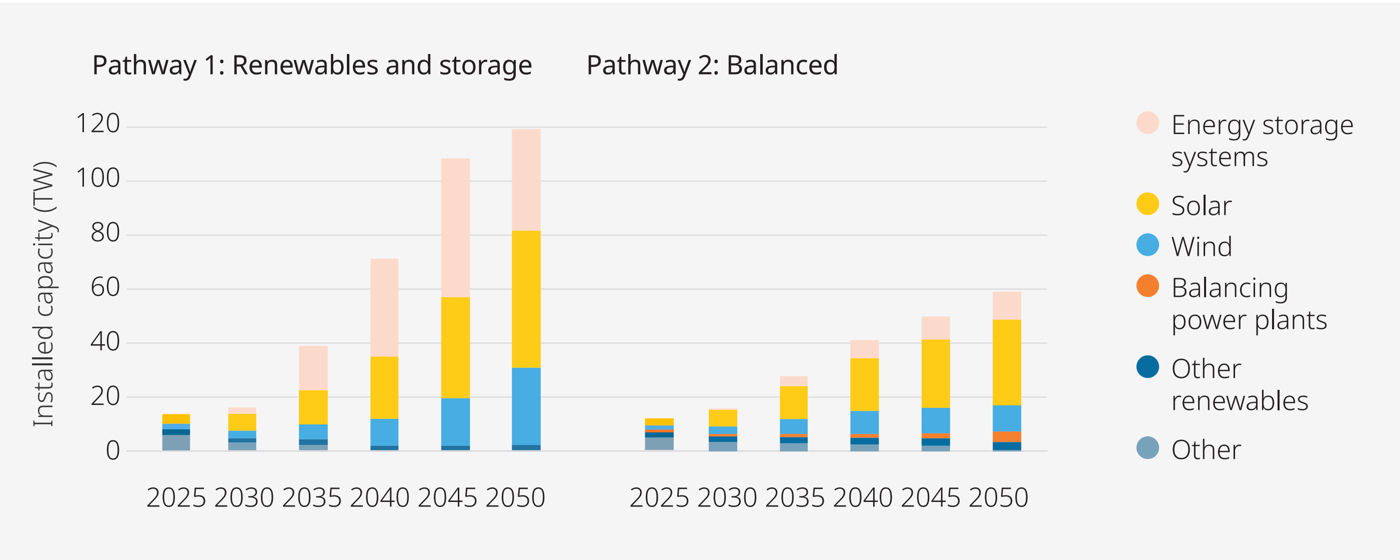


Capacity expansion

In the Renewables and storage path, the installed capacity of variable renewable energy (solar and wind) increases to over 79 TW by 2050, while energy storage capacity expands to more than 37 TW - 31-fold and 441-fold increases respectively, compared to total installed capacities in 2023.

In the Balanced path, variable renewable energy capacity reaches over 41 TW by 2050, with energy storage capacity expanding to over 10 TW - 16-fold and 123-fold increases respectively. This Pathway also incorporates nearly 4 TW of balancing power plants as part of the optimal capacity mix.

Capacity mix
2025-2050



Comparing these results, we see a significantly higher build-out of renewables and energy storage in the Renewables and storage path. This suggests that even a relatively small amount of balancing power plants added in the Balanced pathway reduced the need for extensive over-expansion of renewables and energy storage systems to achieve a cost optimal system.

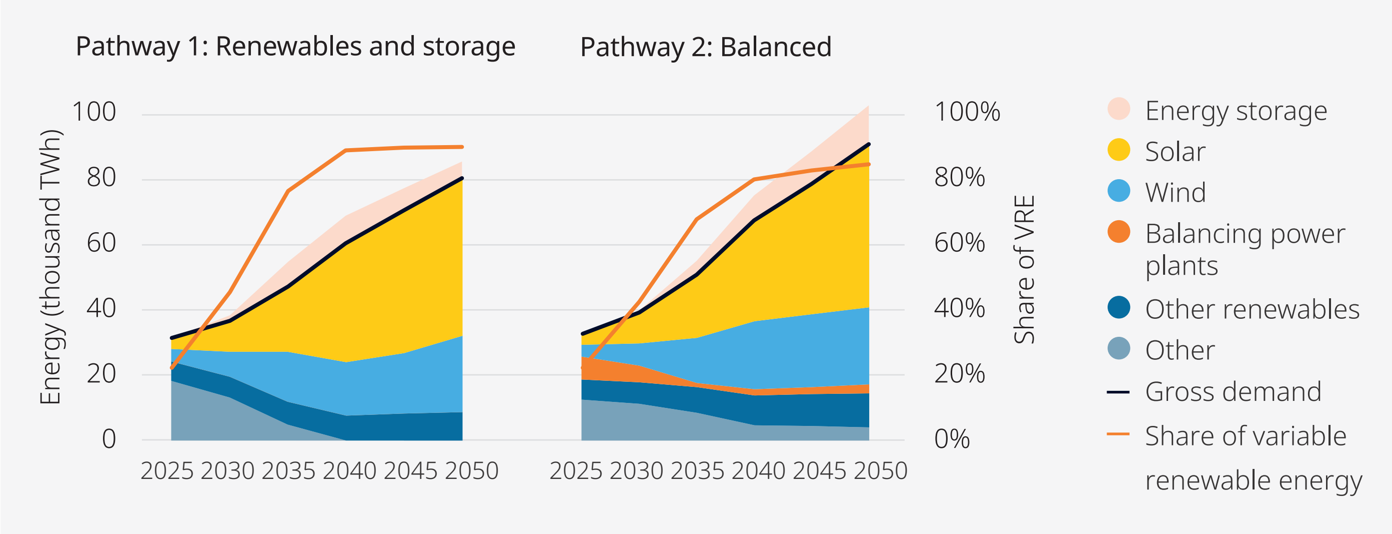
A notable outcome in the Renewables and storage path is the vast scale of renewable expansion required. The land needed for the wind and solar infrastructure alone would cover an area comparable to the size of continental Europe, posing significant challenges for land rights, permitting, and the geographic reach of transmission systems.

