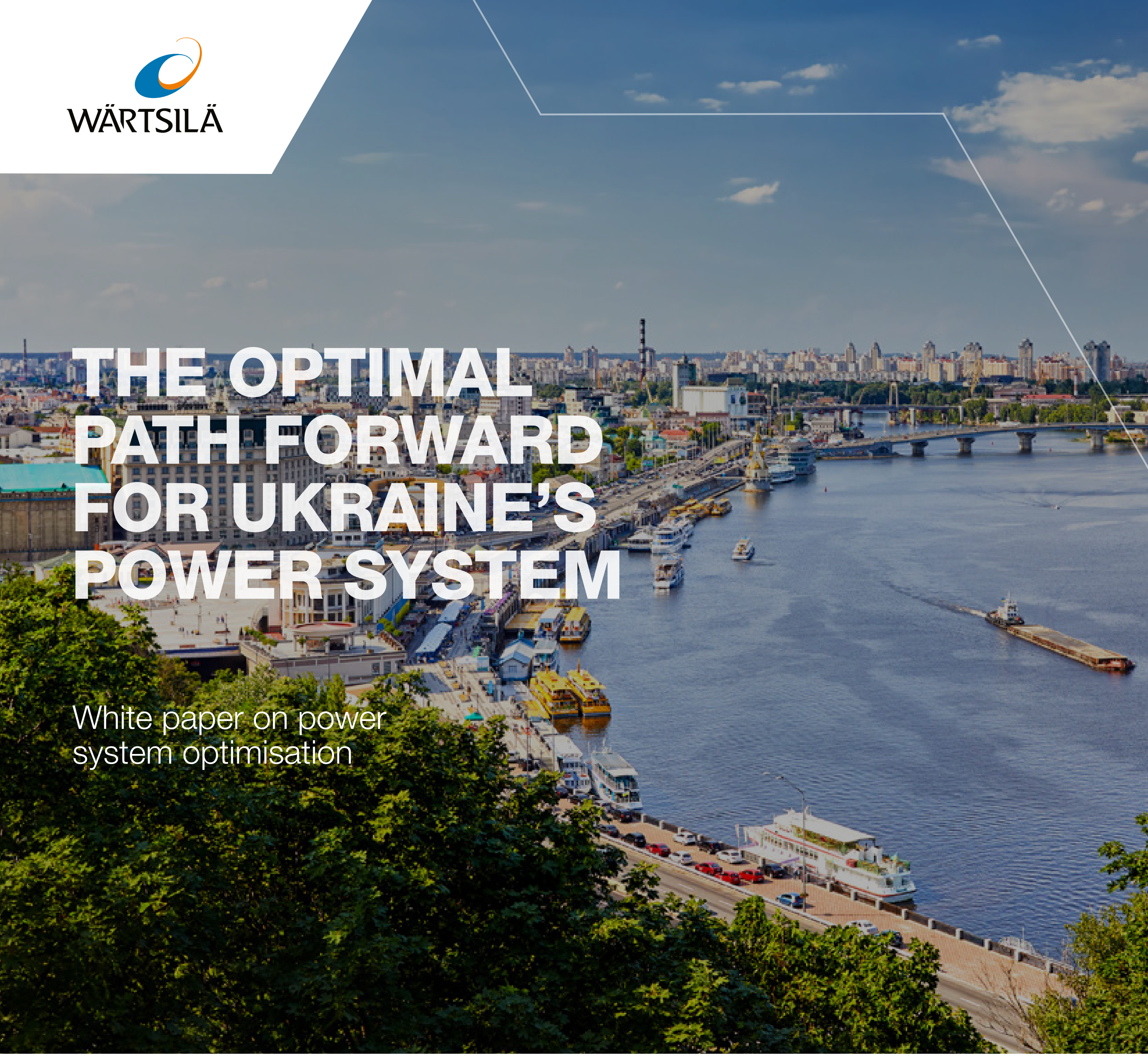

THE OPTIMAL PATH FORWARD FOR UKRAINE'S POWER SYSTEM

White paper on power system optimisation

The global energy landscape is in transition, largely due to the rapidly decreasing cost of renewables. Major players are moving towards flexible and sustainable energy systems with a rapidly increasing share of renewable energy, declining inflexible thermal generation and a wider application of flexible generation and energy-storage technologies.

The recent rapid growth of wind and solar-generating capacity in Ukraine, supported by high feed-in tariffs (FITs), has put financial and technical pressure on the power system and sparked a debate about the country's ability to sustain this trend. Wärtsilä has applied its power system modelling capabilities to offer an analysis of the optimal way forward for the country over the next 30 years.

