WÄRTSILÄ

PLANNING MOZAMBIQUE'S OPTIMAL POWER SYSTEM EXPANSION

Assessing the role of renewables in reducing total system cost

CONTENT

INTRODUCTION

Mozambique's electricity challenges and opportunities

Mozambique has the largest power generation potential in the entire Southern African region thanks to its vast and largely untapped gas, hydro, wind and solar resources. Despite this huge generation potential only 38.6%[1)] of its population had access to electricity in 2021.

The total installed power capacity in Mozambique stood at around 2,800 MW in the year 2021 whereas the peak demand reported by the state-owned energy utility Electricidade de Moçambique (EDM) was at 1,035 MW. Over 50% of the total electricity demand is originating from the capital area Maputo and the surrounding southern part of the country, while only around 20%[2)] of the population is living in this area. Hydropower represents the lion's share of the installed capacity mix at 79%, followed by natural gas at 16%. Liquid fuels and Solar PV respectively represent 4% and 1% of the existing installed capacity base. The country's biggest power plant, Cahora Bassa hydro plant, has an installed capacity of 2,075 MW. Currently, over 75% of the electricity generated from the hydropower plant is exported to South Africa. The remaining capacity, around 1,300 MW, is utilised to meet local electricity demand in Mozambique.

Going forward, the development of new gas resources by the Mozambican government presents tremendous opportunities to rapidly increase gas-to-power generation in the country. Domestic gas from the Northern coast of Mozambique is expected to be available by 2026.

The pressing challenge for Mozambique's energy authorities is to ensure that the entire population gets affordable and uninterrupted access to electricity over the next decade. The country will also need to support its emerging industry and commerce with additional power capacity.

To meet the projected 1.3 GW of electricity peak demand increase by 2032, Mozambique must build significant new power capacity over the next decade. A further 2 GW would be needed to support the planned development of the Beluluane Industrial Park in the Maputo province by 2037.

Policymakers must now determine the optimal power mix that should be built. A power mix that takes advantage of its vast energy resources in a cost-effective way and provides a solid foundation for the long-term development of its power system.

The use of proven power generation technologies coupled with a well-structured and realistic data-driven plan will enable Mozambique to reach its electrification goal.

1) According to the National Statistics Institute (INE) (citing data from EDM), the overall rate of access to electricity has been rising every year and, by 2021, electricity was reaching 38.6% of the Mozambican population

2) https://www.statista.com/statistics/1267937/total-population-of-mozambique-by-province/

Key questions for Mozambique's energy decision-makers

To identify the optimal power system for Mozambique, a few key questions must be considered.

- Should Mozambique cap new renewable energy capacity to 100 MW/year?
- Or should the country add as much renewables as needed to further lower system costs?
- How much flexibility must be built into the system?
- What would the optimal power mix look like in each situation?

→ Answering these questions is key to informing power system planning and strategy in Mozambique

In this study, Wärtsilä presents and compares two potential power system expansion scenarios for Mozambique. Scenarios have been modelled through the PLEXOS software, a world-leading power system modelling tool. Policy makers, system operators, and utilities around the world rely on PLEXOS to identify the most optimal power mix to be built year-by-year to provide additional electricity supply reliably at the lowest possible costs.

Study objectives

The objective of this study is to provide data-driven insights to help Mozambique's policy makers to identify and develop the optimal power mix needed to service electricity demand over the next decade. The study covers two possible scenarios, low renewable and high renewable scenarios, that would enable the country to meet the growing electricity demand and compares them to identify the best pathway to develop Mozambique's power system from 2022 to 2032.

To do this, our model takes into account the various generation technologies, and the role that each one of them can play in the power sector. It forecasts the new solar PV and wind capacity requirements and also quantifies the flexibility and balancing requirements needed to provide the country with a reliable power system.

Gas-based power generation technology candidates belong to two categories: base load technology and flexible gas technology. By baseload gas, we mean combined cycle gas turbines (CCGT) that are usually built in large plant sizes and have an annual capacity factor of >80%. This type of large generation assets, which use steam boilers, are not well suited to accommodate the intermittency and variability which renewables add to the power system. Steam power plants need to operate constantly on a high load. They cannot stop and restart fast enough to balance the flow of renewables, and they tend to cause curtailment of the relatively low share of renewable energy.

By flexible gas we mean modern gas engines, which are capable of multiple starts and stops per day without any additional operations and maintenance costs. They can synchronise with the grid in 30 seconds, can achieve full load in under 5 minutes and ramp down to minimum load in 1 minute. These fast-responding characteristics make engines an ideal candidate for grid balancing services but also to manage contingency events. However, these properties do not leave out the option for gas engines to operate very effectively in baseload generation mode.

