

SMARTER AND CITIZEN-CENTRIC POWER FOR SHARED PROSPERITY

Unleashing the potential of digitally-and AI-enabled power systems



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Foreword



The global energy transition has entered a decade of delivery. Solar power, now among the most affordable sources of new electricity, has expanded at record speed, with global capacity doubling in recent years and costs falling sharply over the past decade. Solar is no longer an emerging technology—it is leading the transformation. It took nearly 25 years for the world to install the first 1,000 gigawatts of solar capacity. Remarkably, another 1,000 gigawatts has been added in just the past two years. Of this recent growth, nearly 40% has come from distributed solar.

In India, however, distributed solar accounts for only about 15% of installed capacity—and the share is even lower across many developing countries. This is set to change. As rooftop and decentralised solar scale rapidly across the developing world, utilities will face increasing complexity in managing millions of distributed energy assets. This is where digitisation becomes indispensable. Smarter, data-driven discoms will be critical to maintaining grid stability, enabling two-way power flows, and unlocking the full value of distributed solar.

At the same time, a clear divergence is emerging globally. Much of the developed world is focused on *energy for AI*—powering data centres and compute-intensive systems. For the developing world, however, the greater opportunity lies in AI for energy: using artificial intelligence to optimise grids, improve utility performance, reduce losses, and expand reliable, affordable energy access at scale.

Renewables already provide around one-third of global electricity, and solar will account for the largest share of future additions. For many countries, especially across the Global South, this is not only a climate story but a development one—expanding access, reducing fuel imports, supporting jobs, and strengthening economic resilience.

Networks designed for centralised systems are struggling to integrate distributed solar, storage, electric mobility, and rising demand. Congestion, curtailment, outages, and limited visibility over distribution systems are slowing renewable integration and increasing costs. Without smarter and more adaptive grids, the promise of the solar revolution cannot be fully realised.

Digitalisation and artificial intelligence must therefore be treated as core infrastructure. AI-enabled power systems provide practical solutions to immediate challenges—reducing losses, improving outage response, managing congestion to defer costly upgrades, forecasting renewable generation and demand more accurately, and integrating rooftop solar, batteries, and EVs at scale. When deployed step by step, beginning with sensing, data platforms, and basic automation, these tools strengthen grid performance today while preparing for a high-renewable future. This spotlight report is designed with that implementation lens: it focuses on concrete use-cases, sequencing, and delivery pathways rather than technology in abstraction.

Implementation pathways differ. Advanced systems must unlock flexibility and optimise complex networks. Emerging markets need digital tools to improve reliability and utility finances. Low-income countries must build foundational visibility and revenue assurance. Small island states require digital control of microgrids and storage to reduce diesel dependence and stabilise fragile systems. AI for energy is a staged, practical pathway aligned with national priorities.

This moment calls for political leadership. A Global Mission on AI for Energy should align policy, build capacity, strengthen data infrastructure, foster innovation, and mobilise finance to move from pilots to system-wide transformation. The International Solar Alliance stands ready to work with partners to turn this agenda into action and deliver power systems that are reliable, affordable, resilient, and truly citizen-centric.

Executive Summary

The World is Witnessing two Transformative Shifts: The Clean Energy Revolution and the AI Revolution

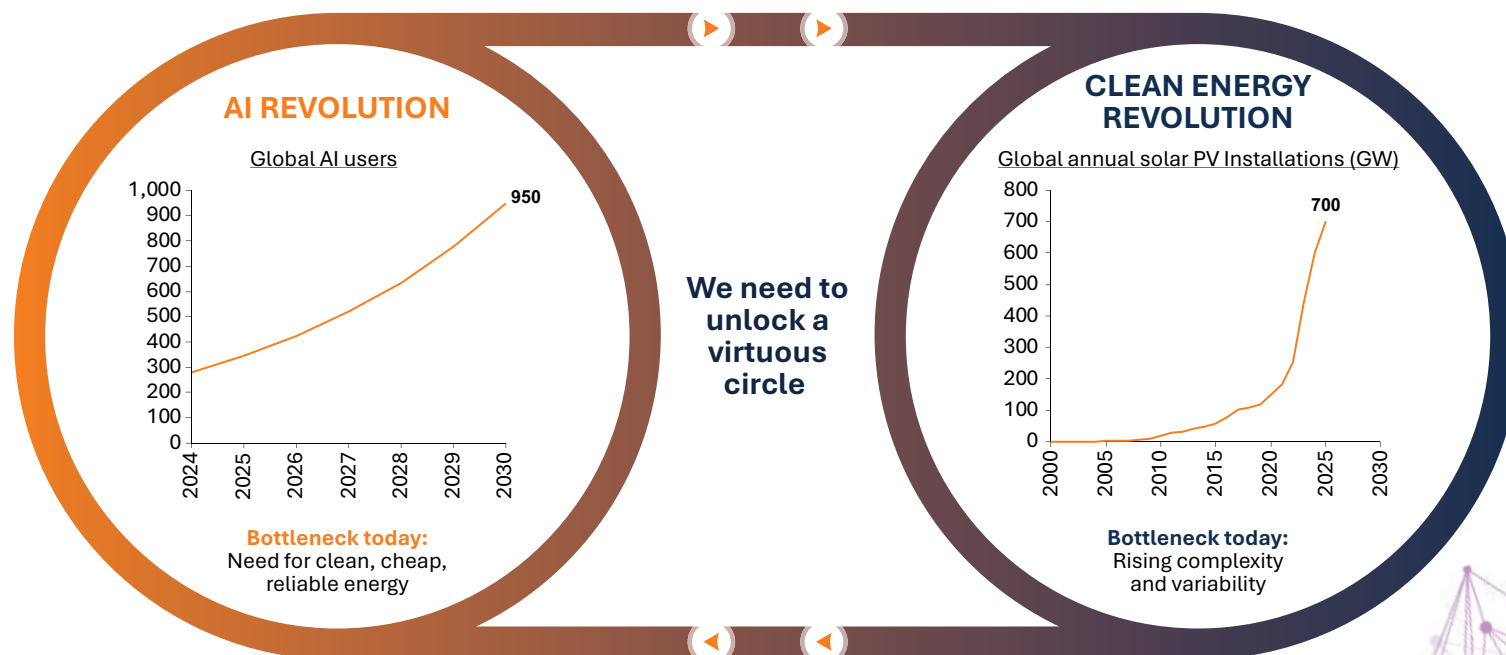
Renewable energy – in particular, solar – is scaling at unprecedented speed and is now the cheapest source of new power in most countries of the world. At the same time, AI is rewriting how complex systems are managed through prediction, optimisation, automation and real-time decision-making. Together, these two revolutions create a powerful feedback loop:

Clean electricity de-bottlenecks the AI revolution by providing affordable, clean, abundant, and reliable electricity for power-hungry data centres and overcoming current grid connection challenges.