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The power system in Ukraine is one of the most inflexible in the world

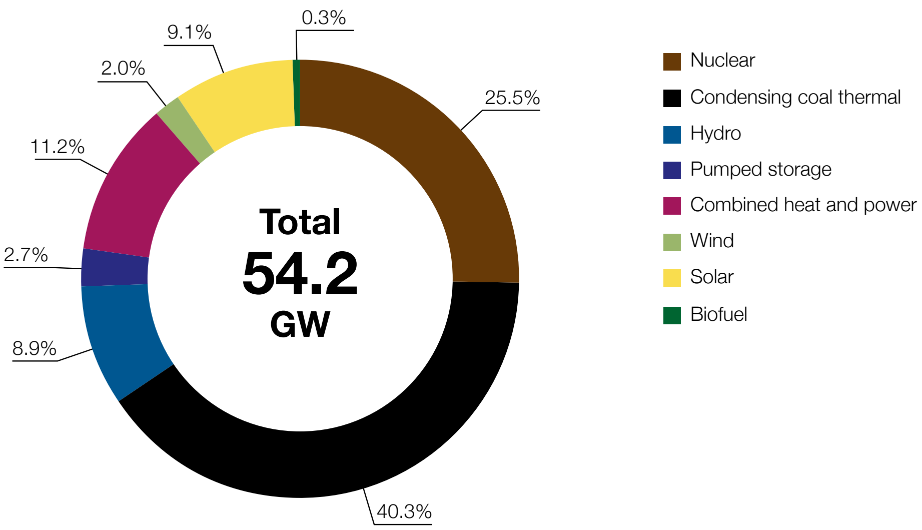
2. MARKET BACKGROUND

The power system in Ukraine is one of the most inflexible in the world. It consists of 15 nuclear power plant units (NPP) that generate up to 55% of total energy, 26 coal and gas-fired district heating combined heat and power (CHP) plants and more than 70 coal-fired thermal blocks, which provide most of the load-balancing support. Most of the thermal and nuclear plants are old, dating back to the 1960s and 1970s. The existing hydro power plant (HPP) and pumped storage (PS) capacities largely depend on seasonal and weather factors, therefore their share of the total power generation varies greatly.

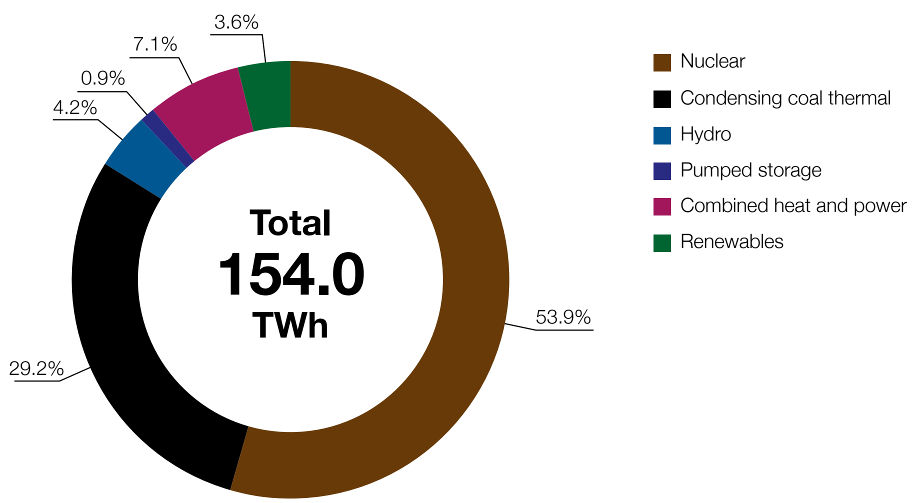
Given the public interest in this case, it was particularly important to provide a realistic analysis of the prospects for nuclear power and coal generation. We reviewed two scenarios:

- A cost-optimised system for 2050 in which optimisation software was allowed to select any configuration of power generation assets in order to achieve the lowest cost of electricity
- A 100% renewable energy source (RES) system by 2050