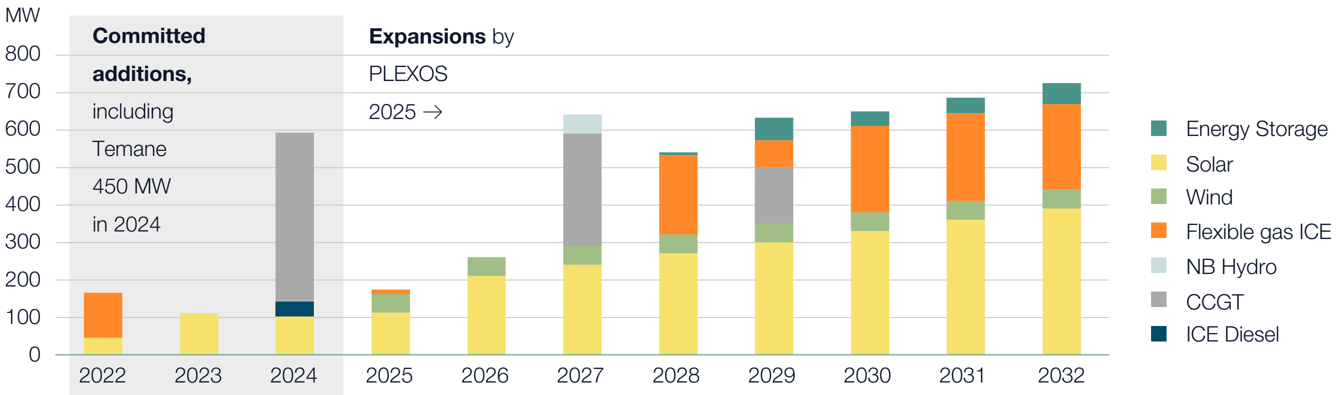
Study highlights

Our analysis reveals that maximising the share of low-cost renewable energy in the power mix will be the most affordable and sustainable way to meet electricity demand over the next decade.

Paired with flexible power such as grid balancing engines that can run on gas now and later be converted to run on sustainable fuels and energy storage, the higher renewable energy penetration will reduce carbon emissions by 5.6 M tonnes in the next decade. This will also generate savings of $84.7 million dollars when compared to a low renewable energy deployment scenario by 2032.

The most competitive power expansion plan, therefore, combines almost 3 GW of new wind and solar capacity, together with 1.1 GW of flexible gas projects, 205 MW of energy storage capacity and 50 MW of new hydropower capacity. It also plans for 900 MW of baseload gas projects to be built from 2022 to 2032, including the 450 MW Temane gas power plant expected for delivery in 2024.

Since Mozambique has high hydro power potential, the country is focusing on developing large hydro projects that aim to be operational at the beginning of 2030's. Hydropower projects play an important role in decarbonizing the power sector in Mozambique. The system flexibility built in this decade will be necessary to support the increase of hydro generation in the system, since water availability varies from year to year.



> **"The advanced power system modelling techniques used in this study show, without the shadow of a doubt, that maximising low cost renewable energy while building flexibility into the power system with grid balancing engines, that can now run on gas and later be converted to run on sustainable fuels, is the soundest, cheapest and cleanest power strategy available to Mozambique right now."**
>
> **Wallace Manyara**
> Business Development Manager, Region South & East Africa, Wärtsilä Energy

STUDY BACKGROUND AND METHODOLOGY

Drawing insights from advanced power system modelling techniques

With its huge renewable energy resources and the development of its immense gas fields, Mozambique has plenty of power generation potential. But which power mix is going to be the most cost-effective? This is an important question to answer before committing to the future power generation mix, as this will have a significant bearing on how the system is designed to support the economic growth of the country while achieving the vision of the government.

Working in cooperation with Electricidade de Moçambique to assist the country in developing its long-term electricity plan, Wärtsilä has examined how an optimal power system could evolve given the changes in technology, availability of domestic fuel and growing electricity demand across different scenarios from 2022 to 2032.

To conduct this study, Wärtsilä used PLEXOS, a leading power market simulation software, for the power system modelling presented in the report. The modelling defined a cost-optimal energy system structure and operation mode for a given set of constraints in each region: power demand; available generation and storage and balancing technologies; financial and technical assumptions; and limits on the installed capacity for all applied technologies.

The model is based on linear optimisation and performed on an hourly resolution for the planning horizon. The system-level cost is the estimated sum of the annualised capital expenditures including the cost of capital, operational expenditures (including ramping costs) and fuel costs for all available technologies.