AI de-bottlenecks the clean energy transition by managing variability, distributed energy resources and complexity, enabling clean power systems to run efficiently, cost-effectively and flexibly.

AI enables clean power systems to scale, manage variability and complexity, and run efficiently

Put simply: the clean energy revolution cannot scale without digitalisation and AI; and the AI revolution cannot scale without affordable and accessible clean power.



Clean, abundant, and reliable electricity enables sustainable and accessible AI

Source: Statista (2025); Energy Transitions Commission (2025), Power Systems Transformations.

The Central Question

How can digitally- and AI-enabled power systems (henceforth referred to as AI-enabled power systems) unlock the clean energy revolution and create more accessible, affordable, reliable and secure electricity for all?

While the digitalisation of the power system has been an ambition and increasing reality across the world for decades, the potential for AI to transform power systems remains a largely untapped opportunity. Yet to successfully build an AI-enabled power system, countries must progress up the “digitalisation ladder”: first digitising their power systems to collect data, then deploying digital technologies to act on data, and finally enhancing decision-making through AI.



There is a critical window of opportunity, as the share of renewable electricity generation in power grids reaches ever higher levels globally. The question is no longer whether grids should modernise, but how quickly and in what manner, for example, open vs proprietary, inclusive vs exclusionary, and pilot-driven vs scalable platforms.



At the heart of an AI-enabled clean power system is the “prosumer”: households and businesses are no longer passive consumers of electrons, but are active customers and producers of electricity, able to generate supply via rooftop solar for example, store surplus power in EVs, and flex their demand up to a point. It is essential that the development of AI-enabled power systems takes a citizen-centric approach, which focuses on developing trust, engagement and participation across society, empowering citizens to take control of their own power consumption and production, and to share in the rewards.



This Study Demystifies “AI-enabled Power Systems”

Through use cases, examples of already deployed technologies and their demonstrated impact, and technology pathways across different country archetypes.

At a Glance

- 01 | Grid constraints hinder clean power
- 02 | Digital and AI unlock system intelligence
- 03 | Citizen-centric models drive inclusive growth
- 04 | Transformation requires stepwise digitalisation
- 05 | Few countries have reached full AI readiness
- 06 | Existing projects demonstrate measurable impact
- 07 | Immediate priorities differ across country archetypes
- 08 | Progress relies on addressing 5 bottlenecks
- 09 | Collective action can unlock system-wide change

Global Mission for AI for Energy

Putting it in Context

01

The development of clean power systems is currently bottlenecked by slow grid build out and legacy power systems which are ill-equipped to manage variable and distributed renewable energy assets.

02

Digital and AI technologies have 6 key capabilities: plan, monitor, forecast, optimise, flex, and transparency. Through these, they can unleash the clean energy revolution by providing real-time visibility of entire power systems, optimising demand and supply, and unlocking opportunities for demand-side flexibility – amongst other use cases.

03

By taking a citizen-centric approach, AI-enabled power systems can support economic and social transformations. Technologies such as peer-to-peer trading, vehicle-to-grid, and consumer aggregation models drive people participation and create new income streams for households and small businesses. In doing so, an efficient, reliable and accessible power system supports productivity and economic growth, boosts social inclusion, and makes better use of existing assets to lower the overall investment required in renewables and grid build out.

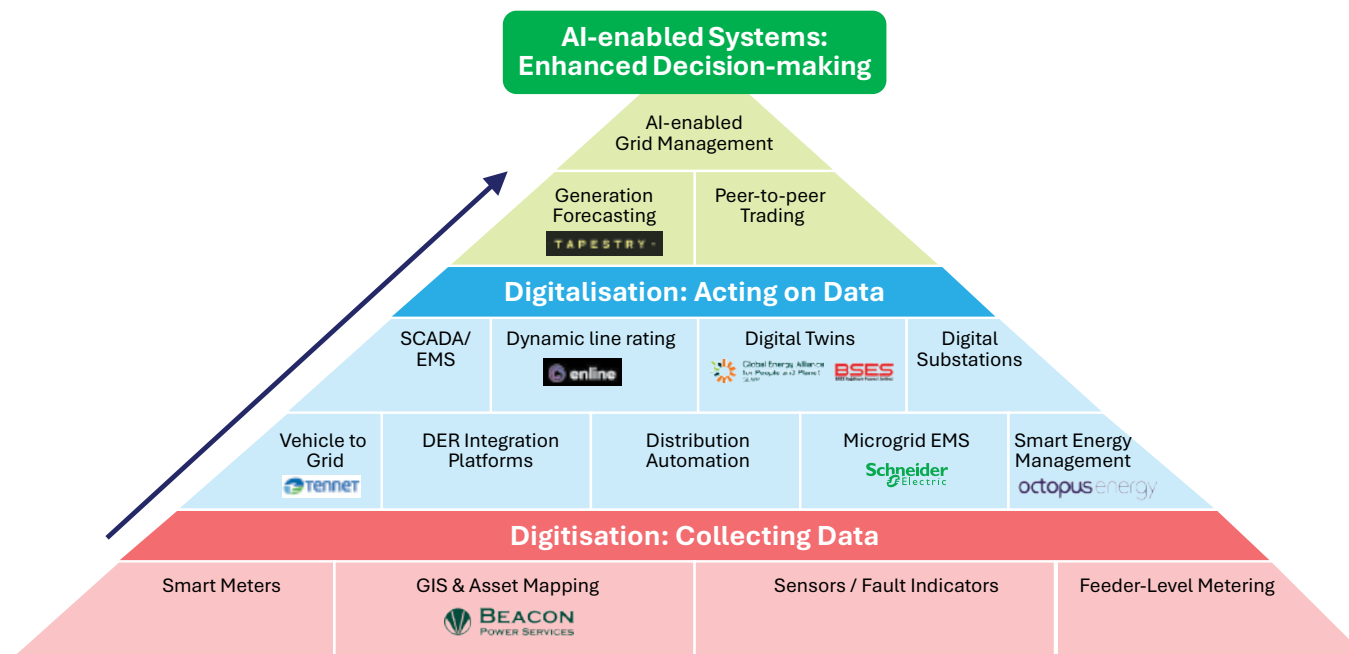
04

There is no one-size-fits-all pathway toward an AI-enabled power system, nor a single defining technology. Instead, progress requires a suite of interconnected hardware and software deployed across the entire energy value chain and along the digitalisation ladder. This transformation cannot be leapfrogged: systems must advance linearly, step by step, from foundational data collection and digital capabilities, to more advanced AI applications.