Installed capacity 31.08.2020



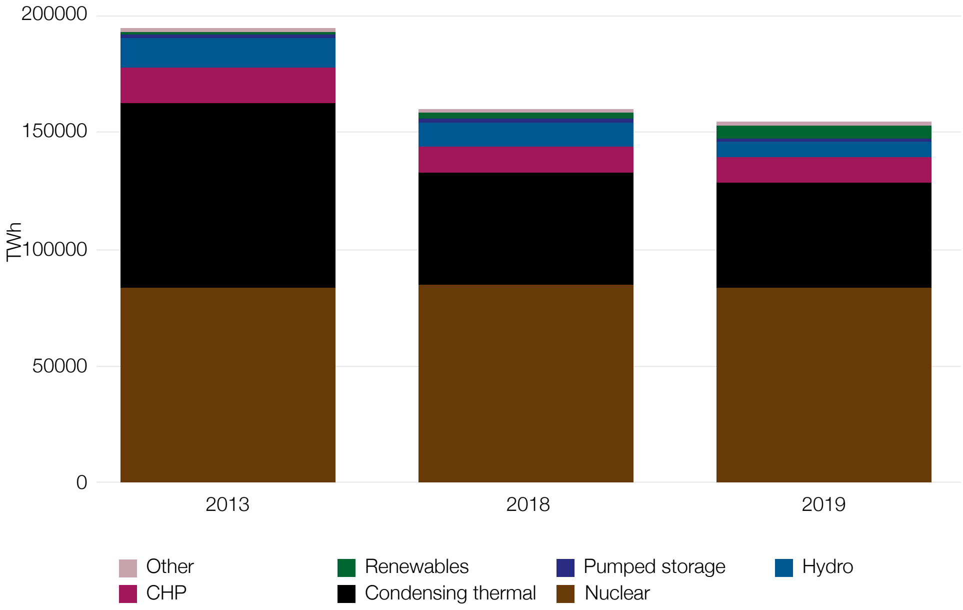
Generation 2019, %



Source: Ukrenergo

The total electricity consumption trend demonstrates a steady decline over recent decades. In the 54 GW power system (installed capacity), demand fluctuates between 24 GW during winter peaks and 12 GW during summer nights, creating a large amount of idle capacity. Thanks to the low cost of nuclear energy, NPP generation has remained about the same, while many old coal-fired blocks have gone offline.

Power generation 2018–2019, TWh

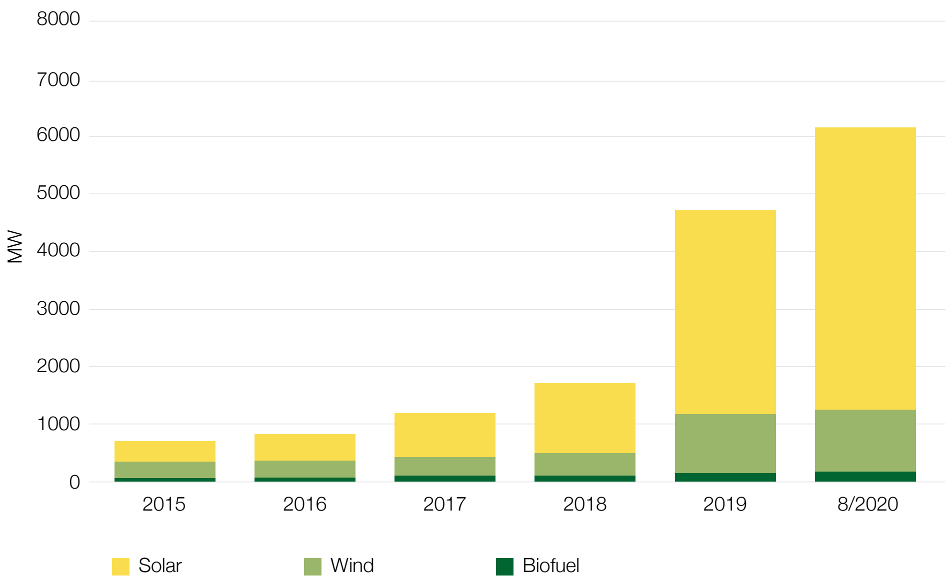


Source: Ukrenergo

District heating CHP plants in most cities operate only during the heating season, and as a rule they are run against the heat demand, effectively increasing the power system's inflexibility. Weather conditions in recent years have been unfavourable for hydro generation, which has made this flexible resource less reliable. The development potential of HPPs and PS plants appears to be limited in the light of both their environmental impact and the project cost and duration factors.

Renewables and the power system

In Ukraine, the trend towards fast construction of new wind and solar generation has been supported by a generous FIT introduced in 2017.



Renewables capacity growth, MW

This development has not been accompanied by adequate legislation to limit the financial impact of the high FIT on the total system cost and on consumer prices as well as the impact of renewable generation intermittency on both the grid and the electricity market.