The scenarios modelled by Wärtsilä will enable policymakers in Mozambique to make informed long-term decisions on building a cleaner and more modern power system for the country.

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.

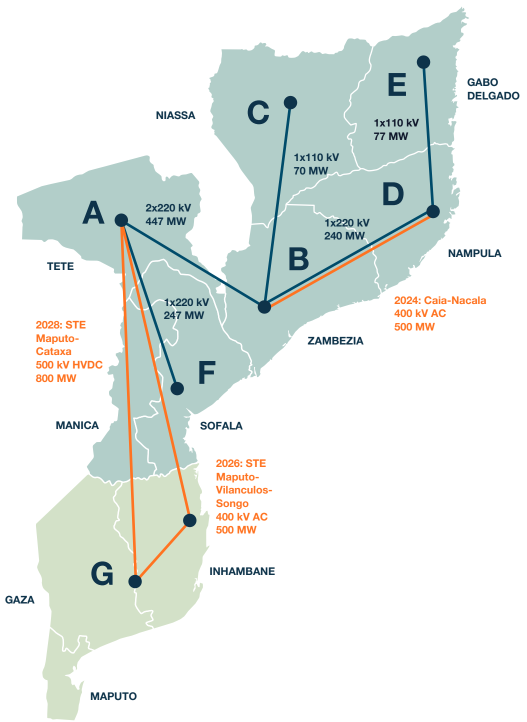
- Understand operations and fundamendals of power systems
- Quantify system level benefits of different generation and storage technologies
- Understand and promote high quality modelling

MODELLING CONSTRAINTS AND ASSUMPTIONS

In this study, two separate power system expansion scenarios have been modelled, with the objective to assess the financial and environmental impact of one key system parameter: *The amount of renewable energy capacity that should be built into the power system each year, leading to 2032.*

Low Renewables Scenario	High Renewables Scenario
The optimal power generation system that can be built with solar and wind capacity additions capped at 100 MW/year to reach a maximum of 1 GW by 2032.	The optimal power system expansion plan if wind and solar capacity are allowed to triple to reach almost 3 GW by 2032.

THE NECESSARY TRANSFORMATION OF MOZAMBIQUE'S POWER TRANSMISSION NETWORK



Currently, the power system of Mozambique is separated into two transmission networks isolated from one another: the Central-Northern and Southern systems. Over 50% of the annual power demand is seen in the Southern system. For the purpose of this study, the electricity system in Mozambique has been divided into 7 different zones and the main transmission lines between these zones are modelled to allow for a flow of power among zones. The new domestic transmission line projects have been included into the model according to their planned delivery timelines.

- Central-Northern system
- Southern system

Regardless of the power system expansion strategy selected by Mozambique, there is a critical need to strengthen Mozambique's power transmission capabilities if the country is to achieve its electricity generation objectives.

SCENARIOS ANALYSIS AND COMPARISON

SCENARIO 1

The Low Renewables Scenario

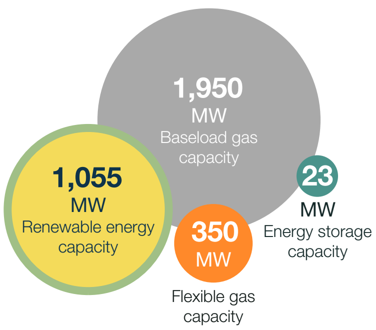
This scenario identifies the optimal expansion of each power generation technology in a power system where new solar and wind capacity has been capped to a maximum of 100 MW/year over the planning horizon, to reach 1 GW of renewable energy capacity by 2032.

Our model therefore limits annual renewable energy capacity addition to 50 MW for solar and 50 MW for wind leading up to 2032. Except for the annual capacity limits (100 MW) on renewables, the modelling software is allowed to select any other power technology based on system requirements.