05

Digital and AI technologies are already deployed today in various forms across the world, but very few countries have progressed fully up the digital readiness ladder to build fully AI-enabled power systems across the whole value chain.

An AI-enabled Power System Involves a Suite of Interconnected Hardware and Software Across the Entire Energy Value Chain



Source: ISA & Systemiq analysis (2025)

Note: logos represent select case studies presented in our report; this is not an exhaustive list.

06

Pilots and existing use cases are already delivering measured outcomes in terms of commercial and consumer savings, lower technical and non-technical losses, and reduced outages.



Digital twins deployed across Jaipur's distribution grid optimised the use of battery assets to reduce power procurement by 15-20%, and facilitated network expansion by cutting the permitting time to connect new industrial loads from 12 weeks, to less than a week.¹



In the UK, a real-time grid management platform and smart energy management systems deployed in homes have enabled dynamic pricing and flexible EV charging. This has cut local peak load by ~50% in some cases, and to date, has saved 2 million customers over \$500 a year.²



AI forecasting deployed at solar and wind farms across Australia increased accuracy by 20%- 30%, increasing the utilisation of renewables and reducing curtailment; this has contributed to a 25% increase in renewable electricity generation.³

07

Immediate priorities to implement digital and AI technologies vary across country archetypes. This report suggests the following priorities for the next 3-5 years:



High-income countries:

- 1) Digitise and digitalise the distribution network to support end-use electrification and the integration of DERs
- 2) Focus on optimising the energy system through AI-enhanced grid management, demand-side flexibility, and advanced analytics and forecasting.



Emerging markets:

- 1) Digitise and digitalise the distribution network and end-use to support end-use electrification and the integration of distributed energy resources (DERs)
- 2) Begin developing the core capabilities and systems to digitally-enhance the operation of power systems.



Low-income countries:

- 1) Build a foundational understanding of network
- 2) Address technical and commercial losses and to improve the financial health of utilities.



Small Island Developing States:

- 1) Develop the core software and data platforms to support the operation of microgrids
- 2) Make targeted investments in digital technologies which can address specific problems (e.g., smart inverters to address the challenge of low inertia in the system).

08

Realising these technology pathways, however, requires countries to address barriers and bottlenecks across five key areas:



Policy and regulation: Fundamental challenge of power markets lacking competitiveness, transparency and flexibility to sufficiently incentivise digital investments.



Capabilities: Persistent gaps in digital skills and institutional capacity in utilities, regulators, and system operators to plan, procure, and operate digital and AI-enabled solutions.



Data governance and infrastructure: Legacy IT systems, weak networks, and unclear data policies that make it hard to collect, share, and effectively use high-quality energy data.



Innovation and ecosystem creation: Underdeveloped innovation ecosystems and weak collaboration between energy, digital and finance communities slow the testing and scale-up of new solutions.



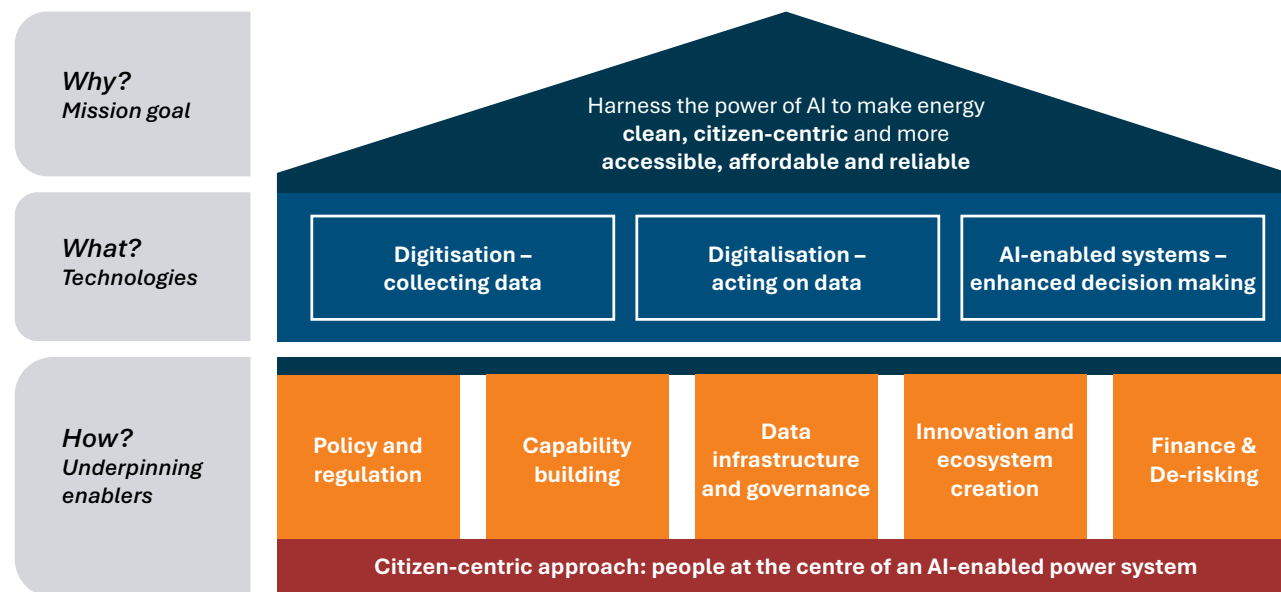
Finance and de-risking: High capital costs, stressed utility finances and limited finance tools hold back investment in digital and AI solutions.

09

These barriers can only be addressed collectively, across the entire value chain and through international cooperation and collective action. This study outlines the need for a formal **Global Mission for AI for Energy** that can unleash the potential of digitally- and AI-enabled power systems across the world.

A Global Mission is needed to institutionalise delivery, bring speed and urgency through focus and specialisation, create a coordination mechanism that shares learnings and best practice, and, crucially, to democratize power systems by incentivising people participation in power systems.

Global Mission for AI for Energy



The International Solar Alliance, with 125 member countries representing some of the highest solar potential globally, is uniquely positioned to harness this convergence at scale and drive this Mission forward. The Global Mission for AI for Energy would work towards achieving the following across five pillars:



Policy and regulation

Institutionalise best practice AI-for-energy policy frameworks



Capabilities

Build a global pipeline of AI-literate energy professionals



Data infrastructure and governance

Define a reference architecture for AI-ready power data



Innovation and ecosystem creation

Launch innovation nodes that convert energy x AI pilots into scale



Finance and de-risking

Mobilise concessional blended finance for AI-enabled power systems

Citizen-centric approach: people at the centre of an AI-enabled power system

At the core of the Global Mission will be people – developing the critical enablers across each pillar which incentivise and drive the participation of citizens within clean power systems. Specifically, it will include:

01

Creating competitive and transparent electricity markets which create value for storage and flexibility, with time-of-use tariffs which enable citizens to share in the rewards.

