WÄRTSILÄ

NIGERIA ENERGY TRANSITION

"30-30-30" and beyond

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EXECUTIVE SUMMARY

Nigeria has set some of the most ambitious decarbonisation targets in Africa. The country seeks to take the lead in climate action and aims to achieve carbon neutrality by 2060 whilst also meeting the nation's growing energy needs and offer universal access to electricity to its population.

Besides its 2060 carbon neutrality target, Nigeria has also established a "30-30-30" target, which aims to reach 30 GW of grid-connected capacity with at least 30% of renewable capacity by 2030. This study provides a realistic and data-driven plan to establish the optimal energy transition strategy that Nigeria can adopt to reach both objectives.

If we fast forward our clocks, and proper planning is agreed and executed, by 2060, Nigeria will reach its targets and carbon emissions in its power system will be zero. During the transition, the cost of electricity generation will progressively drop by 74% compared to the 2022 levels. The key components of Nigeria's power system will be renewable energy sources, supported by storage technologies, together with grid-balancing engines that have been converted to run on green hydrogen.

In this whitepaper, Wärtsilä provides a clear and realistic road map to support Nigeria in developing the most optimal power system expansion plan over the next four decades.

Our power system modelling demonstrates a cost-optimal, reliable and rapid energy transition

We model the cost optimal path towards 100% renewable energy systems for customers, cities and entire countries.

Wärtsilä has already modelled over 200 countries and regions.

- Understand operations and fundamendals of power systems
- Quantify system level benefits of different generation and storage technologies
- Understand and promote high quality modelling

NIGERIA'S ROADMAP TO NET ZERO IN A NUTSHELL

2023-2030 Capacity additions	• 5.0 GW of solar power • 2.7 GW of wind power • 12.2 GW of Internal Combustion Engines (ICE) • 2.5 GW of Combined Cycle Gas Turbines (CCGT)

BY 2030 Nigeria reaches its 30-30-30 target, which means 30 GW of grid-connected capacity by 2030 of which 30% comes from renewables. The amount of unserved energy drops significantly in the later part of the decade, which means that a much larger portion of the population now has access to electricity. A lot of flexibility has been added to the power system thanks to ICE technology. The system is now ready to accommodate the massive renewable energy deployment planned in the 2031-2040 decade. Our model reveals that reaching the 30-30-30 target in the most cost-effective way will require $18.7 Billion of investment.

2031-2040 Capacity additions	• 110 GW of solar power • 14 GW of wind power • 16 GW of ICE power plants • 5.3 GW of ICE with carbon capture technology • 24 GW of energy storage capacity

BY 2040 Nigeria reaches universal access to electricity for its people. In the early thirties, unserved energy has dropped to zero and diesel generators can be totally phased out of the system as the grid can now provide enough electricity to the whole population.

2041-2060 Capacity additions	• 616 GW of solar power • 62 GW of wind power • 259 GW of energy storage • 51 GW of electrolysers

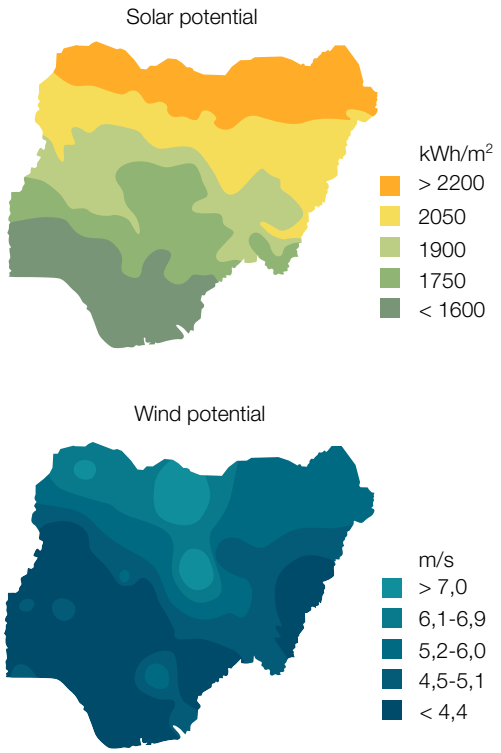
BY 2060 Nigeria's power system runs on 100% renewable energy and reaches net zero with a total installed capacity of 1,190 GW. Renewables also serve to produce green hydrogen using electrolysers to power the converted thermal power plants. Energy storage capacity and hydrogen-capable engines provide the necessary short-term and long-term energy shifting to ensure reliable operation of the grid. The power system is no longer reliant on fossil fuels and carbon emissions have dropped to zero. Renewable energy has become the new baseload. In order to achieve net-zero in 2060, the total investments required are approximately $425 Billion.

UNDERSTANDING TODAY'S POWER SYSTEM CHALLENGES AND OPPORTUNITIES

To identify what needs to be done in the future, it is important to have a clear view of Nigeria's current power system, but also to understand the country's challenges, opportunities, and advantages.

