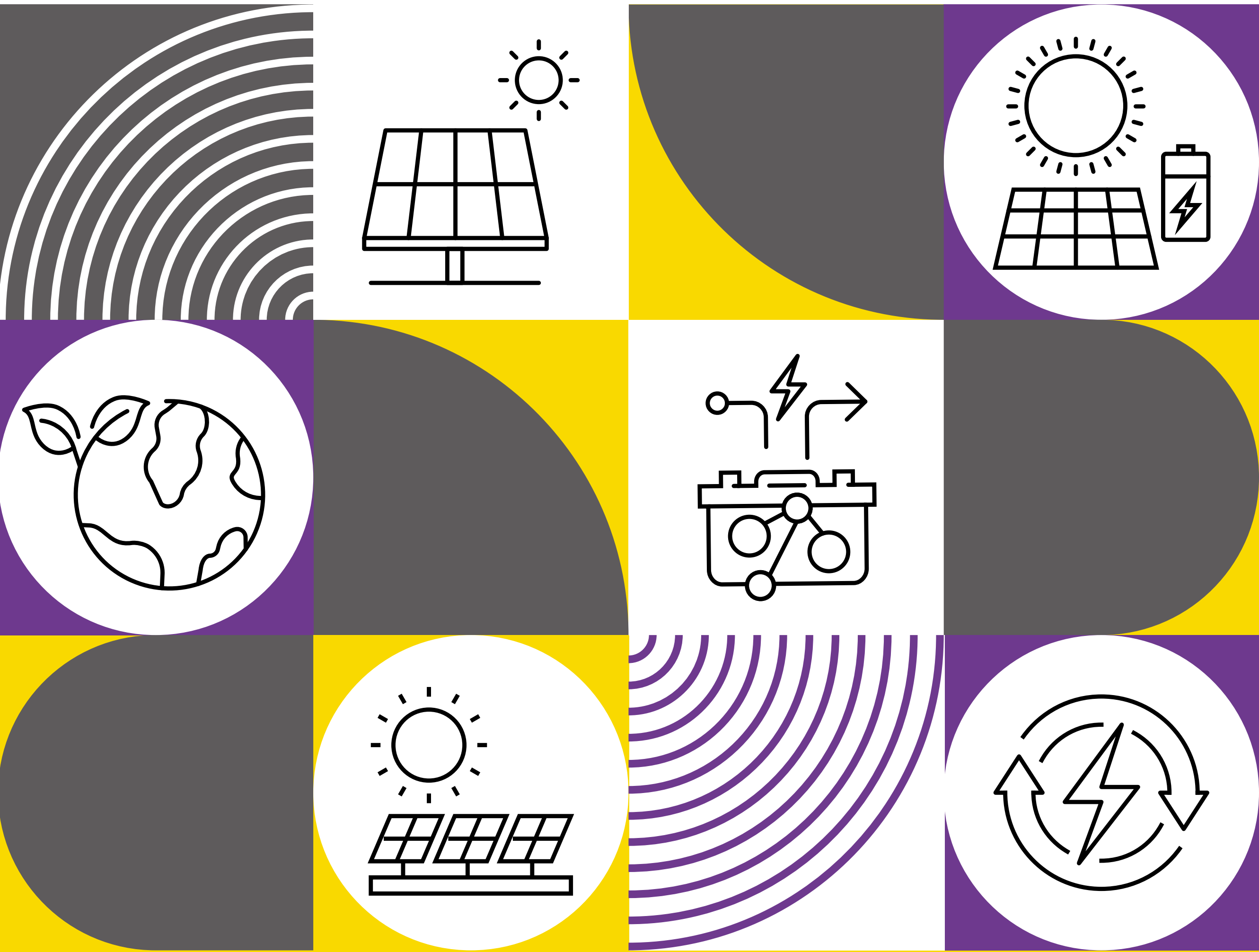
IRENA coalition FOR ACTION

KEY ENABLERS FOR THE ENERGY TRANSITION

SOLAR AND STORAGE

PRELIMINARY FINDINGS



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IRENA Coalition FOR ACTION

About the Coalition

The IRENA Coalition for Action brings together leading renewable energy players from around the world with the common goal of advancing the uptake of renewable energy. The Coalition facilitates global dialogues between public and private sectors to develop actions to increase the share of renewables in the global energy mix and accelerate the energy transition.