02

Building core digital literacy skills across society and an understanding of how clean power systems work, enabling active participation and engagement.¹⁸

03

Interoperable and secure data architecture, which creates safe platforms for data sharing, transparent and trusted transactions, and competition across vendors.

The study serves as a call to action for all stakeholders of goodwill – governments, philanthropies, and others – to join India and the International Solar Alliance in building and advancing this Global Mission.

Endnotes:

¹ Rockefeller Foundation (2025), Initial Learnings from the Rajasthan Grid Digital Twin and Standards Setting for the Digitalization of Utilities for the Energy Transition (DUET).

² Kraken Technologies (2024), SSEN Reference Case: Deferring Grid Infrastructure Upgrades with Dynamic Distribution Grid Pricing.

³ Sustainable Future Australia (2025), AI Forecasting Makes Solar and Wind Power More Reliable Than Ever.

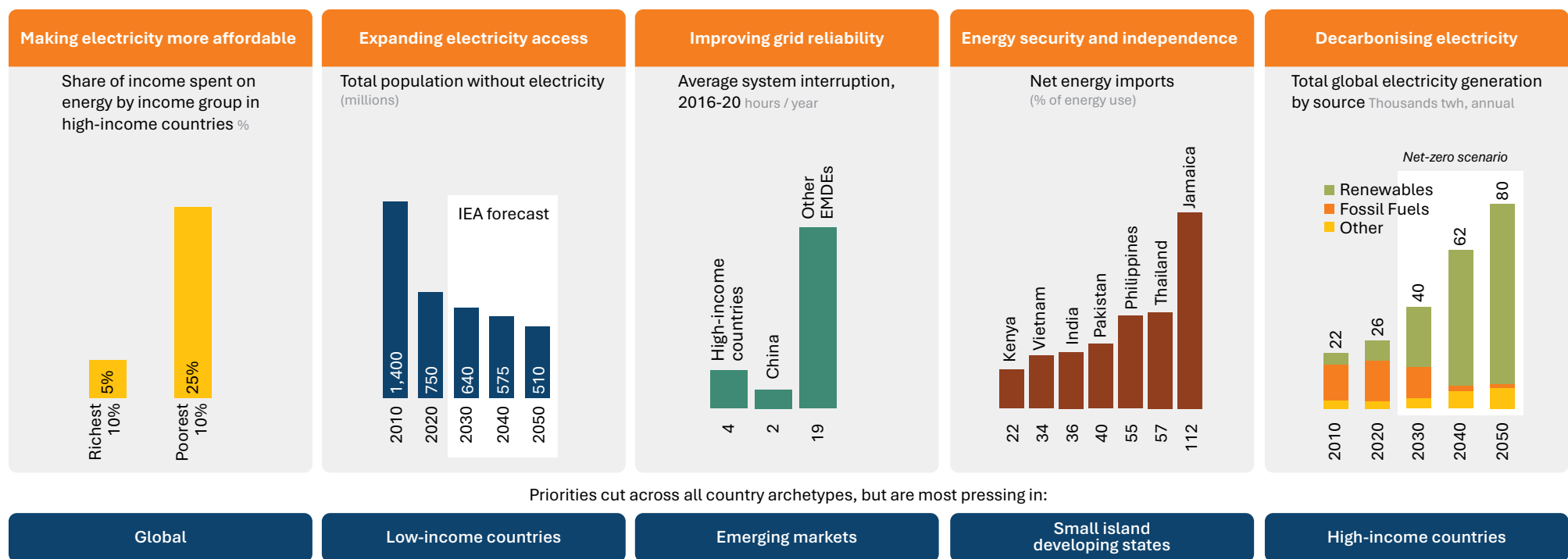
The Challenge: Grids are the Weak Link of the Energy Revolution

The Future is Electric and Primarily Solar

Energy systems are a foundation of economic and social development. Every country ultimately seeks five outcomes from its power system: providing electricity which is (a) accessible, (b) affordable, (c) reliable, (d) secure, and (e) clean. However, immediate priorities differ across geographies.

Exhibit - 1

AFFORDABLE, ACCESSIBLE, RELIABLE, SECURE AND CLEAN ENERGY IS CORE TO INCLUSIVE GROWTH; WHILE ALL IMPORTANT, PRIORITIES DIFFER ACROSS ARCHETYPES



Sources: IEA (2024), Strategies for Affordable and Fair Clean Energy Transitions; IEA (2024), World Energy Outlook; Bloomberg NEF (2024); World Bank (2023), Energy imports, net (% of energy use); IEA (2024), World Energy Outlook.

01

Making electricity more affordable:

Heightened by the 2022 energy crisis, the cost of electricity is a growing political and social issue. In middle- and low-income countries, an estimated 1.2 billion people are energy poor. While in high-income countries, there are huge disparities the poorest 10% of households, who spend a quarter of their disposable income on energy and transport fuels, yet consume half as much energy as the richest 10%.^{1, 2, 3}

03

Improving grid reliability: For many middle- and low-income countries, grid outages occur five times more frequently than in high-income countries.⁵ This has a negative impact on productivity, wellbeing, and the integration of increasing shares of renewable energy.

05

Decarbonising electricity generation: In 2025, renewables accounted for almost 35% of global electricity generation, up from ~20% in 2010.⁷ For the world to reach net-zero, renewable generation must increase 8-fold by 2050, to account for almost 90%.⁸

02

Expanding electricity access: Between 2010 and 2020, the number of people without access to electricity almost halved; however, since then, progress has slowed, due in part to the COVID-19 pandemic.⁴ Under current policies, the International Energy Agency (IEA) expects slow progress to continue, with 500 million people still without access by 2050, primarily in low-income countries.

04

Ensuring energy security and independence: The extent to which a country relies on fuel imports to reach their energy needs is associated with greater exposure to external energy price shocks, geopolitical risks and trade imbalances, amplifying macroeconomic instability.⁶ While the extent of this issue varies significantly across all country income groups, it is a pressing issue for many small island developing states (SIDS), which currently lack domestic energy infrastructure.