Wind and solar installed capacity is expected to reach 7.5 GW in 2020, which will result in the following challenges:

- FIT payments will be up to 20% of the total system cost, disproportionally larger than the share of energy generated by renewables.
- RES curtailments will reach up to 30% due to the lack of flexibility in the system. The value of the take-or-pay curtailed energy will be somewhere between EUR 500 and 600 million.
- Additional coal will need to be burned at thermal plants to provide spinning reserve capacity in order to balance intermittency. The yearly spinning reserve demand is up to 18,800 GWh.
- Some nuclear blocks will be taken offline or partly loaded (if possible) to make space for additional coal-fired generation that provides spinning reserve.

The impact of these challenges has already been visible on the system level through the imbalance of feed-in tariff (FIT) payments and the growing cost of the energy mix. Until recently, according to legislation, renewable plant operators also did not bear any responsibility for balancing yet still maintained the right to receive full payment even for curtailed energy. This was seen as unfair by the public, who felt that they were suffering from rising electricity prices and increasing emissions from coal plants. The result is that public support has been shifting away from renewable energy towards nuclear energy.

On the business side, renewable energy operators have suffered from interruptions to FIT payments. More recently, operators have also been forced to renegotiate their offtake agreements with the government, who have insisted on lowering FIT values. The new renewable capacity introduction under the FIT scheme has been terminated and is to be replaced by auctions. However, this forced, retroactive change has damaged the investment climate in the country, and as a result it is difficult to expect new renewable projects in the near future.

Energy transition

In early 2020 the government published a draft vision of the country's transition towards a decarbonised economy, announcing an intention to achieve a 75% carbon-free power system by 2050. There was a plan to engage various stakeholders in the detailed planning of the energy transition and finalise the vision document by autumn 2020.

This move coincided with the mounting challenges in the power sector described above. Over time, the energy transition topic faded away from the government agenda and the media, giving way to the news about stabilisation efforts in the power sector.

III. MODELLING THE OPTIMAL PATH TO SUSTAINABLE POWER SYSTEMS

Wärtsilä started its modelling of the energy transition in Ukraine in the beginning of 2020, independently of government actions. The study uses the high-precision modelling tool PLEXOS to analyse power system development options over a 30-year horizon. Two scenarios were considered:

- A cost-optimised power system with the lowest total system cost and no RES targets
- A 100% decarbonised system where system-level CO_2 emissions fall to zero by 2050

In both scenarios PLEXOS built an optimal power generation mix each year and optimised dispatch every two hours during the 30-year planning horizon. In the 100% renewable energy scenario, PLEXOS had an additional target to achieve a fully decarbonised system by 2050.

In the model, existing nuclear and coal plants are retired according to plan or based on expected plant lifetime. Transmission losses and electricity exports were excluded. PLEXOS was free to select the best capacity additions from among technology candidates. Scenarios met the demand with adequate reserves throughout the modelling horizon.

The study used power system data (such as actual load and generation profiles, installed capacity, technical and economic data on a unit level) obtained from the transmission system operator (TSO) and market players. The study adopted internationally recognised planning assumptions, such as capital expenditure (CAPEX) learning curves from Bloomberg, in addition to in-house knowledge.