About this publication

Under the Coalition's Towards 100% Renewable System Working Group, the group explores the entire energy system needs and end-use sectors decarbonisation from the policy, innovation, technology, socioeconomics, and institutions perspectives. It develops best practices and policy recommendations for the transition to a 100% renewable energy system enabled by electrification, energy efficiency, grid integration, flexibility and storage solutions. These preliminary findings form part of an upcoming report series, *Key enablers for the energy transition: Grid, solar and storage*, and represents the views of non-governmental Coalition for Action members. This document presents preliminary findings from the series and are therefore subject to change in accordance with those of the forthcoming report.

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The upcoming report is co-authored by Coalition for Action member: Contemporary Amperex Technology Co., Limited (CATL); Xiangfeng MENG, Kangqiao HUANG and Xiaobo CHEN.

Valuable contributions were provided by the following Coalition Members: Alex Campbell, Oghosa Erhahon and Gabriel Murtaugh (Long Duration Energy Storage Council), Morjana Moreira dos Anjos and Andrzej Ceglarz (Renewables Grid Initiative), Eric Quiring (SMA Solar Technology), Francesca Celletti, Yelizaveta Ramisheuskaya and Matteo Miccoli (Enel Green Power), Kexin MAO and Giorgia Epicoco (Huawei), Itamar Orlandi and Jacob Roberts (Pexapark), Máté Heisz, Antonio Arruebo, and Raffaele Rossi (SolarPower Europe), Subrahmanyam Pulipaka, Shubhang Parekh and Muskaan Sethi (National Solar Energy Federation of India), Melody FU, Lin SUN and Quan CHENG (JinkoSolar), Merritt ZHANG (China Photovoltaic Industry Association), Mohammad Hassan Ghafouri, Sama Hamel, Fatemeh Hessami and Golshan Mir Moghtadaei (SATKA Association), Asma Adam (Women In Renewable Energy), Monica Oliphant (World Wind Energy Association), Roque Pedace (International Network for Sustainable Energy), Vivek Mittal (Africa Infrastructure Development Association); Abdallah Alshamali (Global Solar Council), and Andrea Wainer (REN21); and IRENA colleagues, Ilina Radoslavova Stefanova, Jarred McCarthy, Giedre Viskantaite, Jinlei Feng, Larissa Pinheiro Pupo Nogueira, Jaidev Dhavle, Francisco Gafaro, Adrian Gonzalez, Carlos Ruiz and Deborah Machado Ayres under the supervision of Raúl Alfaro Pelico (Director, IRENA Knowledge, Policy and Finance Centre). Technical review was provided by Paul Komor (IRENA).

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PRELIMINARY FINDINGS

The Outcome of the First Global Stocktake at COP28 in the United Arab Emirates, known as the UAE Consensus, called on all Parties to the United Nations Framework Convention on Climate Change to advance the energy transition by tripling renewable energy power capacity and doubling the rate of energy efficiency improvement by 2030. Complementing this call for action, the incoming COP29 Presidency will seek to secure a global pledge to increase energy storage capacity six-fold to 1 500 gigawatts (GW) by 2030; and – through both additions and refurbishment – deliver over 80 million kilometres of transmission and distribution lines by 2040, requiring innovative approaches across technologies and policies.

Electricity demand is expected to grow across the globe in the coming years, due to robust economic development and the electrification of end-use sectors including transport, heating and cooling. This demand will be further compounded by the growth of artificial intelligence (AI) and subsequent energy needs for large-scale data centres. In 2023, new global renewable capacity additions reached an unprecedented 473 GW, accounting for 85.5% of new power generation capacity added and representing a 14% year-on-year increase between 2022 and 2023, in cumulative renewable capacity. in cumulative renewable capacity. Of this 473 GW, 336 GW was attributed to solar photovoltaics (PV) and 104 GW to onshore wind.[1,2] With the electricity system transitioning from one where large baseload production (*e.g.* nuclear, hydroelectric) provided the least-cost source of electricity to one where a more distributed system of variable renewable energy (VRE) technologies – primarily solar and wind – are now fulfilling that role, there is a pressing need to upgrade and modernise markets, grids and energy storage capacity.[3]

It is against this backdrop that the IRENA Coalition for Action will issue a series of reports providing non-governmental stakeholder perspectives on current global challenges and opportunities for the development of grids, solar PV and energy storage.