All of these priorities are possible because of the transition to renewable energy, in particular the solar and battery revolution. Solar is the star of the energy transition: it took 25 years for global solar capacity to reach 1,000 GW; yet in the past two years alone, another 1,000 GW was added globally.⁹ This largely reflects dramatic cost reductions, with the levelised cost of electricity of solar PV falling over 90% since 2010 [Exhibit 2].¹⁰

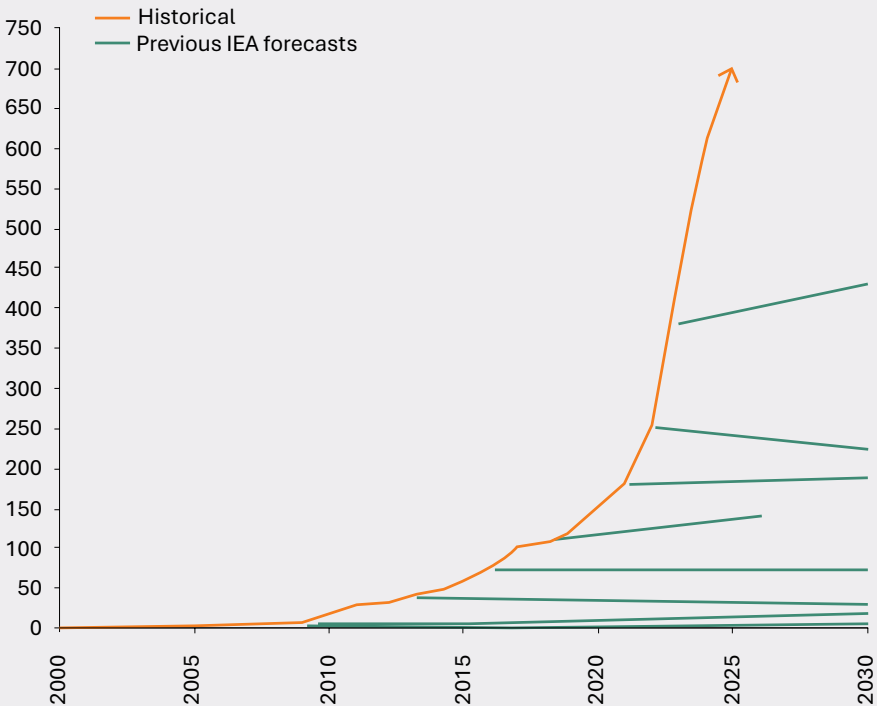
The levelised cost of solar (~35/MWh) is now the cheapest new power source in two-thirds of global markets.¹¹ In countries like India, the cost of solar PV could be as low as \$20/MWh by 2035.¹² This means that by 2050, under a net-zero pathway, renewables are expected to account for 70-90% of electricity generation globally, up from 15% today, and almost two-thirds of this will be solar.¹³

As a low-cost and distributed energy resource, rooftop solar is transforming access to electricity in remote areas with weak and unreliable electricity grids. Solar deployed in mini-grid or standalone home systems could enable access to electricity for 400 million people by 2040, accounting for 55% of new connections.¹⁴ And as natural energy resources, a power system built on wind and solar, manufactured and installed with diversified supply chains, is critical to achieving energy security and independence.

Exhibit - 2
WE ARE IN A ONCE-IN-A-GENERATION ENERGY TRANSITION

The pace of solar installations consistently outpaces expectations

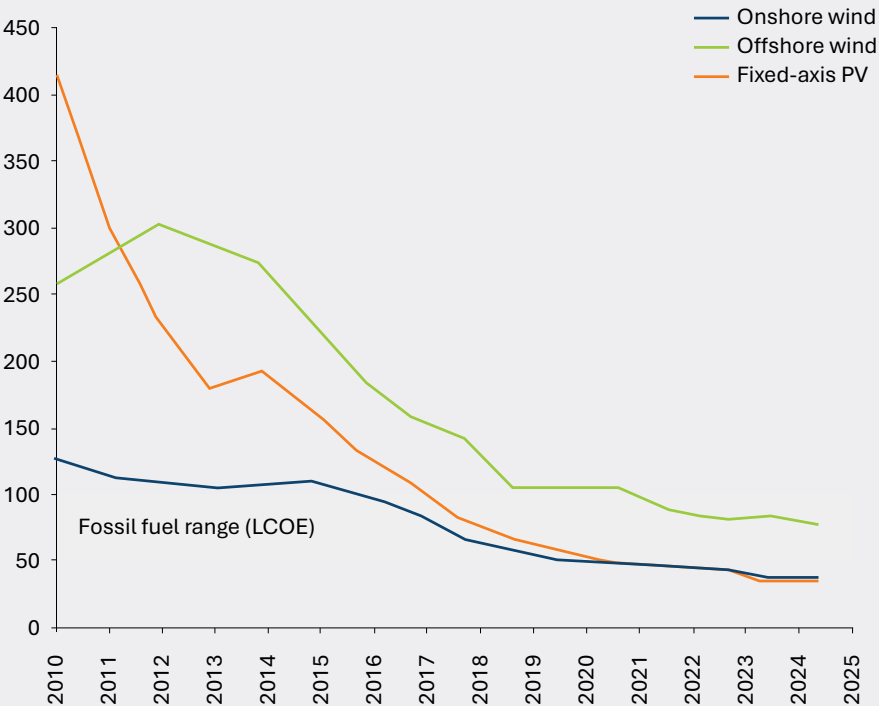
Annual solar PV installations compared to IEA forecasts
GW



Sources: Energy Transitions Commission (2025), Power Systems Transformations.

Solar is now the cheapest way to produce a kwh of electricity

Levelised cost of electricity (LCOE) generation for selected technologies
\$ per MWh (real 2024)