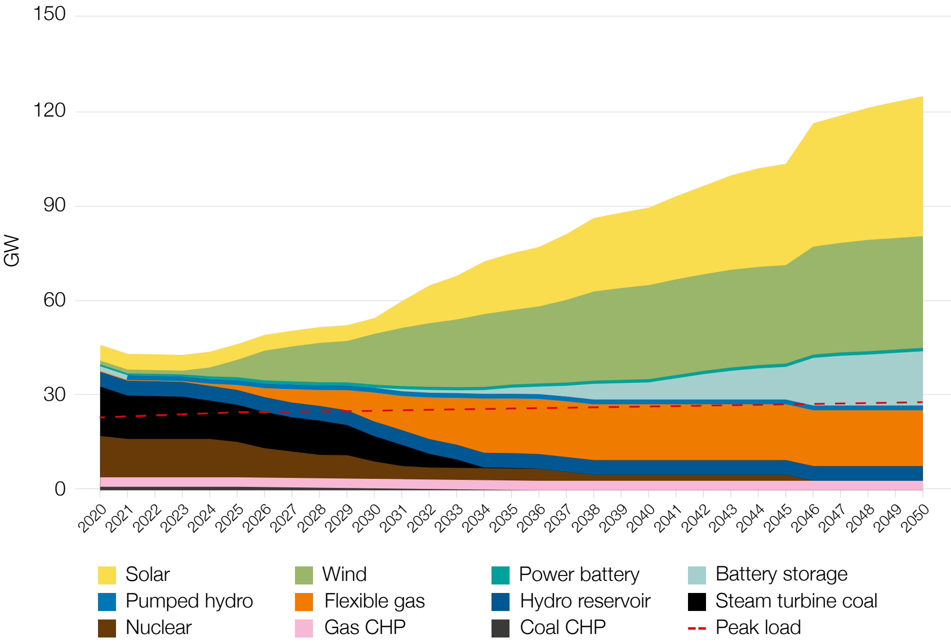
ABOUT PLEXOS ENERGY SIMULATION SOFTWARE

PLEXOS by Energy Exemplar is a proven energy simulation software used by system operators, regulators and planners as well as utilities, traders, consultants and manufacturers. Wärtsilä uses PLEXOS globally for power system modelling, in both long-term capacity development optimisation and short-term dispatch optimisation. PLEXOS is designed to find the cost-optimal solution for each scenario based on the applied constraints.

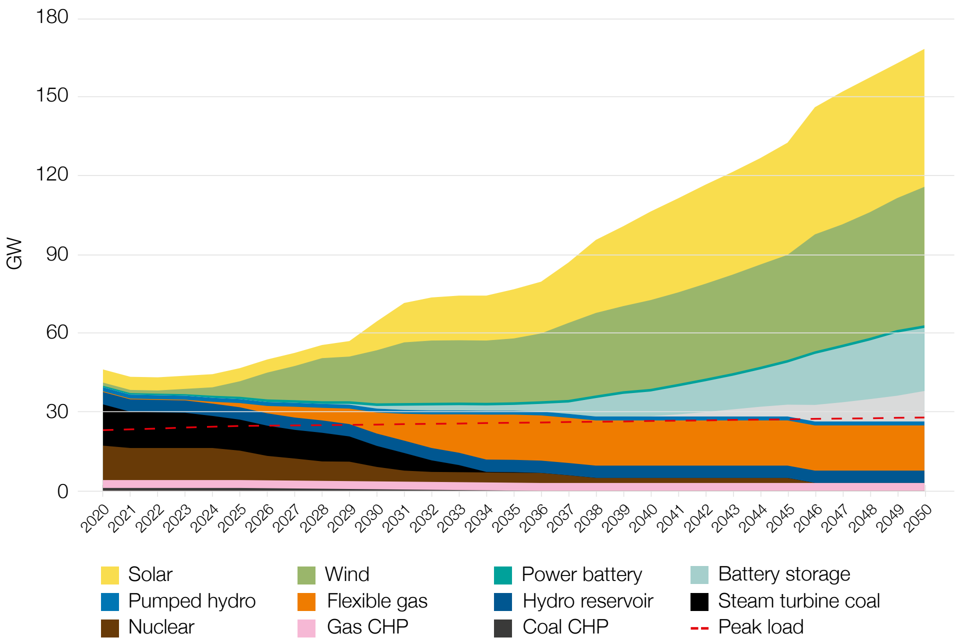
IV. POWER SYSTEM MODELLING RESULTS

The modelling results showed the following power system capacity development until 2050 for the two scenarios:

Scenario 1: Cost-optimised system, installed capacity, GW



The modelled power system provides the lowest cost of all potential options over the time period until 2050. The PLEXOS optimiser built up an increasing amount of wind and solar capacity as time progressed. Major solar buildout starts after 2025 due to the expected falling solar and storage prices. A strong overbuild of renewables and flexible gas starts around 2030. The total system size will reach 126 GW in 2050.



Scenario 2: 100% decarbonised system, installed capacity, GW

To reach a fully decarbonised power system compared to the cost-optimised scenario, 26 GW more wind and solar power is needed and Power-to-Gas (P2G) conversion is also necessary.

The P2G process means that excess wind and solar electricity can be used to produce renewable synthetic gas through hydrogen electrolysis and methane synthesis. The gas is then liquefied and stored, and later regasified for use in flexible thermal power plants.