With its massive gas reserves in the South, and high solar and wind potential in the North, Nigeria has all the natural resources necessary to provide enough electricity for its population. With the right decisions and planning, the country can leapfrog a traditional baseload power system and meet its ambitious decarbonisation and power generation targets.

But there is a long way to go. Today, the country's power generation capacity sits at just over 14 GW, only half of which is operational. Renewable energy represents about 5% of the total power generated in Nigeria. The power system's annual carbon dioxide emissions represent about 50 Mt.



Although 65% of Nigerians have access to electricity, 60 to 70 million people are still without power. The grid is unreliable, and the country continues to struggle with acute electricity shortages and blackouts, which constrain its economic development.

Small, inefficient, expensive, and polluting diesel generators are widely used to compensate for weaknesses in the country's grid capacity. Despite recent improvements, the gas supply system is not stable, which places additional strain on the country's fragile electricity network. To set the country on a new path, the Nigerian government recently launched "the Decade of Gas" initiative, setting gas development and utilization as a national priority.

In this context, ICE technology, thanks to its flexibility and its ability to be converted to run on green fuels as they become available, will be a strong asset to meet energy demand in the short term, and facilitate Nigeria's transition to a 100% renewable energy future going forward.

An improving, but still complex regulatory environment

The continued improvement of the country's regulatory environment will be a key enabler of Nigeria's successful energy transition. Nigeria's power sector reforms began around ten years ago when the government launched an ambitious privatization and unbundling of the vertically integrated historical utility. Power generation plants were transferred to privately held GENCOs, the distribution network went to partially privately owned DISCOs, while the transmission network was kept under government ownership.

The resulting regulatory environment is complex and still evolving today, creating significant uncertainty for independent power project developers. Despite an increasingly strong legal framework and the many government efforts to implement reforms, project developers and sponsors still need to navigate multiple institutions with sometimes conflicting or unaligned regulations. In this context, streamlining planning and permitting processes for projects will be essential if the country is to achieve its power system expansion ambitions.

Expanding the transmission grid and gas infrastructures

The transmission grid must be able to support rapidly increasing power capacity. The aggressive expansion of the transmission network will enable Nigeria to extend to the entire country the benefits from the gas reserves located in the South and the excellent renewable resources found in the North.

There is no doubt that gas has an important role to play in meeting Nigeria's electricity demand in the short to medium term. However, the poor condition of the gas distribution system is a major constraint as domestic supply shortages and unstable pressure levels severely affect the reliability of the power supply. Sustained efforts must be made to accelerate ongoing gas pipeline infrastructure projects and domestic LNG capabilities to secure gas supply availability for new gas-based power plant projects.

Adopting a long-term, data-driven power expansion strategy

The reality today is that Nigeria's power system faces many difficulties. Besides blackouts, fuel shortages, insufficient financing, lack of maintenance, demanding operating conditions and reduced cooling water availability are some of the main challenges that the country needs to cope with.

The gap between the country's energy needs and its current provision is wide, but far from impossible to close. A long-term, data-driven power strategy can be built to make the most of the country's exceptional energy resources. This is the purpose of this study. It will embrace several key trends, including the rapidly increasing penetration of renewables, and the key role of flexible power plants, energy storage technology and hydrogen.