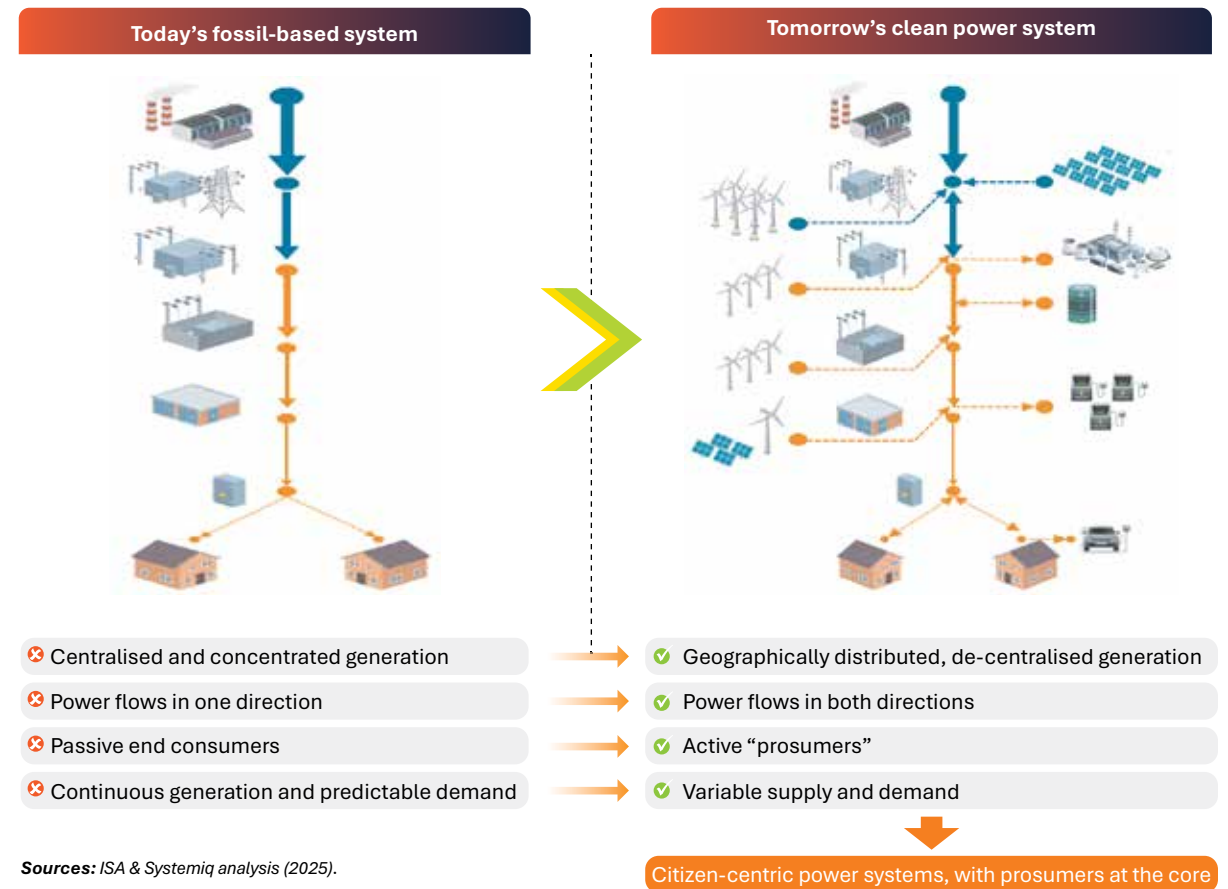


Electricity Grids are the Binding Constraint to the Solar Revolution

Electricity grids, however, are the binding constraint to realising this potential. In today's fossil-dominated systems, grids are linear, top-down structures that deliver electrons from centralised and dispatchable sources of electricity generation to passive consumers. They need to transition to dynamic, interactive networks that connect distributed generation and storage, new sources of demand and "prosumers", and deliver energy services – placing citizen participation at their core [Exhibit 3].

Exhibit - 3

GRIDS WILL HAVE TO PLAY AN INCREASINGLY CENTRAL ROLE WITHIN CLEAN POWER SYSTEMS



Specifically, electricity grids need to adapt to face 4 key challenges within clean power systems:

1. **They need to handle a significant increase in electricity demand:** Global electricity consumption is set to grow from ~26,000 TWh to ~50,000 TWh by 2050 under a current policies scenario, or potentially up to 75,000 TWh under more ambitious, net-zero scenarios.¹⁵ Demand in middle- and low-income countries is set to grow at three times the rate of growth expected in high-income countries. The rate of growth will vary significantly across middle- and low-income countries, with demand expected to double in China, quadruple in India, and grow 15-fold in Sub-Saharan Africa.¹⁶

Key sources of new electricity include:

01

Air conditioning (AC), where rising incomes will see 2.4 billion people living in hot climates gain access to AC by 2050.

02

Electric vehicles, with the global stock of electric 2/3 wheelers expected to reach 360 million by 2035, or over one-third of the total global fleet.¹⁸

03

Heat pumps, where 75-80% of global heating demand could be electrified by 2050, up from ~15% today.¹⁹

04

Other building electricity demand, with higher incomes and improved access to electricity in middle- and low-income countries potentially doubling power consumption for appliances and lighting, and increasing demand for electricity-powered cooking 7-fold by 2050.²⁰

05

Data centres, with global electricity consumption projected to double to ~950 TWh by 2030; middle- and low-income countries are expected to account for almost 45% of that demand.²⁰

Meeting this significant increase in demand sustainably is only possible with renewable generation. Wind and solar is able to convert 100% of renewable energy into electricity, while fossil fuels only convert 30-45% of their energy into electricity.²¹ Similarly, clean energy technologies are multiple times more efficient than their fossil-fuel counterparts: heat pumps are 3-4 times more efficient than a gas boiler, while EVs are around 2-3 times more efficient than internal combustion engines. Renewables are key to unlocking economic growth and prosperity.

As a result, the size of electricity grids must increase 2-3 times by 2050, from ~45 million km today, to 90-120 million km [Exhibit 4].²² Currently, grid expansion is not keeping pace with rising demand and the rollout of renewables, leading to grid congestion, curtailment, and connection queues and limiting emission reductions.

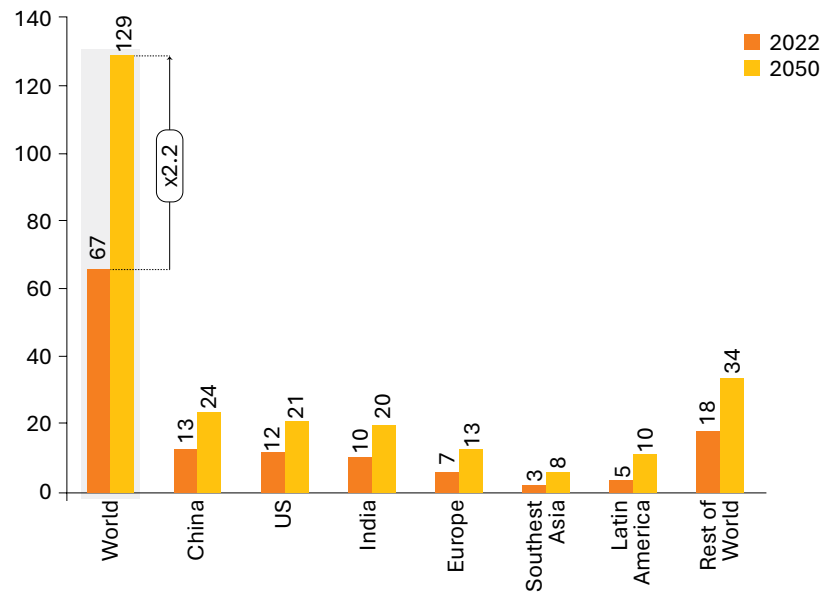
Understanding the pace and nature of electricity demand growth through better data is critical to grid investment planning, while capturing opportunities for demand efficiency can reduce investment in expanding the system.