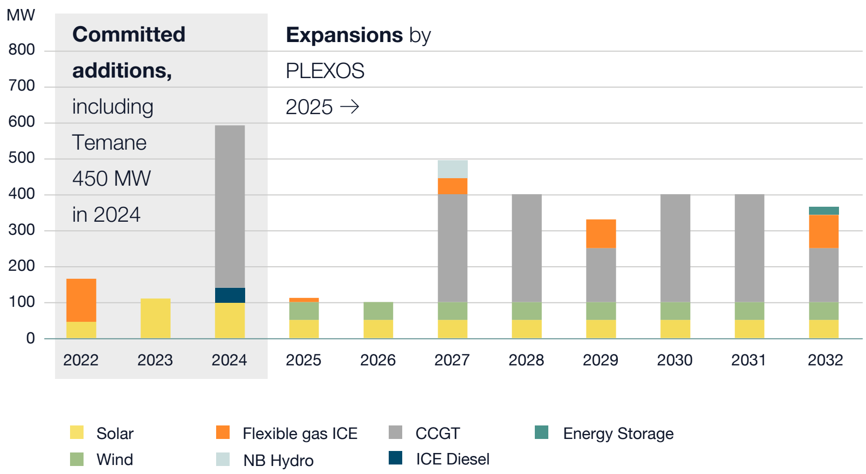
In addition to the planned generation capacity that is likely to be commissioned by 2024, the modelling results indicate that Mozambique will need 1.5 GW of new base load gas projects and 230 MW of new flexible gas projects from 2025 to 2032. The results demonstrate that the system also requires a modest 23 MW of new storage capacity to store and shift the relatively small quantity of variable renewable energy generated.

The model quantifies the total cumulative costs of the Low Renewables scenario at $8,909.7 Million.

Optimal low renewables Power System expansion 2022 to 2032



Total system cost:
$8,909.7 Million



SCENARIO 2

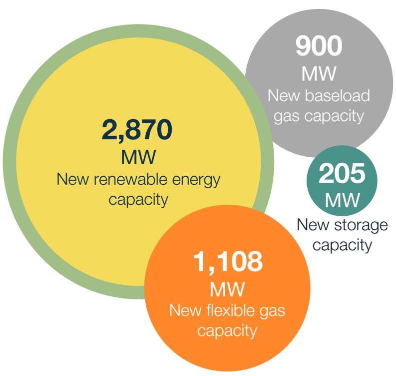
The High Renewables Scenario

In this scenario, the annual capacity limit on renewables was increased to 200 MW per year with a gradual increase of 15% as compared to 100 MW of annual capacity limit on renewables in the low renewables scenario. In total, renewable energy in Mozambique reaches 2,870 MW by 2032. To manage the intermittency of renewables, the model requires much more flexible gas and energy storage capacity to be added to the system. Flexible gas assets and storage capacity are essential to support the increasing share of variable renewable generation added to the system.

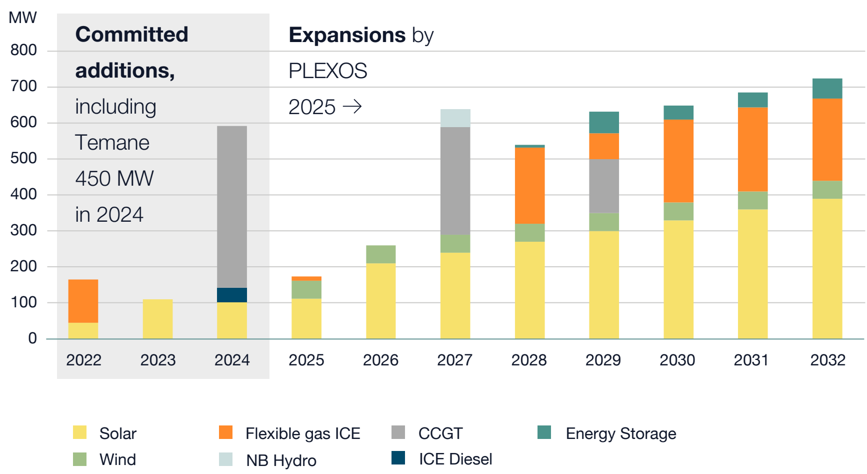
In addition to the planned generation capacity that is likely to be commissioned by 2024, the modelling results indicate the need for 450 MW of new baseload gas projects and 988 MW of new flexible gas projects from 2025 to 2032. The model also requires 205 MW of new storage capacity to store and shift the increasing quantity of variable renewable energy generated.

The total cumulative cost of the system, including variable and fixed operational expenses and capital expenses, reaches $8,825.0 Million for the High Renewables Scenario.