1 IRENA (2024), *Renewable energy statistics 2024*, International Renewable Energy Agency, Abu Dhabi.

2 IRENA (2024), *Renewable power generation costs in 2023*, International Renewable Energy Agency, Abu Dhabi.

3 *Ibid*.

INTRODUCTION

The first report in this series will highlight the roles of solar PV and storage in meeting global renewable power capacity targets. It will highlight the need for new national and regional policies, as well as an enabling regulatory environment to ensure future electricity systems can function flexibly and reliably under high VRE penetration.

PV-hybrid storage applications are proposed as key opportunities for enhancing grid flexibility and reliability. However, challenges remain; solar PV is, by its nature, variable and will not always be available to meet electricity demands. System operators will need to increasingly rely on solar PV to cover baseload and demand fluctuations, since this technology will displace many traditional centralised generation sources such as coal, nuclear and gas power plants.

As solar energy production is likely to exceed demand during certain hours, operators and regulators will need to address the potential for curtailment and grid congestion, and associated costs. This proactive approach will be essential, especially as we transition away from centralised coal and nuclear power sources. Therefore, storage solutions will become increasingly essential to support the integration of a high share of VRE sources like solar PV into the grid, playing critical roles in peak shaving and load shifting.

PV-hybrid storage can lead to a more distributed power system than what currently exists and can also be the basis for the development of community and micro power systems, which could eliminate the need for building new or upgrading the existing infrastructure. A more distributed electricity supply is key to a resilient grid that is already being seriously impacted in many regions by weather phenomena associated with the climate crisis, such as more intense storms and greater risk of forest and rangeland fires. Market design and the regulatory environment for operating a more distributed and flexible grid systems will be impacted.

THE SOLAR PV AND STORAGE LANDSCAPE

PV-hybrid storage can be effective in supporting widespread renewable energy integration and end-use electrification, in view of their declining costs and growing role in reducing emissions across sectors. The global weighted average levelised cost of electricity (LCOE) for solar PV fell by 2% year-on year from 2022 to 2023, and 90% overall between 2010 and 2023, and 90% overall between 2010 and 2023,[4] while battery storage project costs declined 89% between 2010 and 2023, from USD 2 511/kilowatt hour (kWh) to USD 273/kWh.[5]

Energy storage solutions are diverse and include a variety of short- and long-duration technologies, such as lithium-ion battery storage, compressed air energy storage, hydrogen storage, all-vanadium flow battery storage, gravity energy storage, pumped hydropower storage and molten salt storage, among others. Each technology has its respective advantages in terms of costs, energy efficiency, safety and maturity, and vary in their use-case solutions and development potential. The most widely deployed type of storage technology used in electricity grids today is pumped hydropower storage at over 179 GW,[6] followed by lithium-ion batteries at 89 GW (or 189 GWh).[7] Ensuring energy storage and grid development keep pace with the growing deployment of renewable energy sources, requires innovative PV-hybrid storage applications as well as policy and financial mechanisms that enable the sustainable development of the renewable energy industry.

4 IRENA (2024), *Renewable power generation costs in 2023*, International Renewable Energy Agency, Abu Dhabi.

5 BNEF (2024), *1H 2024 Energy Storage Market Outlook*, Bloomberg New Energy Finance (subscription required).

6 IHA (2024), *2024 World Hydropower Outlook Opportunities to advance net zero,* International Hydropower Association.

7 BNEF (2024), *1H 2024 Energy Storage Market Outlook*, Bloomberg New Energy Finance (subscription required).

ENABLERS FOR ACCELERATING DEPLOYMENT

PV-hybrid storage applications – and by extension the success of the global energy transition and associated renewable power, efficiency and storage goals – still face barriers. The forthcoming report will identify the pressing need for national energy storage targets, including a collective commitment to adding storage capacity based on renewable power capacity through 2030 national energy development plans. The report also calls for stronger storage capacity investments to support the acceleration of the transition towards a renewables-based energy system. While there are several enablers to the deployment of PV-hybrid storage, three will be explored in more detail in the forthcoming report:

- **Policies and incentives**

  Siloed policy making continues to hinder the systemic shifts required in energy policy and planning, namely: (1) operation within the energy market; (2) pricing mechanisms where policies and financial incentives need to provide investment signals, sustainable business models and market mechanisms; and (3) insurance and financing.