Share of generation

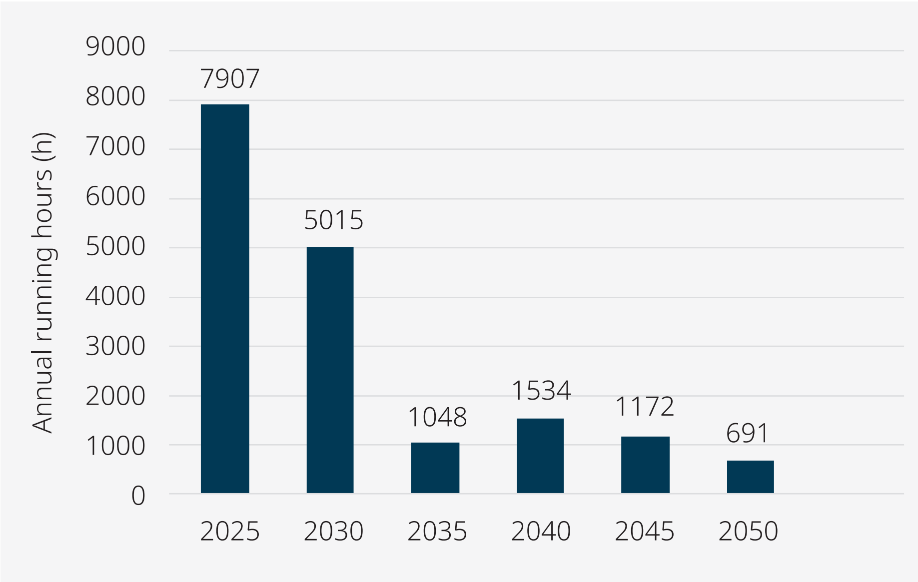
In both pathways, variable renewable energy meets the majority of total electricity demand by 2035, reaching 90% and 85% of total net power generation by 2050 in the Renewables and storage pathway and Balanced pathway, respectively. The share of demand met by energy storage in 2050 reaches 6.5% in the Renewables and storage pathway, while in the Balanced pathway it reaches nearly 13.5%. In the Balanced pathway, the share of demand supplied by balancing power plants gradually decreases from approximately 23% in 2025 to 3% in 2050.

Although balancing power plants play a key role in optimising the system, the modelling results show they will be operated with relatively low running hours. However, their operational profiles are characterised by high ramp rates and frequent starts and stops. This indicates that a high degree of operational flexibility is essential for these assets to effectively support renewable balancing, making inflexible assets, such as legacy baseload plants, ill-suited.