Optimal high renewables Power System expansion 2022 to 2032



Total system cost:
$8,825.0 Million



Low Renewables scenario VS High Renewables scenario

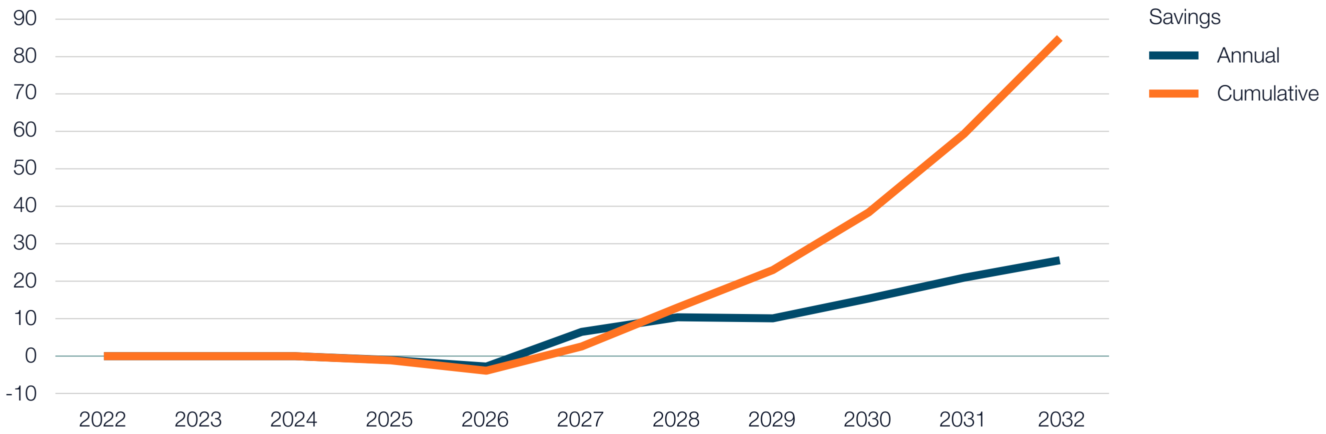
The optimised scenarios show that investments in solar and wind power, together with flexible gas engines and energy storage, offer the most cost-effective path to expand Mozambique's power system, while mitigating its carbon footprint.

The total cumulative cost of the system, including variable and fixed operational expenses and capital expenses, reaches $8,909.7 M for the Low Renewables Scenario and $8,825.0 M for the High Renewables Scenario. Increasing the share of renewables in the system is $84.7 M cheaper than capping it at 100 MW/year.

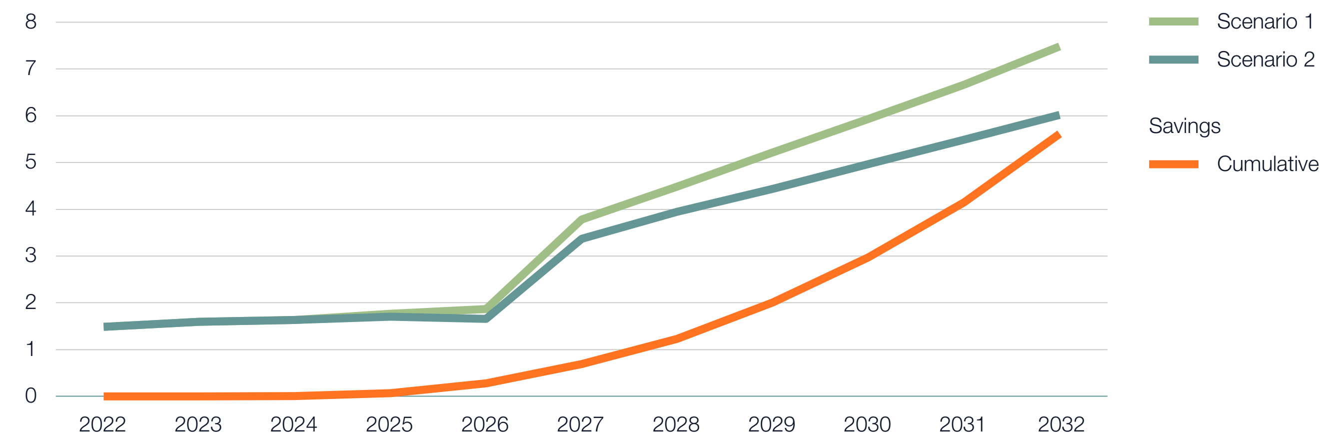
The **High Renewables Scenario** will also enable Mozambique to achieve 5.6 Mt of CO2 emissions savings compared to the Low Renewables Scenario.

The graphs below show the total cumulative savings in terms of cost, and emitted CO2 emissions of each scenario over the modelling period 2022-2032.