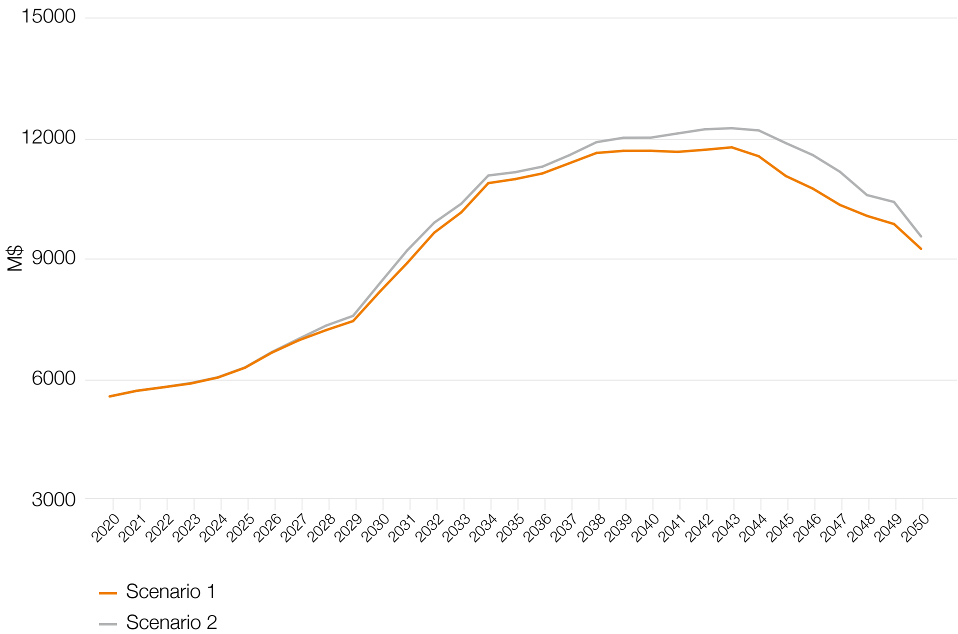
Comparing the two scenarios' final installed capacity mix in 2050

Installed capacity in 2050	Scenario 1: Cost optimised (GW)	Scenario 2: 100% renewables (GW)
Solar	44	52
Wind	35	53
Flexible gas engine	18	15
Hydro reservoir	5	5
Gas CHP	3	3
Generation total	**105**	**129**
Pumped storage	3	3
P2G	0	12
Battery storage	17	24
Power battery	1	1
Shifting total	**21**	**40**
System total	**126**	**169**

The total system costs in both scenarios are similar. When pushing the system towards 100% decarbonisation by 2050, total cost increases by 3%.

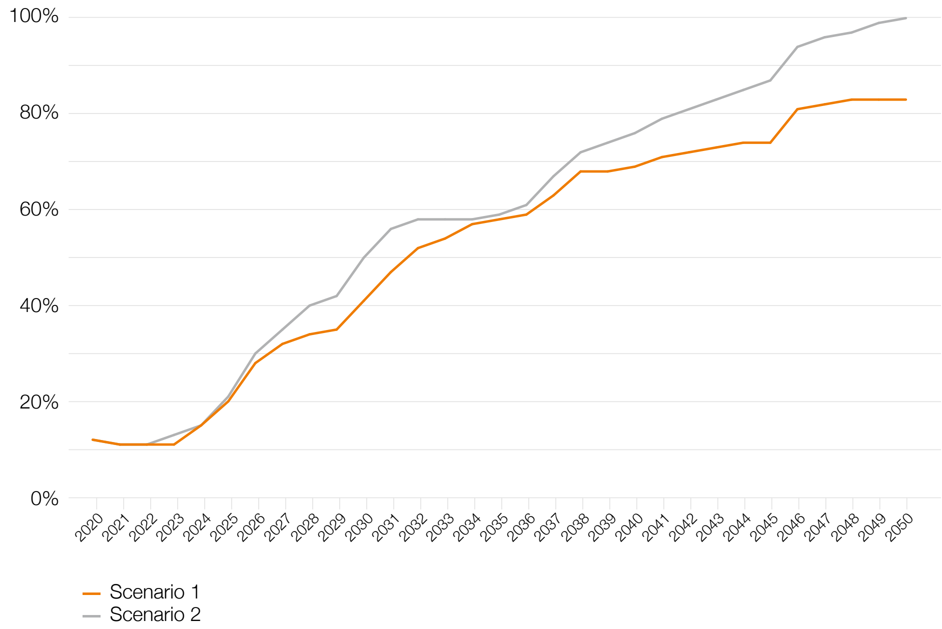
Total system cost

The cost-optimised scenario provides 83% of energy from RES in 2050 and is both close to carbon neutral and the most efficient option.