- **Storage in grid expansion and modernisation plans**

  » Energy storage must be factored into grid modernisation and grid infrastructure expansion planning. With regard to the COP29 Presidency's call to add or refurbish more than 80 million kilometres of grid infrastructure by 2040, flexibility – and the way storage provides it – will be a key driver of the energy transition and a founding principle of new energy systems.

  » Digitalisation will also play a key role; by forecasting grid development trends, power load growth, renewable electricity capacity and generation by technology, one can assess the requirement for grid flexibility enhancement.

- **Standards and certification**

  Standards and certification, and related compliance, across research and development (R&D), safety evaluation, supply chain compliance and life-cycle management, will be critical to the scaling up of PV-hybrid storage applications to meet demand.

  » For the solar PV industry, extensive standards and certifications exist. The main challenge is convincing market participants to "accept the value of compliance with international standards, and inspection and certification to those standards.[8]

  » For storage, standards and certification at the system- and grid-level are lacking.

8 IRENA (2024), *Solar PV supply chains: Technical and ESG standards for market integration*, International Renewable Energy Agency, Abu Dhabi

Several accidents involving deployed energy storage systems have occurred globally. If there are little or no quality control standards during the design phase, system safety standards to follow during grid integration, or empirical testing to verify equipment reliability before connection to the grid, significant safety risks to the grid will remain.

» Finally, a grid-related gap exists owing to the lack of standards for grid-forming converters that is becoming increasingly relevant as more VRE is added to the grid; virtually no standards exist in this regard, and "the mentioned regulations are generally not exhaustive on the design parameters, which can jeopardise further deployment of PV in areas where they already represent a high share of the real-time electricity mix.[9]

9 *Ibid*

POLICY RECOMMENDATIONS

The report will call for specific policies to accelerate the growth of grid flexibility – particularly in the form of solar and storage – as major steps to accelerate the decarbonisation of energy systems. These policies will contribute to achieving the target of tripling renewable power capacity by 2030 and moving towards fully renewable energy-based systems thereafter. The policy recommendations include:

Promote solar and storage as key enablers for the global tripling target

- **Adopt national energy storage targets to accelerate storage capacity investments to support grid flexibility and reliability**
  - » This is a collective commitment to adding storage capacity in parallel with renewable power capacity. Assessments of national grid flexibility should be conducted that consider renewable capacity deployment commitments. [10]
  - » National energy development plans with storage targets are needed to facilitate an increase in VRE. This includes both short- and long-duration energy storage for intraday, weekly, monthly and seasonal power shifts.
- **Provide long-term commercial viability to the energy storage industry**
  - » Energy storage should be established as an independent market participant in electricity markets to obtain revenue. It should be recognised as an independent bi-directional charging and discharging entities within the grid (neither as an energy producer nor a consumer) and should not be subject to double-payment of network charges for charging and discharging (*i.e*. only one charge should apply). Policies and financial incentives are needed to provide the energy storage industry with a sustainable business model and market predictability, where energy storage is not treated as a cost item but rather as providing value for VRE renewables such as solar and wind.
- **Develop an action plan to address skilled labour shortages**
  - » Conduct a national assessment to identify gaps in the renewable energy workforce and related skillsets. Specialised training for relevant professionals is needed in both solar installations and energy storage deployments. A just and inclusive transition must prioritise support for fossil fuel-dependent regions and workers to ensure that the shift to sustainable energy does not lead to widespread unemployment

10 An example includes IRENA's FlexTool, which performs power system flexibility assessments based on national capacity investment plans and forecasts.

and economic displacement. Therefore, training programmes should also be made available to traditional fossil fuel workers with the skills and specialisations needed to fill renewable energy roles.

Enhance grid flexibility and stability via energy storage

- **Establish country level commitments on storage based on supply and demand forecasts**
  - » The global power system – including regional power load growth – should be analysed to determine the strategic optimisation and integration of grid developments. This includes setting up country-level interim (*e.g.* 2030) energy storage targets building on existing and upcoming supply and demand forecasts.