Energy mix 2025-2050



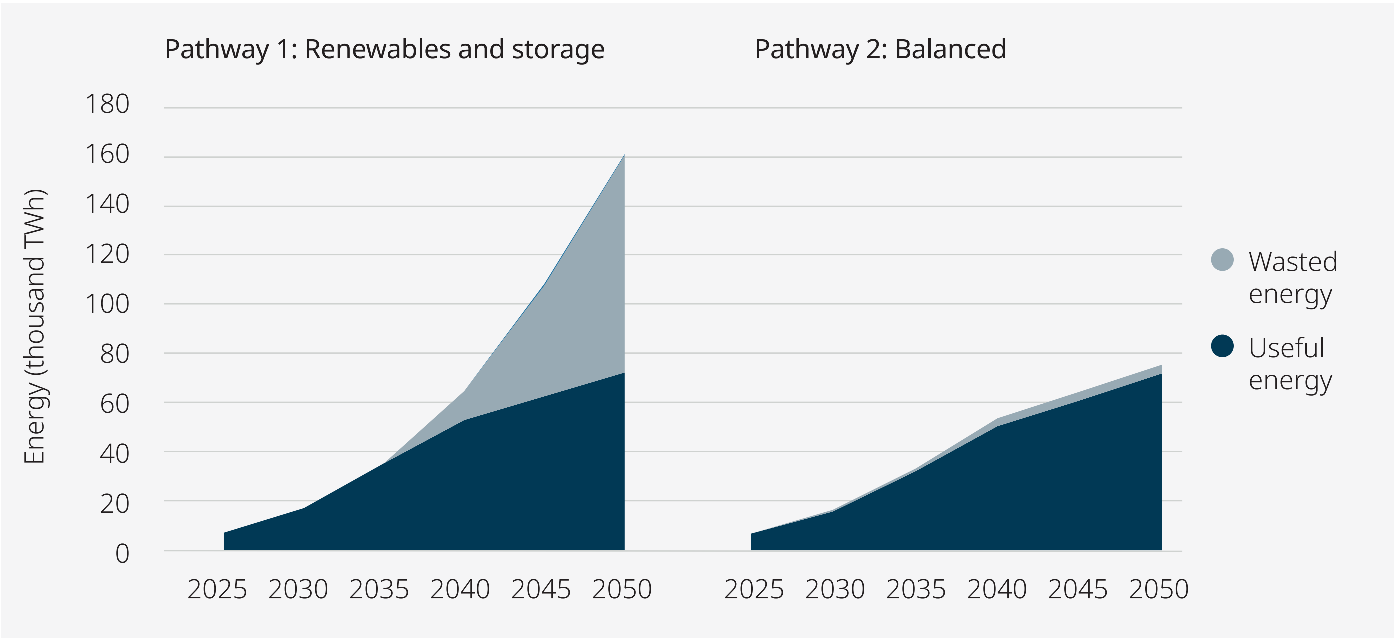
Equivalent running hours of balancing power plants



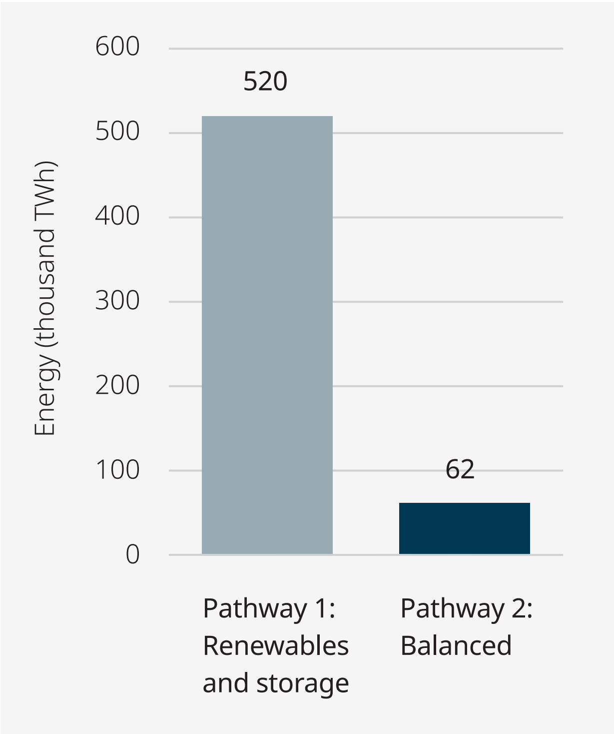
Curtailment

While both pathways meet a substantial share of power demand through renewable energy generation, the differing levels of capacity expansion across the pathways have a significant impact on how renewable generation is managed by the system. Although curtailment does not necessarily indicate system inefficiencies and can play a crucial role in maintaining stability and overcoming transmission constraints, in practice excessive curtailment may signal serious system constraints or limitations, resulting in wasted energy.

Curtailment of renewable energy



In the Renewables and storage pathway, renewable energy curtailment rises sharply in 2035 and beyond, reaching approximately 55% of total renewable energy generation by 2050, compared to only 5% in the Balanced pathway. To contextualise this, the cumulative curtailed energy in the Renewables and storage path from 2025 to 2050 would be enough to meet the entire 2023 power demand of the world (based on current electricity consumption) for more than 15 years.