Annual OPEX+FOM+CAPEX Comparison, MUSD



Annual CO2 emission comparison, Mtonne

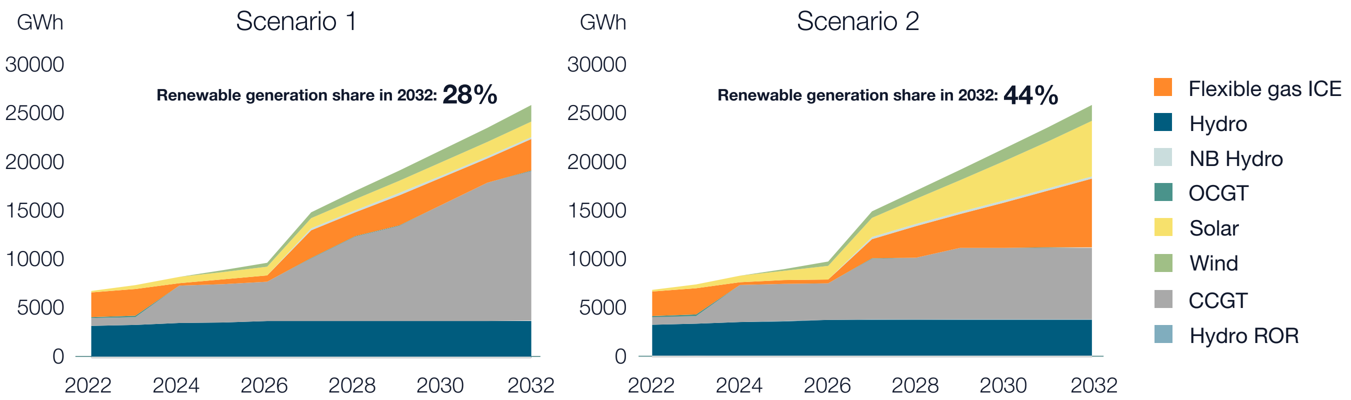


In this study, the domestic electricity demand of Mozambique is estimated to grow from 7 TWh in 2022 to 26 TWh in 2032.

In the **Low Renewables scenario**, the total solar, wind and hydro generation in the system in 2032 is 7.3 TWh, resulting in a renewable share of 28% of the total power generated.

In the high renewables scenario, renewable energy generation reaches 11.4 TWh, representing a share of 44%. Let us note that in this study, it is assumed that 25% or around 3.5 TWh of annual generation on Cahora Bassa hydro power plant is serving the Mozambique power system, while the rest is exported to South Africa.

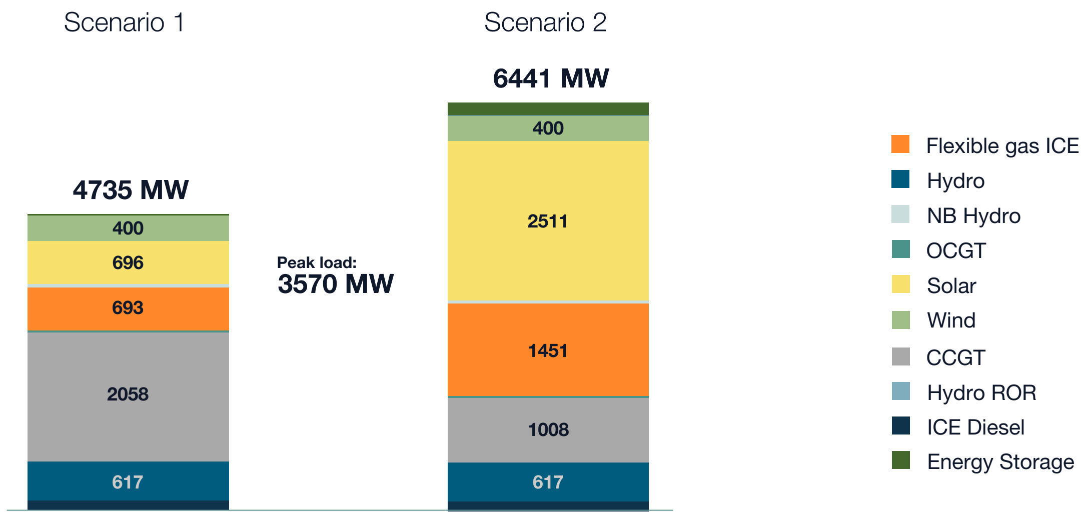
Annual power generation by source, 2022-2032



The peak load of the system is expected to reach 3,570 MW which includes domestic power demand as well as that from the Beluluane industrial park. The total installed capacity of the power system in 2032 in the Low Renewables scenario results in 4,735 MW of which 1,096 MW or 23% would be solar PV and wind capacity.

In the High Renewables Scenario, the total installed capacity of solar and wind reaches 2,911 MW in 2032, representing 45% of the total installed capacity of the system.

Total installed capacity of the system in 2032



This power system expansion modelling exercise shows that opting for high renewables expansion supported by flexible gas engines brings superior savings both in CO_2 emissions and total system costs.