- **Improve and fully develop the regulatory framework for grid and energy storage integration and ensure mechanisms to secure the investments**
  - » A comprehensive regulatory framework is essential for the smooth and rapid integration of energy storage into the grid, encompassing clear technical standards and investment incentives. Regulatory predictability is critical for attracting capital-intensive investments in energy storage, providing the operators with long-term viability to make informed decisions. Further to that, it is important to adapt the grid tariffs and provide a level playing field for storage as a flexibility option on the market.

- **Enhance capacity of grid-forming solutions**
  - » The increased penetration of VRE in grids undermines their safe operation; therefore, enhanced grid strength should be prioritised by policy makers. When VRE is combined with energy storage solutions, grid system strength and stability can be significantly improved.

Develop solar and storage through favourable financing and insurance policies

- **Introduce diversified financial mechanisms**
  - » Fiscal incentives are necessary tools for mass adoption of renewable energy technologies, including in industry and cities. These can include preferential tariffs, feed-in tariffs, capital subsidies for relevant equipment, reward schemes tied to energy savings and greenhouse gas (GHG) emission reductions, and other innovative tools. A collective action platform – such as an investment alliance, comprising banks, regulatory bodies, suppliers, financial institutions, and energy service companies, etc. – can help channel financial resources from private equity investors to the renewable energy sector.

- **Ensure favourable insurance policies**
  - » Solar and storage currently face several barriers to development - such as high initial investment requirements and policy changes. Insurance services can play a crucial role in overcoming these obstacles for solar and storage integration. Specifically, they offer protection against losses due to technical risks such as equipment failure. They can also provide more options in terms of financial support - such as premium financing - to develop investor confidence and help project developers better navigate market competition and policy uncertainties.

Support the development of standards and certifications

- **Encourage participation, compliance and implementation**
  - » International collaboration, through technical committee discussions where international standards are developed, must be encouraged. Platforms are needed to develop industry standards, such as the International Quality Infrastructure Forum, that ensures components for solar PV and storage are technically sound and safe. Different stakeholders across government, industry associations and the private sector should be encouraged to participate.

- **Design systematic technologies to support the development of standards and innovation**
  - » It is necessary to develop relevant testing and validation equipment and technologies, leveraging R&D to provide reference points for the development of solar and energy storage standards. Governments can maintain and expand support for R&D at public universities and research institutions to encourage innovation and technology advances that support reduced risks and costs, and improve grid services.

- **Establish sound safety evaluation standards**
  - » The successful development of the solar PV and energy storage industries relies on standardisation. Although many standards have already been introduced, existing mandatory safety-related standards are insufficient, especially for battery storage. At system level, many norms still follow voluntary principles and are not formally established. In addition, safety requirements for energy storage products vary due to differences in the materials used and manufacturing processes employed, for example. Integration of existing safety standards is therefore essential to implement standardised industry-wide safety procedures.

- **Promote supply chain compliance and diversification**
  - » Resilient and efficient supply chain networks that facilitate rapid, timely and cost-effective delivery must be developed. Improvements to the security and resilience of solar PV and storage supply chains require a better understanding of risks while also maintaining commitments to fair trade practices. The environmental, social and financial sustainability of these industries must be improved by ensuring compliance with international quality and certification standards. Labour rights need to be respected, and robust project documents and/or auctions must also be developed. This includes responsible mining, and the processing and recycling of critical materials needed for supply chain diversification.

- **Conduct life-cycle safety assessments of energy storage systems, including reuse, recycling and end-of-life disposal**
  - » For solar and storage, recycling of material needs to be considered throughout project life cycles. Solar panels and batteries should be designed with longevity and recyclability in mind. It is also important to improve recycling and waste management technologies and practices during production, and to develop a practical model for recycling systems.
  - » Safe operation of energy storage systems must be ensured. Over time, the material stability of batteries tends to decrease, causing more safety hazards. To address this challenge, a safety standard or testing guidance is needed specifically for energy storage products with long charging and discharging cycles.