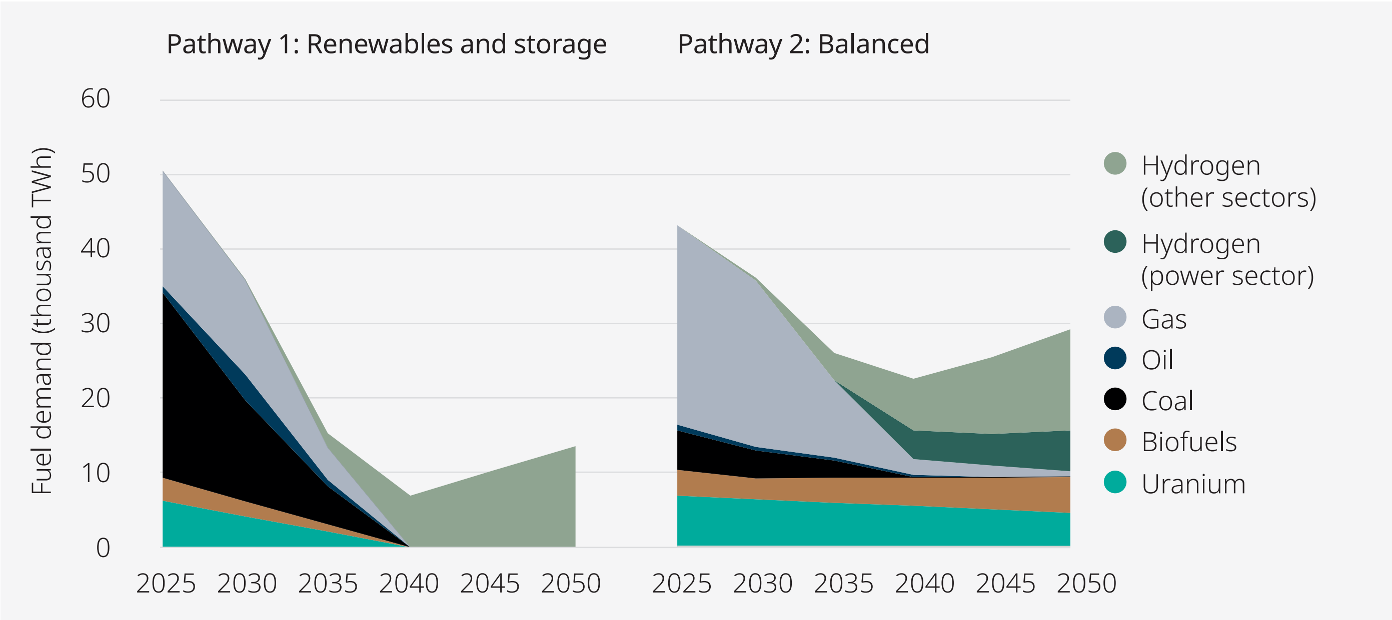


Total curtailment of renewable energy 2025-2050

Fuel demand and sustainable fuels

In both pathways, the power sector plays a critical role in the production of sustainable fuels, essential for economy-wide decarbonisation, especially in hard-to-electrify sectors like industry, marine transport, and aviation.

Fuel demand



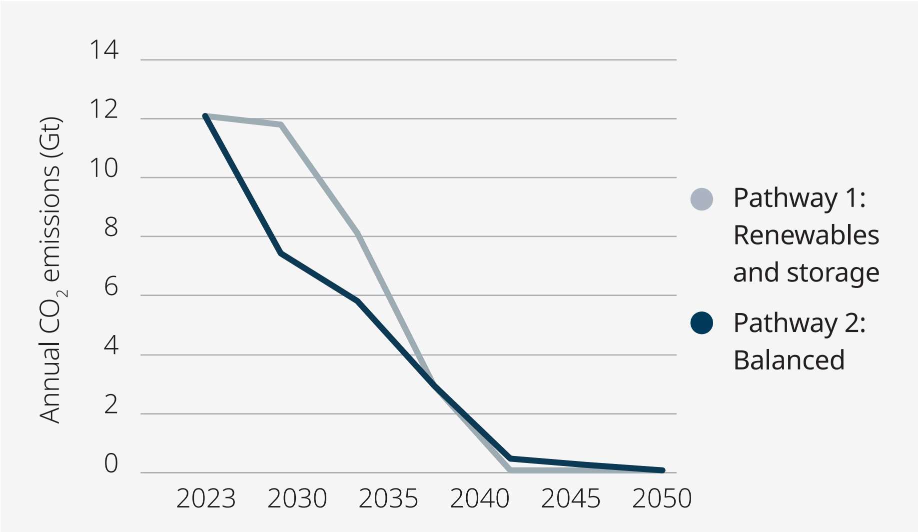
In the Balanced pathway, additional hydrogen is generated for the power sector from the mid-2030s onward. Given the relatively high cost of hydrogen-derived sustainable fuels, these fuels are used exclusively for low-running-hour balancing power, providing additional system flexibility when the installed energy storage reaches its power or storage limits.