BENEFITS OF A HIGH RENEWABLES + FLEXIBLE GAS ENGINES STRATEGY

Making the most of low-cost renewable energy

The cost of solar PV generation has plummeted over the past decade, making it the lowest cost source of energy, especially in Southern Africa. The cost of wind farms has declined significantly too. However, for the power system to benefit fully from these low-cost sources, it requires pairing with flexible sources of generation capable of adjusting their output rapidly in response to the intermittence of renewables, to maintain a balanced system and prevent power outages.

Inflexible coal and gas turbine power plants are designed to operate most efficiently at full capacity, producing a stable baseload, and are therefore ill-suited to adapt their output in response to supply and demand fluctuations. Relying on these technologies to balance the grid is inefficient, leading to higher operations and maintenance costs, lower margins, as well as higher emissions.

Build flexibility into the system with grid balancing engine technology

Advanced energy system modelling demonstrates that engine power plants are best suited to support renewables thanks to their flexibility. Comprised of multiple generating units, which can be started up instantaneously, they offer a large range in power supply availability without sacrificing efficiency. When considering a full fleet of assets, these flexible power plants can not only unlock the full potential of renewable energy assets, but they also offer the lowest levelised cost of energy (LCoE) as well as reduction in CO_2 emissions.

This is because engines (internal combustion engines) can synchronise with the grid in 30 seconds, can achieve full load in under 5 minutes, can ramp down to min load in 1 minute, and can provide multiple starts-stops a day without any additional operations and maintenance costs. These fast-responding characteristics make engines the ideal candidate for grid balancing services but also to manage contingency events. These events include unplanned generation or transmission outages, delayed commissioning of planned projects, droughts, unforeseen increases in electricity demand, or forecast errors in wind and solar generation. During such a contingency, the capacity of the engine may be dispatched to maintain the balance of supply and demand in actual operations.

Natural gas is not the only fuel that can be used as a feedstock for powering engines. Research and tests show that grid balancing engines can be operated on fuel blends. Currently, engines can use up to 25% of green hydrogen for power generation. Research also indicates that the same asset could be modernised to operate on 100% green hydrogen or other sustainable fuels in the future.

FASTSTART	BASELOAD	LOAD FOLLOWING	LOW-LOAD OPERATION	FAST STOP
VALUE • Grid stability support • Ancillary Service market	**VALUE** • Competitive life cycle generation cost • Any output, same generation cost	**VALUE** • Wind and solar balancing • Ancillary Service market	**VALUE** • "low load" = No load • Not running when no revenue	**VALUE** • Not running when no revenue • PV enabler
FEATURES • Power to grid in 30s • 2-5 min to full power • Start up efficiency	**FEATURES** • Highest simple cycle efficiency • Multi unit → high firm capacity • Flexicycle™	**FEATURES** • Part load efficiency unaffected • No EOH cost for cycling	**FEATURES** • 1min shutdown • No minimum down time • Zero fuel cost • Zero emissions	**FEATURES** • 1min shutdown • No minimum up time • No EOH calculation

Technology modularity is key

Technology modularity also plays a key role. Mozambique requires between 100 MW and 500 MW of new generation annually to be built across the country to be able to meet the increasing demand. On a regional level, this represents 60 to 80 MW of new power generation. This is much lower than the capacity of typical CCGTs plants which average 300-400 MW that must be built in one go, leading to unnecessary expenditure.

Engine power plants, on the other hand, are modular, which means they can be built exactly as and when the country needs them, and further extended when required. With this strategy, Mozambique will also avoid locking the systems in for decades to come with large baseload plants, and benefit from a more distributed power system. Furthermore, by building required generation capacities closer to the load centre Mozambique also stands to gain by way of avoiding costs in expanding the country's underdeveloped transmission and distribution network.

Benefits of distributed energy systems

The installation of low-cost solar PV and wind farms combined with the support of flexible power generation utilising its gas resources also respects the realities of the country on the ground.

Today, 60% of the population has no access to electricity, and about half of the demand is from Maputo. There is a clear need to widen access without concentrating it in defined areas. Renewable off-grid projects and energy storage systems would support electrification in rural and more remote areas of Mozambique and strengthen the country's transmission and distribution.