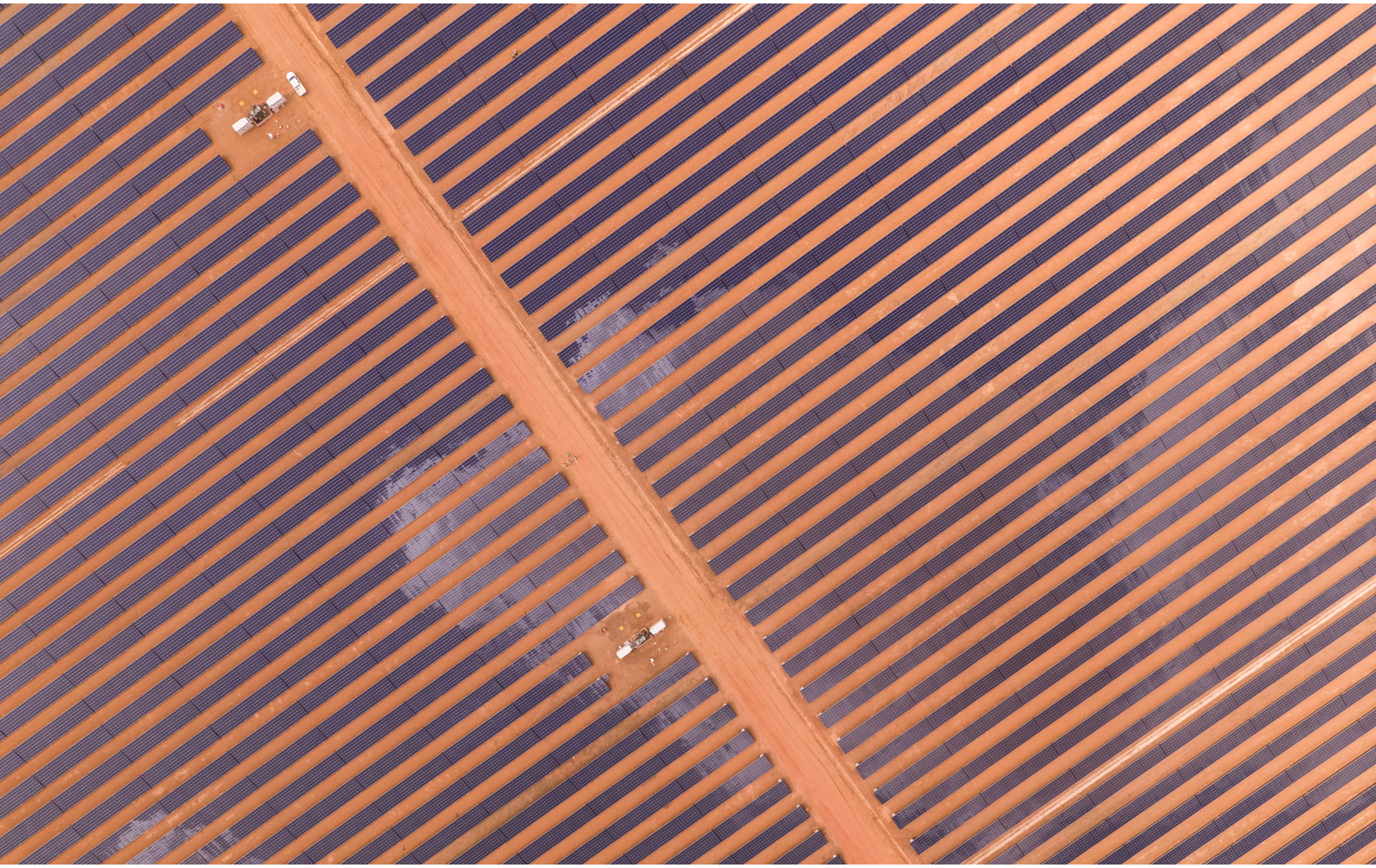
If Nigeria can manage to create an economically viable and thriving renewable energy industry, the benefits will be huge. At the end, securing universal access to reliable and sustainable electricity has the potential to transform the country's economy and improve the lives of millions in the process.

INTRODUCTION TO WÄRTSILÄ'S POWER SYSTEM EXPANSION MODELLING TECHNIQUES

Wärtsilä's highly experienced analysts have used PLEXOS, a leading power system simulation software, to model the optimal way to build a fully decarbonised power system in Nigeria. The modelling defined the cost-optimal energy system structure and operation mode for a given set of constraints in each region: power demand; available generation capacity, storage and balancing technologies as well as financial and technical assumptions.

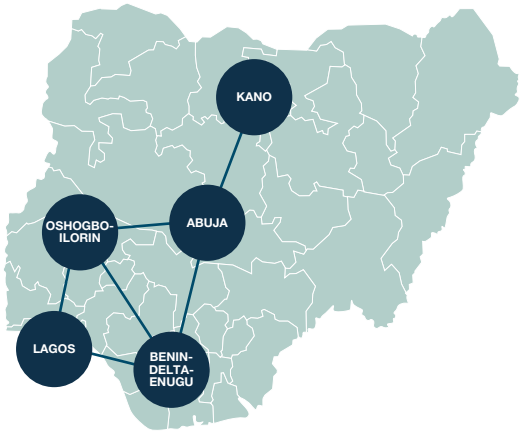
The model is based on linear optimisation and performed on an hourly resolution for full years. The costs of the entire system are calculated as the sum of the annualised capital expenditures, operational expenditures and fuel costs for all available technologies.

The model has been set to define the optimal power expansion plan to meet Nigeria's targets for 2030 and 2060. The scenario modelled by Wärtsilä will enable policymakers in Nigeria to make informed long-term decisions on building a cleaner and more modern power system for the country.



Modelling approach and system assumptions

The Nigerian power system has been simplified into five major demand zones: Lagos, Benin-Delta-Enugu, Oshogbo-Ilorin, Abuja, and Kano. These regions are inter-connected with transmission lines and each region has a specific hourly electrical demand as well as its own hourly solar and wind generation profile. PLEXOS will calculate the hourly electricity generation needed in each zone to provide enough electricity to match the demand in a cost-optimal way. Today, the estimated peak load of the country is 30 GW and it is expected to quadruple to 130 GW by 2060.



Optimising the energy mix

To meet the rapidly growing energy demand, more production capacity is needed. PLEXOS gets information on the technical and commercial parameters of each technology, including fuel prices and availability. This information is used to optimise the best-suited technologies to be built each year.