Emissions

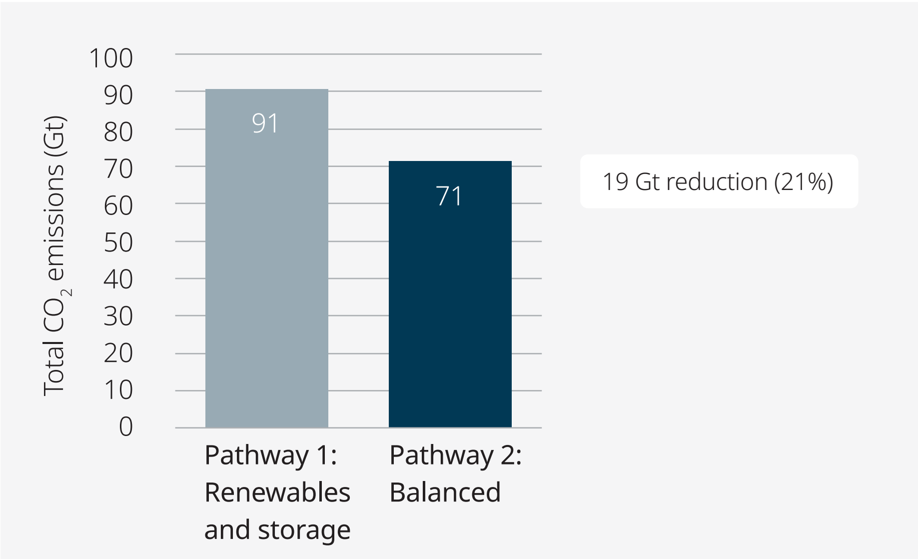
In both pathways, carbon emission limits are imposed to ensure compliance with Paris Agreement targets, with both pathways achieving net zero by 2050 at the latest. However, the rate of emission reduction varies significantly between the two pathways. In the Renewables and storage path, the rate of decline is more gradual, due to the lack of long duration flexible capacity necessary to completely eliminate the need for legacy inflexible power plants.

By contrast, the Balanced pathway sees a more rapid decline in emissions as inflexible assets are phased out and replaced by renewables supported by energy storage and sustainable-fuel ready balancing power plants to provide firm, reliable power over long durations. Consequently, the Balanced pathway achieves a near 21% (19 Gt) reduction in cumulative emissions by 2050 compared to the Renewables and storage pathway, equivalent to over 1.5 years of current global power sector emissions.

A notable finding in the Balanced pathway is that over 76% of annual emission reductions are achieved before sustainable fuels are introduced in the power sector in the mid-2030s. This reduction is driven primarily by the scale-up of renewables and energy storage, along with reduced operating hours for balancing power plants running on gas. The remaining 24% of annual emission reductions are achieved following the adoption of sustainable fuels.



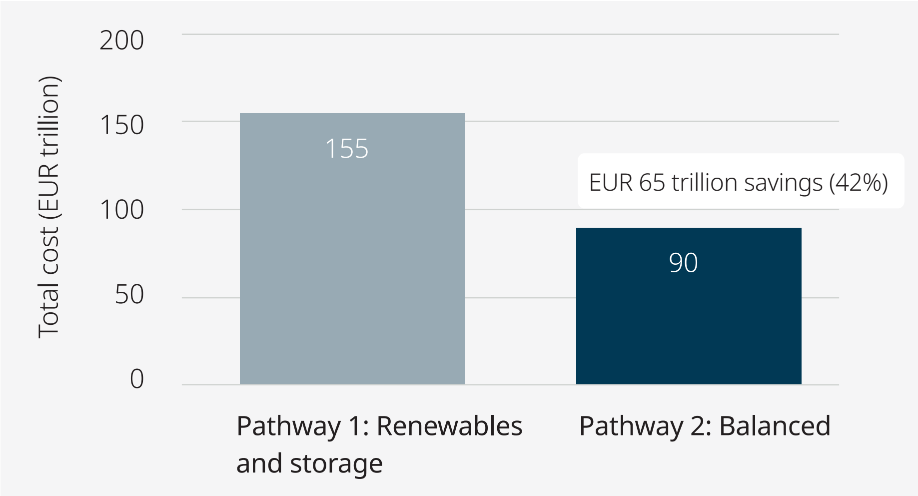
Annual CO_2 emission comparison (power sector)



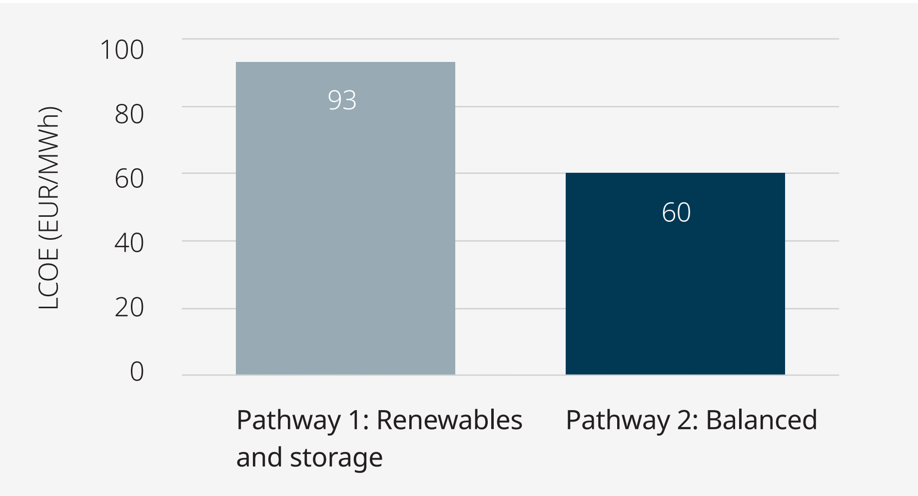
Total CO_2 emissions 2025-2050 (power sector)