Saving Water

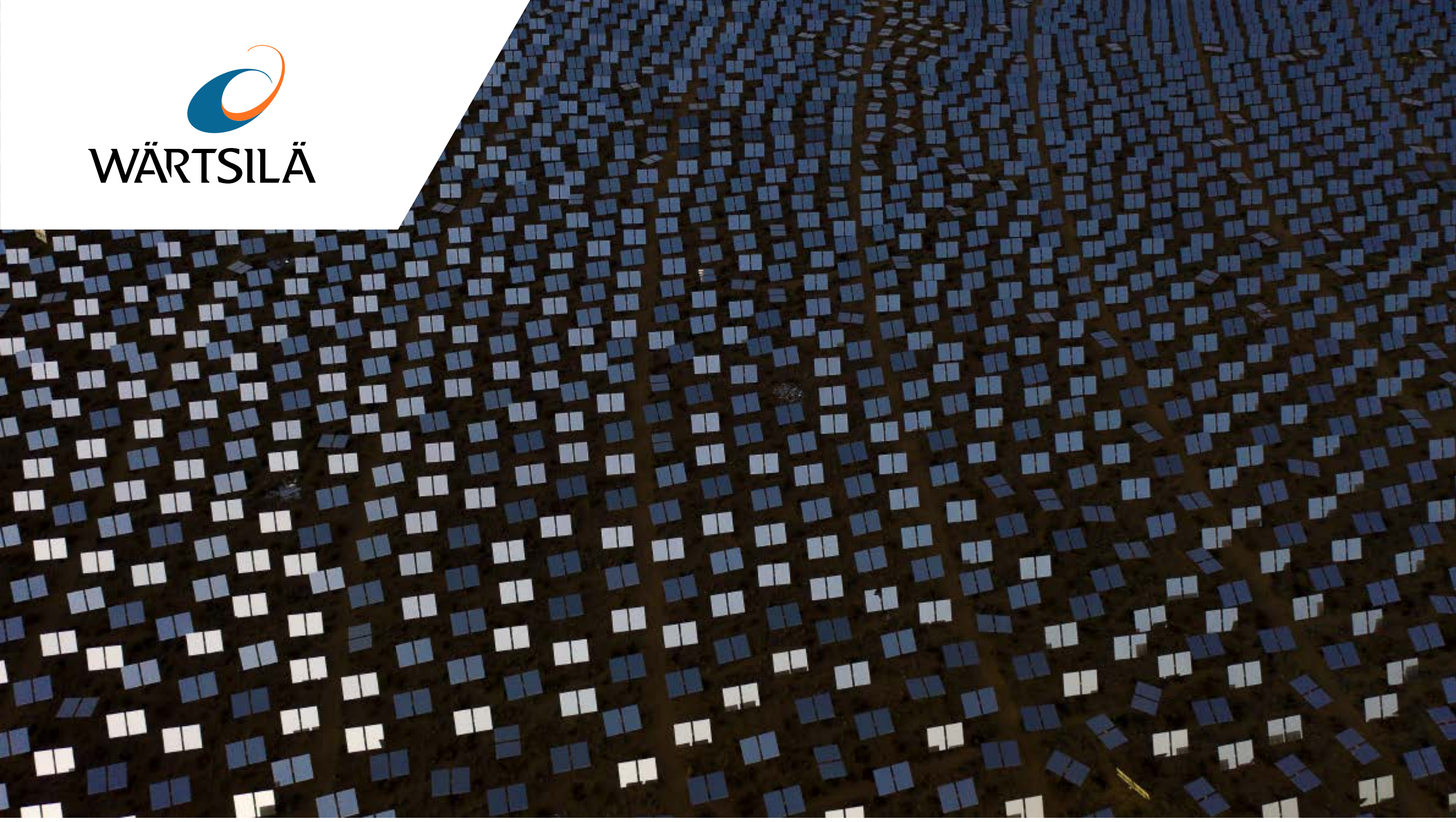
Last but not least, engine power plants consume far less water than similarly sized generation technologies, namely, gas turbines, coal, or nuclear plants. In a country like Mozambique, which has suffered from both cyclones and droughts, and in the context of global warming, water consumption is a parameter that cannot be ignored when assessing new power generation options.

CONCLUSIONS

Mozambique is at an important juncture: The decisions taken today will have a significant impact on the future of energy in the country. Mozambique has massive gas, hydro, wind and solar energy resources.

By maximising the use of low-cost renewable energy and utilising its local gas resources to produce flexible power generation, Mozambique will take a giant step towards its goal of providing access to affordable, reliable and cleaner electricity to its population.

However, this will require considerable policy support and an updated Integrated Resource Plan (IRP) to provide clear investment opportunities to investors and technology providers. Strengthening the transmission grid will play an important role in improving quality of power to industrial and residential consumers and decarbonisation of the grid. With these steps the country can lay the foundations for a renewable and at the same time affordable energy future.



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.

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