Exhibit - 4

THE SIZE OF ELECTRICITY GRIDS NEED TO INCREASE 1.5-2 TIMES GLOBALLY

Estimated length of required T&D networks

Million km



Source: Energy Transitions Commission (2025), Power Systems Transformations.

Note: ETC's Accelerated but Clearly Feasible scenario (ACF), which models technological change that is clearly technically and economically feasible, but in some sectors will require more forceful policy support than currently in place.

2. They need to manage increasingly distributed renewable generation.

Unlike centralised and large-scale fossil fuel generation plants, wind and solar generation are distributed energy resources (DERs). Distributed solar will account for ~40-45% of PV expansion to 2030 globally; and this share is likely to be even higher in middle- and low-income countries, where mini-grids and standalone solar systems are a key solution to unreliable electricity grids.²³

DERs have the advantage of bringing generation closer to load centers, reducing transmission costs and losses; however, managing widespread, small-scale, and variable generation brings operational and regulatory challenges. In particular, the potential need for bi-directional energy flows from rooftop solar, batteries, and “vehicle-to-grid” charging.

In addition, unlike fossil-fuel plants with large rotating turbines, renewable generators provide little or no physical inertia. As renewables scale, system inertia falls and frequency stability must be maintained through dedicated balancing and control services.²⁴

Managing geographically distributed and bi-directional energy assets requires clear visibility of all sources of generation and demand, including real-time operational, frequency and inertia data.

- 3. They need to manage variability of demand and supply:** The core challenge facing renewable-dominated power systems is how to match fluctuating supply and demand across all time scales – from seconds, to seasons, and unpredictable shocks. Systems with 70-80% wind and solar penetration can reliably deliver electricity at cost levels comparable to today, provided that grids are underpinned by: a) significant long-distance transmission to pool variable output; b) storage technologies; c) demand-side flexibility; and d) smart digital management of network assets.²⁵

Managing these complex and interconnected assets, and delivering micro- and time-sensitive transactions, requires a strong digital underpinning.

Specifically, electricity grids need to adapt to face 4 key challenges within clean power systems:

4. **They need to be more resilient to increasing risks and disruption:** As the clean energy transition accelerates and electricity demand grows, electricity grids face a growing spectrum of threats:

01

Cyber security: the risk of cyber-attacks increases as more devices and assets get connected, giving attackers more entry points and more controls to cause harm.

02

Climate change: warming climates and unpredictable, extreme weather will create unprecedented physical risks to grid infrastructure, operational risks (e.g., extreme heat reduces transmission capacity due to line sag and risk of transformers overheating; droughts reduce the output of hydropower), and can significantly increase peak electricity demand (e.g., due to greater AC use).

03

Geopolitical risks: as has been demonstrated with recent conflicts, power systems can be a key target of sabotage, damage, and cyberattacks.

04

Supply chain risks: the ability to procure and maintain the physical materials and equipment needed within a power system is increasingly limited by risks, including shortages and lead times for key equipment (e.g., transformers), critical material shortages (e.g., copper and tantalum) and concentration of materials and manufacturing in specific countries / regions, and a lack of standardisation of components.

Being able to better prevent and predict these risks, as well as rapidly restore service, will be critical.

These issues pertain to countries across the world as they transition to clean power systems. However, the extent to which power systems are equipped to address these challenges varies significantly across countries. In many middle- and low-income countries, power systems face additional bottlenecks and challenges [Box A].²⁶

The next chapter discusses how digitalisation and artificial intelligence (AI) can help solve the four challenges facing the energy transition, while at the same time delivering accessible, affordable, reliable, and secure electricity.

Box A

Additional power sector challenges in middle-and low-income countries

The state of power systems today in many middle-and low-income countries are ill-equipped for this transition, although issues vary considerably across countries:

- Many grids are unreliable and underdeveloped, leading to outages which have a significant social and economic cost; the IEA estimates that outages could cost middle- and low-income countries \$1.3 trillion between now and 2030 without sufficient investment in developing grids.²⁷ As a result, many households and businesses rely on expensive and emissions-intensive back-up diesel and gasoline generators. Installed back-up capacity in middle- and low-income countries (excluding China) is estimated at 350-500 GW, costing ~60 billion a year to run, and contributing to more than 100 MtCO₂ a year.²⁸
- Many grids are inefficient, with huge losses: average transmission and distribution (T&D) losses in middle- and low-income countries are almost 3 times higher than those in high-income countries, at ~15% of total output compared to 5%. In Sub-Saharan Africa, losses can reach 25%.²⁹ This reflects poor maintenance, poor network sizing, and a lack of digitalisation. Non-technical losses (e.g., those due to faulty or bypassed meters and illegal connections) can also be significant.
- The power sector in middle- and low-income countries faces financial and regulatory challenges. It is estimated that only 40% of utilities can cover their operating and debt service costs, with challenges relating to the lack of end user's ability to pay, high costs but low tariffs, system losses, inefficient payment collection, and poor planning.³⁰ In addition, regulators are typically under-resourced, with weak enforcement capacity, and often lack independence. As a result, energy markets are less competitive, with state-owned utilities dominating in many countries.

Opportunity: Digitally- and AI-Enabled Power Systems will Drive Prosperity, Resilience, and Decarbonisation

AI-Enabled Power Systems Demonstrate 6 Technical Capabilities

Digitalisation and AI have the power to accelerate the energy transition and at the same time, make energy more affordable, accessible, reliable and secure for all – unlocking inclusive growth for people and a sustainable future for the planet.

A digitally- and AI-enabled power system (henceforth referred to as an “AI-enabled power system”) is built on full end-to-end visibility of the entire network, with data and analytics on all connected demand, supply and storage assets across the whole value chain.

While the digitalisation of the power system has been an ambition and increasing reality across the world for decades, the potential for AI to transform power systems remains a largely untapped opportunity. In recent years, AI has rapidly transitioned from a technological concept to a trillion-dollar industry. While the potential opportunities for it to transform the power sector are clear, there are huge uncertainties on how quickly AI will be adopted, its key capabilities, and the extent to which it will transform productivity and efficiency. AI also has huge implications for the size and nature of required power demand and supply, but this issue is not explored in detail in this report.³¹

To date, use of AI within the energy sector has largely focused on how to optimise the exploration and extraction of oil and gas.³² However, as this report explores, AI is not yet being used to its full potential to fundamentally transform societies by lowering emissions and electricity costs, and making power more accessible and reliable.



An AI-enabled power system has 6 technical capabilities.³³

1.



Monitor: with a greater understanding of the performance, operation and health of assets within the network at a given point on time, AI-enabled power systems can enable predictive maintenance, automation, and intelligent decisions.

2.