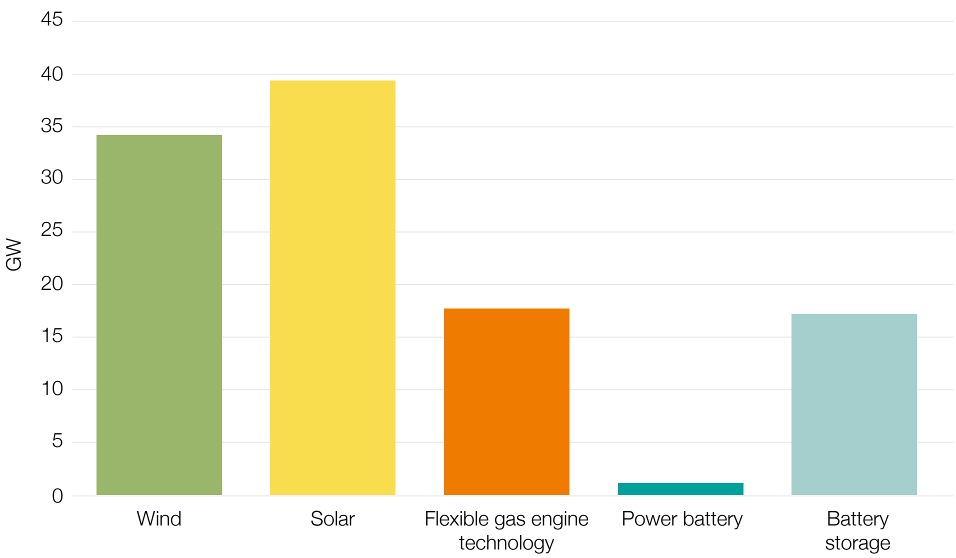
Share of renewable generation

PLEXOS did not select any new traditional generating capacity.

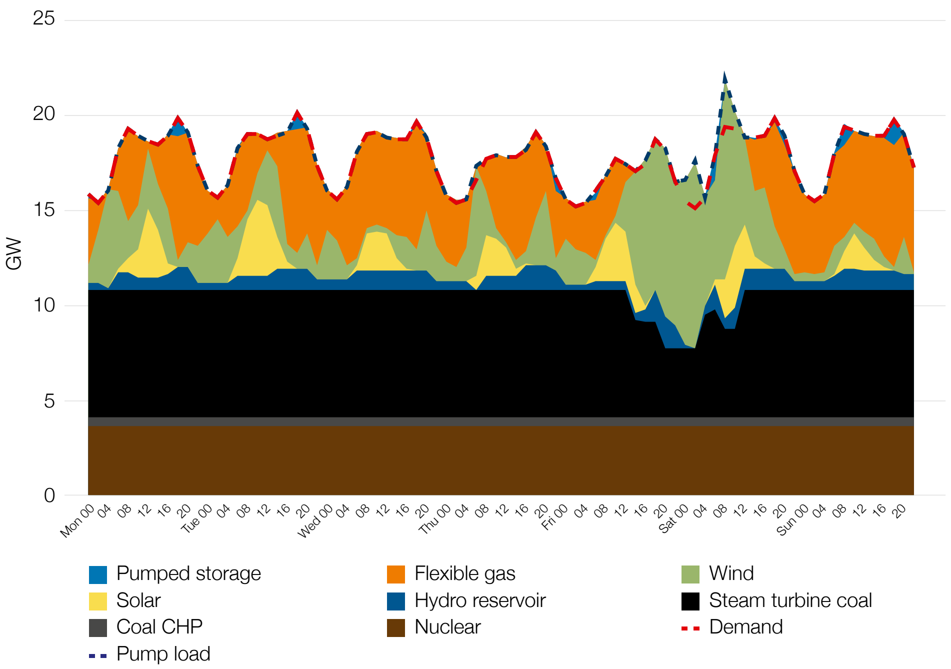


To allow large solar and wind buildout in the cost-optimised scenario, 17.7 GW of flexible gas engines together with 18.3 GW of battery technology is needed. PLEXOS did not select any new traditional generating capacity.

PLEXOS simulated power system dispatch to meet demand every two hours in the 30 year period. It used the available generating capacity and the new capacity additions selected from candidate technologies.