Newbuild candidates include all major power technologies: renewables, energy storage of different durations, electrolysers, hydrogen-capable power plants and carbon capture technology. The cost of solar, wind, energy storage and electrolyser technology are expected to continue to decrease going forward. This downward price trend has been considered in the model by using learning curves from research institutions.

Making informed strategy decisions

In order to avoid mistakes made by early-mover countries with ambitious decarbonisation targets, a proper plan must be in place before actions are taken. **Nigeria has a clear opportunity of leapfrogging over a power system dominated by** large inflexible baseload power plants if it focusses investment on renewables and future proof flexible thermal technologies. In other words, Nigeria doesn't need to build up a huge fossil fuel capacity first and then adopt renewables: our study shows that with the right technology mix, Nigeria can leapfrog directly to a system largely based on renewable energy, making choices that are both environmentally friendly and economically competitive.

The plan will define **what type of power system to build** and how to ensure it will be reliable and provide affordable electricity with the additions of vast amounts of variable renewable energy. PLEXOS has the information of the declining price curves for solar, wind and energy storage solutions, and it optimises the introduction of these capacities in the time scale so that the nation gets **maximum benefit** of the downward price trends.

This study has been conducted to support policymakers in identifying the most cost-effective and reliable capacity additions that can be built each year in Nigeria. It will support Nigeria in engineering the optimal power system transition, using **modern power system expansion software and supercomputers.**

NIGERIA'S OPTIMAL POWER SYSTEM EXPANSION PLAN: THE ROAD TO 2060

STAGE 1: 2023 TO 2030

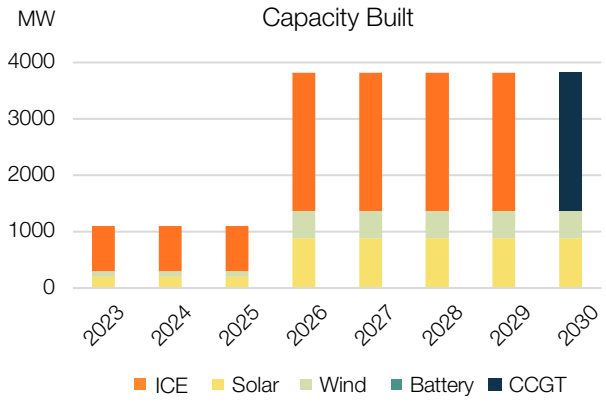
Building solid foundations for the decarbonisation of Nigeria's power system

Key actions

- Start investing in new solar and wind power capacity
- Ramp up investments in flexible ICE power plants
- Improve the transmission grid and gas distribution network

Leading up to 2030, the priority for Nigeria is to ramp up the investments in flexible thermal power plants. This will increase power generation as well as support the poor transmission grid as breakdowns of different components in the grid require fast ramping up and ramping down capabilities. Solar and wind power capacity is progressively added, as the country begins its journey towards net zero.

Engine power plants possess many characteristics which make them the ideal technology in Nigeria. They have a high operating efficiency even at partial load and are designed to cope with regular start and stops.



But there is more. Flexible engine power plants offer several other advantages relevant in Nigeria. Thanks to their modular design, engine power plant projects are easy to construct, fully scalable and can be deployed in phases. They can be ramped-up or down quickly to adjust to demand, and also provide a great hedge against fuel supply risk, as they can be operated on multiple types of fuels. What is more, flexible engine power plants require little water to operate: Their water consumption is lower than that of other competing gas-to-power technologies, a crucial advantage when operating in Nigeria.

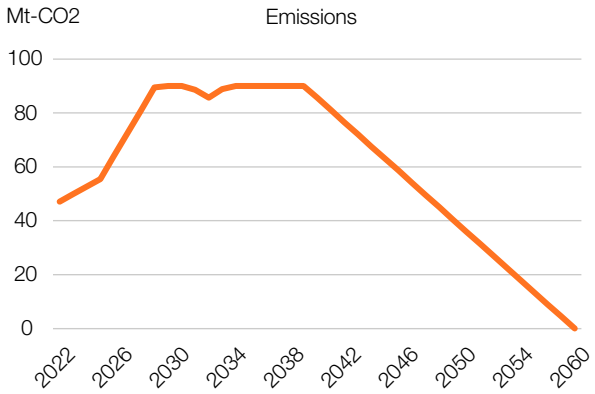
Flexible power plant assets create the necessary foundation for a smooth transition to net zero, as they will enable the grid to accommodate an increasing amount of renewable energy in the coming decades.