INNOVATIVE PV-HYBRID STORAGE CASE STUDIES

PROJECT	Ordos Green Power Supply: Research and Application Demonstration Project of the "Zero-Carbon Super Generator Set"	Grid Booster, Kupferzell	Blackhillock Project
SCALE	660 000 kW of wind power, 340 000 kW of solar power, and 160 000 kW/4 hours of electrochemical energy storage	Pilot	200 MW / 800 MWh
LOCATION	Ordos, China	Kupferzell, Germany	Blackhillock, Scotland
DATE	2023 – 2024	The project was initiated in 2019 and is expected to be completed in 2025	2023 – 2024
CHALLENGES	In recent years, the concept of "eco-industrial parks (EIPs)" has increasingly been recognised as an effective tool in overcoming challenges related to inclusive and sustainable industrial development within the scope of the UN Sustainable Development Goals (SDGs). Countries such as Denmark, France, Japan and the Republic of Korea have leveraged key elements of the EIP concept to promote more inclusive and sustainable action to improve industrial competitiveness in line with climate change goals.	The current transmission grid is heavily utilised. Energy transport from North to South, in particular, is increasingly challenging for transmission system operators. This is because the power lines are currently being utilised below their capacity limit to protect against overloads. In addition, so-called 'preventive redispatch' measures are used, in which power plants are switched off upstream of the starting point of the overloaded line and ramped up again downstream of the end point. These measures are necessary to secure the power supply. However, they are expensive, and counter-productive to the goals of the energy transition.	Lack of stability due to retirement of conventional synchronous generation and increase of inverter-based resource (IBR) power generation

SOLUTIONS	Zero-carbon parks represent a new commercial model for solar and storage applications. Typically situated in high-energy-consumption industrial parks, they integrate solar and storage solutions with other smart energy management systems (including flexible conversion of electricity, heating and cooling). This project aims to provide green electricity to high-energy-consuming enterprises and establish a new business model for direct renewable energy supply to industrial parks. The energy storage system utilises a high-voltage direct current (HVDC) energy storage technology route, which includes a storage valve and a flexible direct current (DC) converter valve. Compared to traditional low-voltage storage solutions, the HVDC direct storage system features a large capacity, high efficiency and strong support. It operates independently without the need for diesel generators or grid support, achieving self-frequency/voltage regulation, self-inertia regulation, grid connection and disconnection, and island operation functions, thus establishing the world's first "zero-carbon industrial park" scenario demonstration. By leveraging local peak-valley price differentials, regional subsidies and future carbon emission market designs, high-carbon industries can reduce operation costs and achieve emissions reduction. In addition to China, the zero-carbon park model is expected to be replicated and expand into other markets in the future.	With the help of a Grid Booster, the existing transmission grid can be utilised to a greater extent than before. This is because a Grid Booster is able to compensate for potential transmission grid overloads in a matter of seconds by (partially) automatically feeding in stored energy downstream of the bottleneck and reducing the feed-in after the bottleneck. The Grid Booster balances out the overload for up to one hour until curative measures such as the connection of power plants downstream of the bottleneck, switching measures or feed-in management are implemented. The Grid Booster Kupferzell has a capacity of 250 MW, making it one of the largest grid battery storage systems in the world.	The Blackhillock project is an initiative aimed at advancing the UK's transition to a net-zero economy by 2050. Blackhillock is part of the National Grid Electricity System Operator's (NGESO) Stability Pathfinder project, which aims to purchase grid-stability services from diverse asset classes. This project leverages inverter and battery technology to enhance grid stability and integrate more renewable energy into the national grid. Initially focusing on synchronous condensers, the project has now expanded to include grid-forming inverter assets, diversifying the range of stabilisation solutions available. The Blackhillock battery project, with a capacity of 200 MW / 400 MWh, will provide a full suite of energy, ancillary, and stability services. The implementation of this project is expected to reduce consumer bills by over USD 220 million over 15 years and contribute to energy independence.
IMPACTS AND BENEFITS	The project has a total investment of approximately USD 820 million. It will be built with an annual power generation capacity of about 2730 GWh, allowing for a renewable electricity supply ratio of ≥80% for enterprises. The project implemented multi-purpose assets based on Battery Energy Storage System (BESS) energy arbitrage, ancillary service and stability services.	The project is expected to enhance grid stability and resilience, lower operational costs and support the broader integration of renewable energy sources into the grid, ultimately making the energy transition more sustainable and economically viable.	The project implemented multi-purpose assets based on BESS energy arbitrage, ancillary service and stability services in a marked based tender. In terms of socio-economic and environmental benefits, the project not only supports the UK's net-zero objectives but also enhances energy efficiency and stability, contributing to a more sustainable and resilient energy infrastructure.

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