Total system cost

Overall, the total system cost between 2025 and 2050 is estimated at approximately EUR 155 trillion for the Renewables and storage pathway and EUR 90 trillion for the Balanced pathway. This translates to a cumulative saving of over EUR 65 trillion for the Balanced pathway compared to the Renewables and storage pathway - equivalent to more than 60% of global GDP today.



Total system cost 2025-2050



Levelised cost of electricity 2025-2050

These cumulative costs translate to a levelised cost of electricity (LCOE) of EUR 93/MWh for the Renewables and storage pathway and EUR 60/MWh for the Balanced pathway. The significant cost disparity between pathways is largely due to the substantial overcapacity of renewables in the Renewables and storage pathway and the high volume of wasted energy due to curtailment.

Clear pathway forward

In evaluating the different pathways to achieve net zero, the modelling results are compelling: the inclusion of balancing power plants is crucial for cost-effective system optimisation. Renewable energy sits at the core of decarbonisation, but system reliability hinges on flexibility.

Flexibility comes in various forms, each playing a vital role. Energy storage is essential for near-instantaneous flexibility and short-duration energy shifting, while balancing power, available during extended breaks in renewable generation, provides flexibility over sustained periods. Ultimately, deploying balancing power alongside energy storage is the optimal technology mix to support renewables.

A call to action for the power sector

As the optimal pathway is clear, decisive actions from the entire power sector are now crucial to achieve a low-cost and low-emission energy transition in line with the 2050 Paris Agreement. Instead of only focusing on the acceleration of renewable build up, a holistic system-level thinking must be in place when investing in and planning power systems. Strategic planning for future power systems and capacity additions should be guided by data to achieve a rapid transition and a cost-optimal technology mix for affordable electricity.

1. Enable an accelerated expansion of renewables and balancing technologies

- Enable fast expansion of renewables by upgrading transmission systems, streamlining permitting processes, and investments in regional interconnectors.
- Rapidly expand short and long duration balancing technologies to ensure grid reliability and resilience. Together, these technologies support the rapid growth of renewable energy, reduce reliance on inflexible assets, such as coal plants, and accelerate emission reductions.
- Mobilise financing to secure the development of renewable and balancing power projects at the necessary scale and speed.

2. Redesign electricity markets to incentivise flexibility

Reform electricity market structures to support greater integration of variable renewable energy. Balancing should be incentivised to provide essential flexibility to optimise renewable energy systems.

- Increase dispatch granularity to 5-minute resolution in energy wholesale markets. Shorter and more precise time frames for pricing and supply adjustments will support variable renewable energy integration and incentivise flexible balancing power plants that can respond quickly to changes in electricity demand.
- Introduce new ancillary services, such as reserve, ramping, voltage, and inertia products, to guarantee grid stability. The need for ancillary services increases with higher renewable penetration, and the supply can be co-optimised with energy and balancing requirements and provided by balancing technologies.
- Establish bankable revenue models for low-running-hour balancing power plants, including mechanisms like flexibility-linked capacity payments and scarcity pricing. Balancing power plants provide crucial system-level benefits, yet due to low capacity factors, additional revenue mechanisms are needed to yield sufficient investments into balancing assets.

3. Choose the right future proof technologies and prepare for sustainable fuels

- Select balancing technologies that are future proof and ready for the introduction of sustainable fuels to fully decarbonise the power sector from the mid-2030s onwards.
- Support rapid ramp up of renewables and enable the phase out of legacy technologies, by using natural gas as a transition fuel for flexible balancing power plants. This should not be confused for a 'status quo' approach, as gas will be used very differently than today, and in much smaller amounts. Bridging the transition with gas for balancing can cut more than 75% of annual power sector CO2 emissions by 2035 (in comparison to 2023 level).
- Prepare for the introduction of sustainable fuels by building the needed expertise and infrastructure to ensure a seamless transition to a fully decarbonised power sector in the future. Once sustainable fuels become viable at scale, i.e. commercially available and competitive, emission reductions can be pushed to 100%. Competitiveness or cost-parity of sustainable fuels will require policy action, which could be in the form of subsidies, regulation, or carbon taxes (or a mix).