BY 2030

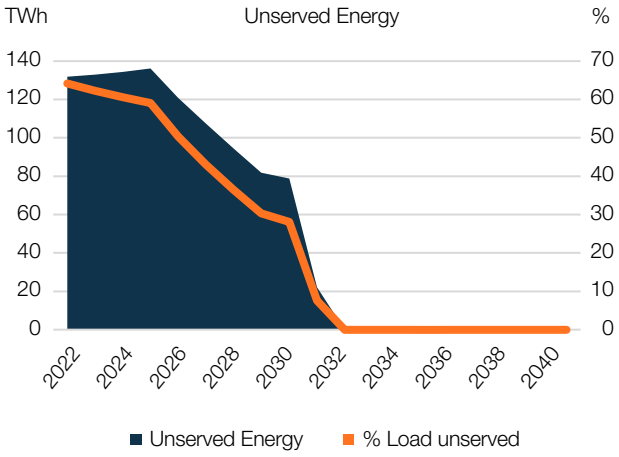
5.0 GW of solar power and 2.7 GW of wind power capacity has been added to the system, enabling the government to meet its 30-30-30 target. Renewable energy now represents little over 10% of the generated electricity and 30% of the total installed capacity.

12.2 GW of new flexible capacity has been built into the system, which is now ready to accommodate the massive renewable energy deployment planned in the 2031-2040 decade. Our model reveals that reaching the 30-30-30 target in most cost-effective way will require **$18.7 Billion of investment.**

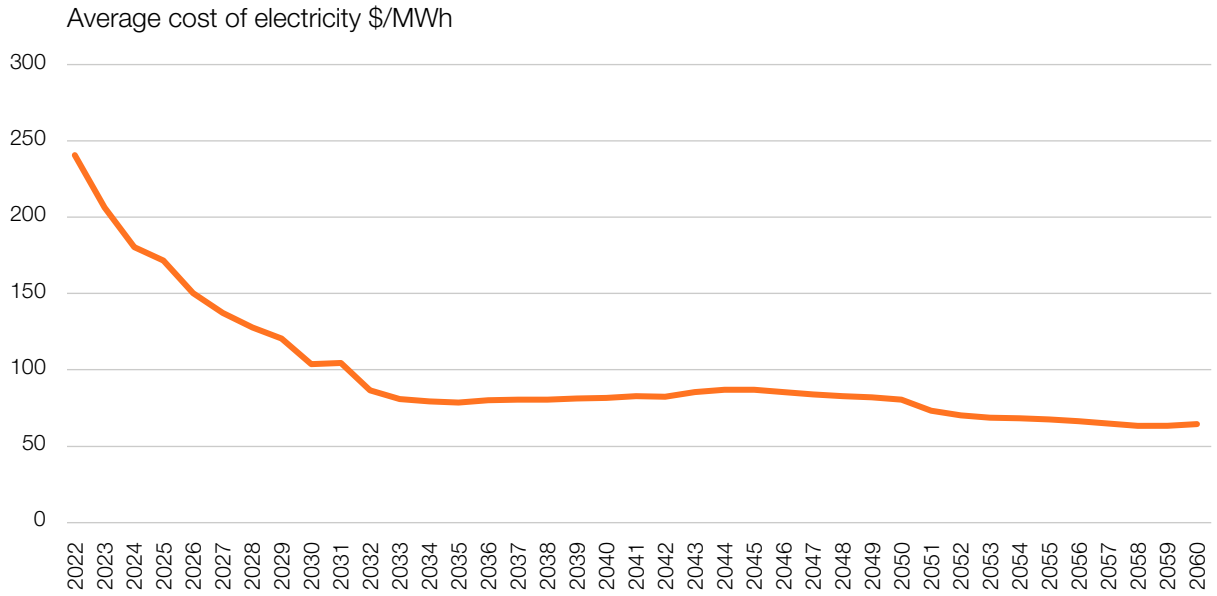
The power system carbon emissions temporarily increase up to 90 Mt. Although emissions are at a higher level in 2030 compared to 2022, the emission intensity (ton of CO2 per MWh produced) decreases significantly. The rise in total CO2 emissions is inevitable given the massive new thermal power capacity needed for the system to satisfy the booming energy demand. CO2 emissions will progressively drop to zero when more renewable energy is being built and hydrogen replaces gas as a fuel in thermal power plants starting in the early forties.



By the end of the decade, the country's power generation capacity has been massively ramped up. As a result, the percentage of unserved energy is halved by the end of the decade, meaning that Nigeria is now able to meet a much larger share of the country's total power demand.



As more capacity is added to the system, the average cost of electricity in the country falls drastically until 2030, as locally sourced natural gas fuels increasing proportion of the power generation at the expense of expensive diesel. The cost of electricity is further lowered thanks to the increased deployment of low-cost renewable energy.