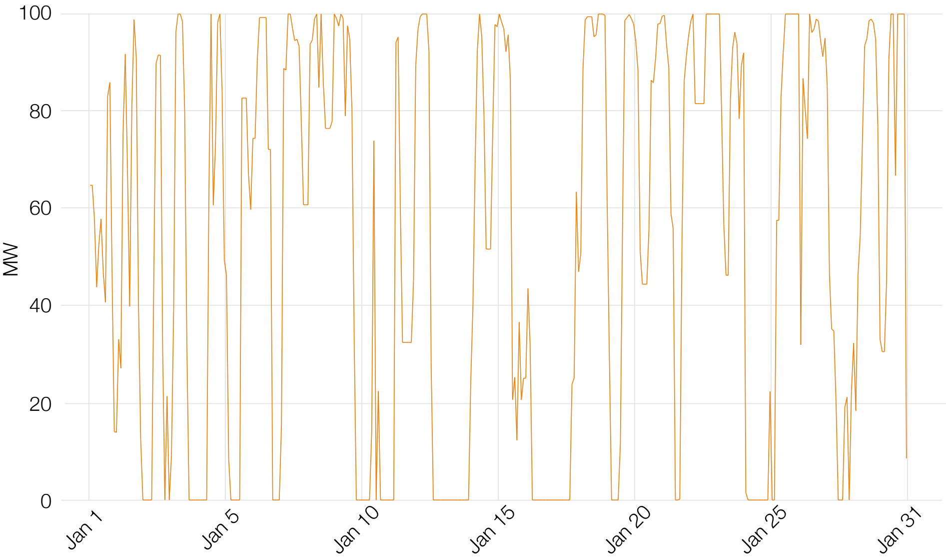
Total capacity additions in the cost-optimised scenario over 30 years



System dispatch in 2030, week 12

In both scenarios, the amount of RES will require an adequate balancing capacity by 2030, and flexible gas engine generation will provide this. Gas engine generation allows for frequent start-ups and shut-downs as well as part-load operations.

One month of gas engine power plant dispatch in Jan 2030



At the final stage of the energy transition, when P2G technology becomes feasible, flexible gas engine generation will switch to synthetic fuels produced with excess renewable energy.

V. RECOMMENDATIONS AND BENEFITS

The modelling of Ukraine's power system demonstrated that over the 30-year planning horizon, power system optimisation means gradually replacing traditional (fossil fuel and nuclear) generation with renewable energy sources (RES). This change eventually drives the total system cost down while also reducing the carbon footprint of the system.

To ensure reliability of the energy supply, flexible gas engine generation along with battery storage will need to accompany the wind and solar additions.

In scenario one, the cost-optimal power system will achieve 83% carbon-free generation while providing the lowest cost of electricity for consumers.

If political decisions require a 100% renewable energy system, this last step will rely on commercialisation of P2G technologies.

The recommended path forward in each scenario is similar:

- No newbuild of traditional capacity, including coal and nuclear
- Massive buildout of solar, wind, energy storage and flexible generation capacity
- Natural gas generation switches to synthetic gas when feasible
- Generating capacity grows to 105 GW and 129 GW respectively in both scenarios

OUTCOME OF THE TWO SCENARIOS

IN THE COST-OPTIMISED SCENARIO, 83% OF ENERGY IS GENERATED FROM RENEWABLES

IN THE 100% RENEWABLE ENERGY SCENARIO, COSTS ARE JUST 3% HIGHER

IN BOTH SCENARIOS RENEWABLES WILL GENERATE MORE AFFORDABLE ENERGY, WHILE REDUCING EMISSIONS

VI. CONCLUSION

The modelling provides evidence that renewables will be playing a leading role in shaping the future power system in Ukraine in both the cost-optimised and 100% renewable energy scenarios. In both cases, RES will generate more affordable energy while simultaneously reducing the carbon footprint of the system.

In the cost-optimised scenario, 83% of energy is generated from RES, mainly solar and wind, with a combination of energy storage and flexible gas engines for balancing.

If there is a need to reach a 100% decarbonised system an additional investment would be needed, and this also relies on P2G technology. The total system cost in the 100% RES scenario is 3% higher.

Neither scenario suggests that investment in traditional inflexible power generation technology such as coal or nuclear power plants is necessary for optimisation.

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WÄRTSILÄ ENERGY IN BRIEF

Wärtsilä Energy leads the transition towards a 100% renewable energy future. We help our customers unlock the value of the energy transition by optimising their energy systems and future-proofing their assets. Our offering comprises flexible power plants, energy management systems, and storage, as well as lifecycle services that ensure increased efficiency and guaranteed performance. Wärtsilä has delivered 72 GW of power plant capacity in 180 countries around the world.

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