Market insights

Americas

United States: The composition of U.S. power generation has been transformed in the last decade. Coal generation has dropped drastically and is rapidly being replaced by renewables and natural gas, resulting in greenhouse gas emissions reductions of over 5% since 2015. Government incentives, such as the Inflation Reduction Act (IRA), state-level net-zero mandates and declining technology costs will continue to power renewable generation's rapid growth. This growth brings more variability in energy production and requires flexible dispatchable generation to manage that output. While, for example, Texas has become the leader in wind and solar generation, the state also introduced a fund to support new investment in flexibly dispatchable, non-duration limited balancing power. The fund aims to support its rapidly growing economy and ensure reliable, affordable electricity. In 2023, California, long held as the front-runner for renewable energy ambitions, needed to curtail over 2.6 million MWh of renewable energy due to grid inflexibility. That's enough energy to power 250,000 homes. Flexible balancing power is crucial to support intermittent renewables and avoid massive curtailments that will otherwise result in costs for the consumer. More incentives are needed to ensure balancing technologies are embedded in the US power systems.

Risto Paldanius
Vice President,
Americas

Brazil: Extreme weather conditions, like Brazil's historic drought this year (2024), have highlighted the urgent need for energy diversification to ensure system reliability. With reservoir levels sharply declining, flexible solutions are urgently needed to prevent blackouts and maintain power system stability. Incorporating balancing power plants will be key to enhance system reliability and flexibility. Balancing power, such as flexible engines, can support renewables, especially during critical drought periods, and are economically accessible and technologically advanced. As Brazil prepares to host COP30 in 2025, the focus on sustainable energy solutions becomes even more critical. The country has a unique opportunity to showcase its commitment to a resilient and affordable energy future by integrating renewables, energy storage, and balancing power, to deliver a balanced approach to achieving net-zero emissions. This approach not only ensures system stability but also accelerates decarbonisation and reduces overall emissions.

Chile has bold ambition to achieve a fully renewable energy mix by 2050. The country has already made significant progress in adding renewable generation, but greater system flexibility is needed to address the intermittency of solar and wind energy. This aligns with the findings of our report, which emphasises the critical role of balancing power plants in enhancing system reliability and flexibility during extended breaks in variable renewable energy generation. Incorporating flexible balancing power, such as grid balancing engines that can be rapidly started and stopped, could provide the necessary balance when renewable resources are unavailable, complementing the country's carbon neutrality goals. Our research in Chile estimates that combining renewables, energy storage, and balancing power could save $17 billion by 2045. However, similar to global challenges, limited transmission infrastructure and the need for a supportive regulatory framework remain critical challenges for efficiently integrating renewable energy and ensuring a sustainable transition. This underscores the need for coordinated action in renewable expansion, market reform, and leveraging existing technologies to enable a timely and cost-effective transition to net zero.

Europe and Africa

Finland aims to achieve carbon neutrality by 2035, with a significant increase in weather-dependent renewable capacity, particularly wind power. Concurrently, the power system will see a gradual reduction in firm capacity as older inflexible fossil-fuel units retire. Despite this, firm and flexible capacity remains essential to compensate for wind power during unfavourable weather conditions, especially during extended cold and low-wind periods. Our recent Finland modelling indicates that, with the current power system in Finland, electricity prices will be 30% higher by 2027 compared to 2023. To address this, we calculated that integrating 2 GW of firm and flexible balancing power can reduce electricity costs by 10%, equivalent to EUR 1.3 billion, and enhance system stability. Therefore, it is crucial to adopt a carefully designed, future-proof capacity mechanism. New firm and flexible capacity, alongside energy storage and demand-side response, will also be key to ensuring future security of supply and achieving climate targets.

Kenneth Engblom
Vice President,
Africa and Europe

Poland is aiming to accelerate its shift away from coal, which is currently its leading source of power and heat generation. The country has brought forward its coal phase-out target from 2049 to 2035, and is aiming to achieve carbon neutrality by 2050. The share of renewables in Poland is steadily growing, accounting for 27% of energy production today (up 3% year-on-year), with plans to increase onshore and offshore wind capacity from 10 to 25 GW by 2030. The critical challenge is the lack of balancing capacity in the grid, which poses a risk to stability.

Poland also has the largest district heating network in Europe, with a total capacity of 54 GW consisting mostly of coal-fired boilers. Decarbonisation and modernisation of this sector poses both a challenge and an opportunity, as district heating networks also represent the largest source of flexibility for the grid. Our recent modelling in Poland shows that cost-effective decarbonisation of both sectors is possible by co-optimising heat and power. This will allow Poland to increase its share of renewable energy to 68% in 2032, reduce the share of coal to 26% in power and 8% in heating, and deliver cumulative savings of 3.8 BEUR. To achieve this, it is paramount that Poland introduces a diverse range of flexible technologies, with combined heat and power engines, heat pumps, and heat storage as key facilitators, supplemented by electric boilers and battery energy storage.