STAGE 2: 2031 TO 2040

Accelerating the decarbonisation process

Key actions

- Continue investing in flexible gas engines and ramp up investments into renewables to replace diesel generators still in place and meet rapidly growing electricity needs.
- Start investing in energy storage technologies
- Introduce carbon capture technologies to lower carbon footprint of gas-based power plants

During this crucial decade, our model recommends the installation of over 125 GW of renewable energy capacity, most of which is solar energy. These investments are concentrated in the Northern areas of the country with more favourable weather conditions. Renewables become a significant source of energy, providing nearly half of the needed electricity by the end of the decade. During the same period, 21 GW of new thermal power plants are built, mainly in the Southern regions of the country with higher electricity demand and better access to low-cost and locally sourced gas.

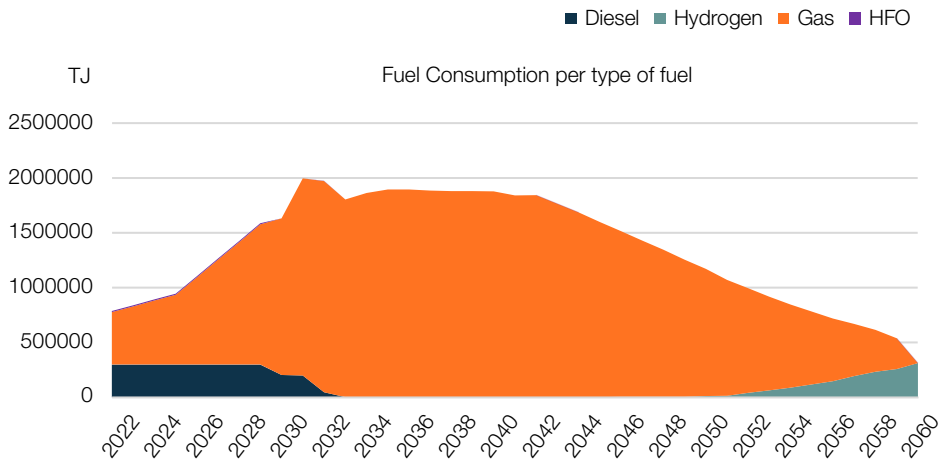
Because of the large deployment of intermittent renewables, the capacity factors of thermal power plants decrease significantly and daily starting and stopping is required. This is the time when the previously built flexibility starts to pay off as flexible engine power plants can easily handle this kind of operational profile.

Thermal power plants and additions in renewable energy capacity contribute to meeting the country's remaining unserved energy demand, which rapidly drops to zero by 2032. The increased capacity in the power system removes any dependence on expensive diesel generators, which become obsolete.

Energy storage capacity is massively ramped up during the decade, with 24 GW of new additions, matching the rapid growth in intermittent renewable energy capacity. Carbon capture technologies are introduced to allow the country to continue using its natural gas resources whilst keeping carbon emissions at a lower level.

BY 2040

Nigeria reaches universal access to electricity. Unserved energy has dropped to zero and diesel generators have been totally phased out of the system.



STAGE 3: 2041 TO 2060

Final steps towards a carbon neutral power system

Key actions

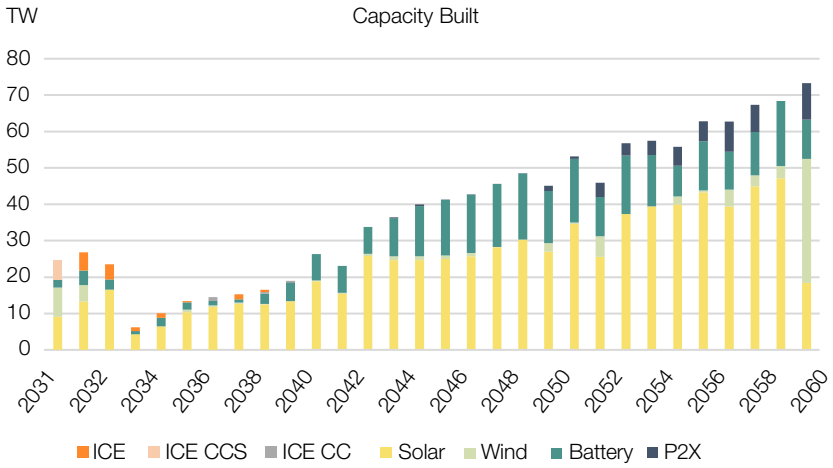
- Strengthen solar power and energy storage investments
- Start investing in electrolysers to produce green hydrogen from renewables
- Convert gas-based thermal power plants to run on green hydrogen

The last major step to achieve the 100% carbon neutral system is to convert existing thermal power plants to run on green hydrogen, thus providing an additional component to reach net zero. Hydrogen provides the last piece of the power system decarbonisation puzzle: the long-term energy storage capacity.

In the 2040s, the cost of electrolyser technology is expected to drop significantly, and it has become a cost-competitive solution. 51 GW of electrolyser capacity is progressively added to the Nigerian power system to produce green hydrogen from renewable energy.

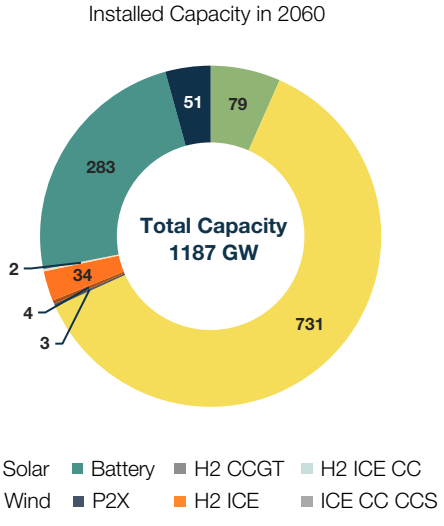
During these two decades, hydrogen will progressively replace natural gas to become the fossil-free fuel powering Nigeria at times when the wind is not blowing, and the sun is not shining.

The country also continues to build new renewable energy and storage capacity. As much as 616 GW of solar power, and 259 GW of energy storage is built during these 20 years. Typically, batteries are used for short-term energy storage while hydrogen is a more economical solution for long-term energy shifting, which means that hydrogen-powered power plants will be ramped up when the output of renewables decreases for an extended period of time.

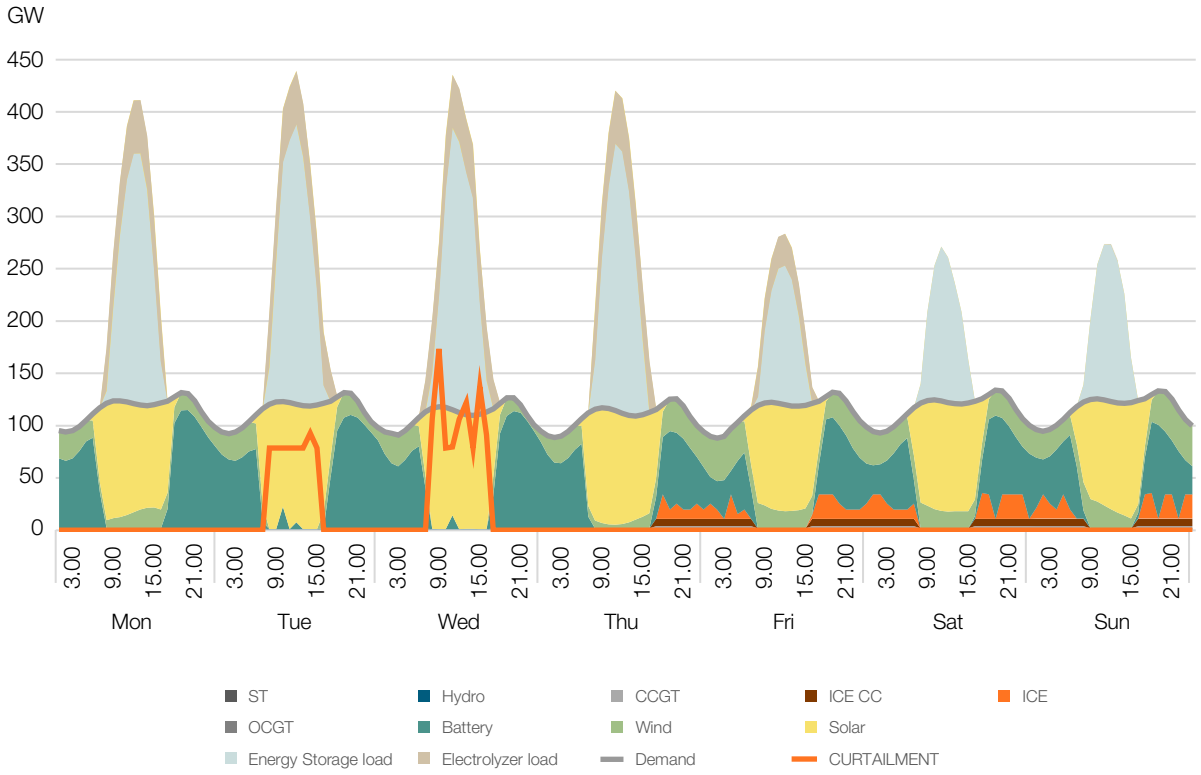


BY 2060

Nigeria's power system provides clean, 100% carbon neutral, reliable and affordable electricity to its population. The decarbonised power system reaps the benefits of low-cost renewable energy: The average cost of electricity has dropped 74% compared to today. Fossil fuels are no longer needed to provide power and all thermal power plants can now operate solely on green hydrogen. Renewable energy represents 100% of the power generation mix, and carbon emissions have dropped to zero. To achieve net-zero in 2060, the total investments required will be in the magnitude of $425 Billion during the four decades.