South Africa plans to grow renewable capacity to 17.7 GW by 2030. Our analysis in the country shows that a balanced system with flexible power generation, running on gas, and energy storage is crucial to integrate this variable renewable capacity, ensuring grid stability and reliability. The state-owned power utility Eskom's recent 3 GW GASIPPPP tender for ultra-flexible gas validates the need for this flexible generation identified in our modelling.

Morocco's updated nationally determined contribution (NDC) commits the country to reducing its greenhouse gas emissions by 18.3% by 2030. To achieve that it has the ambition of achieving 52% renewable electricity by 2030, however integrating renewables at this scale poses challenges. Our modelling in Morocco recommends a balanced system with renewables, battery energy storage, and flexible power plants, including 60% of grid-balancing engines. This combination can optimise renewable integration, reduce fuel costs, and ensure reliability to achieve that ambition via a cost-effective, low emission pathway.

Middle East and Asia

Frederic Carron
Vice President,
Middle East and Asia

India: Imagine a future where India's power grid seamlessly integrates 500 GW of non-fossil fuel sources by 2030. To achieve this vision, it is vital to invest in resources like balancing power plants. Studies indicate that by 2030, India will need 9 GW of flexible balancing engines, utilising gas, to efficiently and reliably integrate renewable energy. By restructuring the power market to provide a bankable revenue model, we can attract investments in flexible technologies and low-running-hour balancing power plants. This strategic shift will ensure a stable and sustainable energy future for India.

Indonesia: Achieving Indonesia's net zero target by 2060 or sooner is possible but requires significant efforts to add renewables and balancing solutions at scale, while phasing out inflexible power plants. Expanding renewable energy generation rapidly in the short-term is crucial for achieving climate goals. Our recent modelling of Indonesia shows that renewable power generation in Indonesia could be 3-4 times higher than the current targets, but it is vital to match the increase in renewable power with the addition of balancing technology to optimise overall energy production costs.

Saudi Arabia has started its energy transition journey, and its first giga-scale renewable energy projects are now in construction. Currently 8 GWh of energy storage capacity is being tendered and a new generation of young, environmentally conscious Saudis are playing a key role in the country's future energy planning. The Saudi vision is focused on achieving 50% renewables and 50% natural gas-based electricity by 2030. The need for flexibility is being recognised as the crucial enabler of system reliability and renewable integration.

United Arab Emirates is the green energy leader in the Middle East. However, with the technology changes in water desalination and the addition of nuclear energy and robust solar farms, the UAE is facing new challenges with its energy system. The winter season will require efficient balancing, while the hot season needs firm and efficient power. National utilities have identified the need for additional dispatchable and flexible capacity and will install over 2.5 GW of gas-based power plants to cater peaking and mid-merit demand of the system. This will enable further acceleration of the clean energy transition in the UAE.

Methodology

The analyses in this report are based on techno-economic optimisation to determine the least-cost capacity mix required to meet future electricity demand while adhering to emission limits and other political constraints. Conventional power plants are included with their technical specifications and fuel sources to accurately model their emissions and role in balancing variable renewable generation. Wind and solar generation are modelled using hourly profiles based on weather data.

This detailed optimisation uses a chronological approach, balancing the variability of renewable generation and load on an hour-by-hour basis from 2023 to 2050. The model co-optimises system expansion with dispatch, using a one-hour resolution to capture load and renewable generation patterns in high detail.

The global power system is aggregated into a single model, aligning various regional power profiles to preserve daily patterns such as demand peaks and solar output regularity. This aggregated approach avoids time-zone discrepancies that could distort demand and generation profiles.

Common assumptions

Both Pathways share baseline assumptions for key factors:

- Starting capacity mix in 2023[4, 5]
- Annual power sector CO_2 limits through 2050, consistent with Paris Agreement and net the zero CO2 emissions of the whole energy sector by 2050[5]
- Renewable target of 11 TW by 2030[1]
- Fuel and carbon prices[5], CO_2 content per fuel type[6], load growth[3], technology costs and learning curves[3] and renewable/load profiles[7].
- No land-use restrictions; land requirements calculated post-simulation.
- Sustainable fuel is assumed to be hydrogen, but other carbon-neutral fuels could also be modelled

Limitations

The model is based on a single weather year, a common approach for long-term planning but limited in capturing multi-year variability. Consequently, the results do not include a reliability margin, and capacity needs may be slightly higher in scenarios with adverse weather years. This limitation particularly affects the Renewable Energy Only Pathway, making the presented cost and curtailment estimates conservative.

Sources

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Wärtsilä Energy is at the forefront of the transition towards a 100% renewable energy future. We help our customers and the power sector to accelerate their decarbonisation journeys through our market-leading technologies and power system expertise. Our solutions include flexible engine power plants, energy storage and optimisation technology, and services for the whole lifecycle of our installations. Our engines are future-proof and can run on sustainable fuels. Our track record comprises 79 GW of power plant capacity, of which 18 GW are under service agreements, and over 125 energy storage systems, in 180 countries around the world.

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