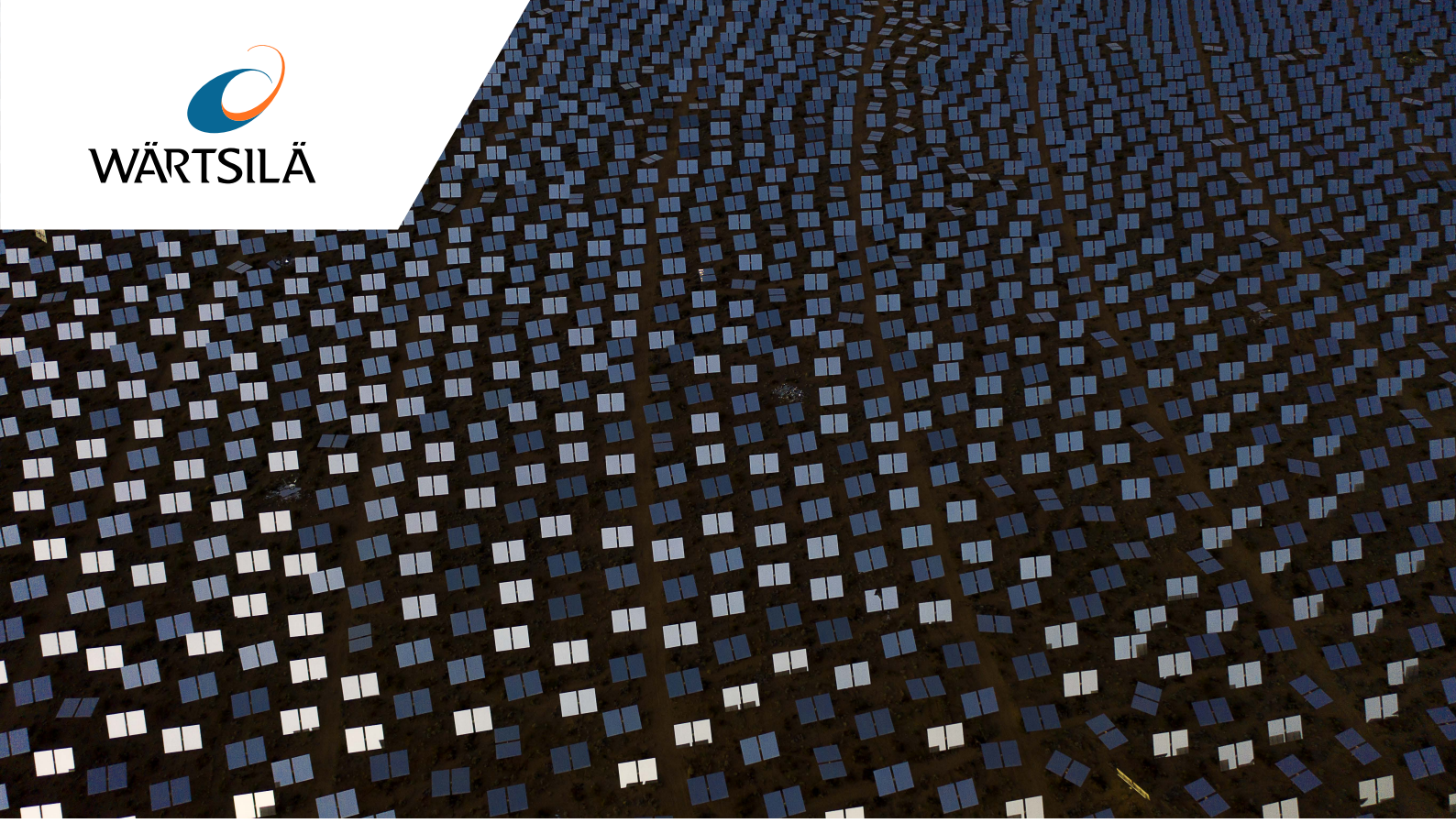
The figure below provides a final snapshot showing how a fully decarbonised Nigerian power system would be operated in week 24 in 2060. By then, renewable energy sources produce all the electricity needed in the country. When the output from the renewable energies decrease, energy storage is discharged, and hydrogen is burned to satisfy the demand.



THE LAST WORD

The power system expansion scenario presented in this study shows the optimal path for Nigeria to achieve its ambitious 2030 and 2060 targets. With its huge gas reserves and high renewable energy potential, Nigeria has all the natural resources necessary to lead the country to a successful energy transition.

If the country can improve its power transmission infrastructure, develop a sound policy framework, and deploy a data-driven power expansion plan based on renewable energy and flexibility; it will take a giant step towards its goal of providing universal access to affordable, reliable and fully decarbonised electricity.



ABOUT WÄRTSILÄ

Wärtsilä leads the transition towards a 100% renewable energy future. We help our customers to decarbonise by developing market-leading technologies. These cover future-fuel enabled balancing power plants, hybrid solutions, and 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 portfolio comprises 76 GW of power plant capacity and more than 110 energy storage systems delivered to 180 countries around the world.

www.wartsila.com/energy