Forecast: enhanced by AI's ability to learn relationships between variables, AI-enabled power systems can better analyse and predict changes in demand, supply and the weather. This enables inherently better system planning and operation.

3.



Plan: with greater visibility of all assets within a power system comes a greater ability to model, simulate and optimise the siting and operation of new and existing assets.

4.



Optimise: with real-time information and better forecasting, digital platforms are able to optimise the operation of power systems, including smart management of power flow, voltage, and load across lines, as well as making best use of distributed energy assets and storage.

5.



Flex: a better understanding of consumption patterns and how this aligns to renewable generation enables AI-enabled power systems to identify opportunities for demand-side flexibility, which can then be automated through AI-enabled building management systems and dynamic pricing.

6.



Build trust & transparency: digital solutions are also required to ensure that data and, crucially, data-driven decisions are trusted and transparent, driving innovation, enabling the participation of “prosumers” and empowering citizens to productively engage with power systems. These include peer-to-peer trading and open data platforms, traceability tools for renewable energy certificates, and data visualisation platforms for customers.

Exhibit - 5
DIGITAL AND AI-ENABLED POWER SYSTEMS: 6 TECHNICAL CAPABILITIES

Monitor	Forecast	Plan	Optimise	Flex	Build trust and transparency
- Real time monitoring and control - Predictive and preventative maintenance - Better understanding of electricity demand profiles 	- Probabilistic risk assessment - Early warning systems and simulations - Demand and supply predictions 	- Spatial planning and siting decisions for generation, storage, DERs - Strategic grid expansion planning - Identify priority parts of the grid for upgrade 	- Smart balancing of demand and supply - Support complex grid management - Dynamic voltage control - Better utilise existing capacity with the grid 	- Unlock opportunities for demand- side flexibility - Optimise combination of renewables + storage - End-user automation 	- Guarantees of origin - Data visualisation and analytics - Interoperability - Data exchange 

Source: Source: Systemiq analysis (2025). Technical capabilities draw from AI value clusters as identified in IRENA (2025), Digitalisation and AI for Power System Transformation.

Digital and AI Solutions can Unleash the Renewable Energy Revolution

These capabilities enable AI-enabled power systems to support fundamentally higher shares of renewables on the grid, by solving the 4 key challenges facing clean power systems outlined in Chapter 1:

- 01 | **They can better manage demand growth and electrification** digitalisation of energy assets enables a better understanding of new demand profiles, which supports grid expansion planning. Digital and AI solutions, such as digital twins, can identify and reduce inefficiencies (e.g., lower losses), while technologies such as dynamic line ratings and power flow control can significantly increase the transmission capacity of existing lines and reduce the overall investment need.
- 02 | **They can support complex management of distributed resources** with a greater understanding of all energy assets, AI-enabled power systems can optimise the transport and utilisation of electricity across the whole network, making better use of local assets (e.g., rooftop solar), reducing grid congestion, peak demand, and the cost of transmission per unit of demand.
- 03 | **They can better manage variable supply and demand** with accurate forecasting and enhanced communication between grid operators, generators and utilities, AI-enabled power systems can optimise the real-time use of renewable generation and better utilise storage, reducing curtailment and the need for dispatchable fossil generation. They can also unlock demand-side flexibility by enabling time-of-use-pricing and the use of smart EV charging and appliances
- 04 | **They can improve the resilience of grids through advanced data and analytics**, which enables a) real time monitoring of weather conditions and grid stability, b) early warning systems, c) predictive maintenance that can reduce the risk of faults and outages and extend the lifetime of grid assets.

Developing AI-Enabled Power Systems Requires a Citizen-Centric Approach

At the centre of a clean AI-enabled power system lies the prosumer: households and businesses are no longer passive consumers of electrons, but are active customers and producers of electricity, able to generate supply, store surplus power, and flex their demand [Exhibit 6 and Box B]. The development of AI-enabled power systems must take a citizen-centric approach, focusing on:

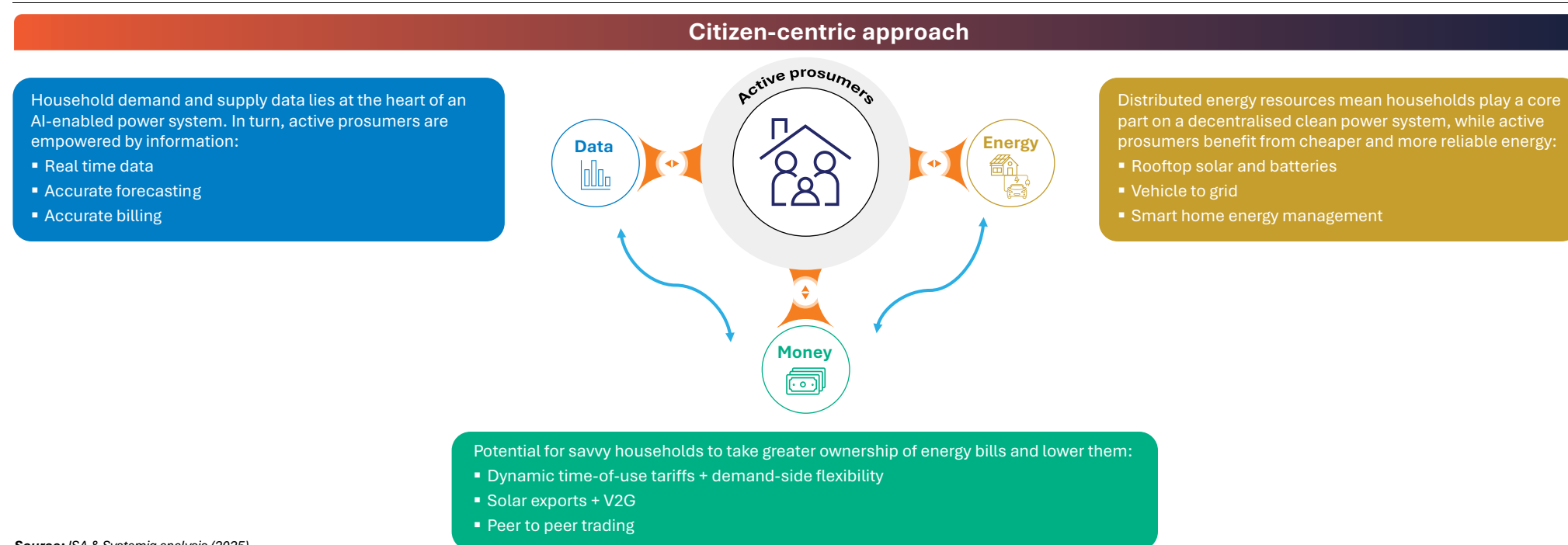
- Developing the basic infrastructure and data sharing frameworks that enable household decision-making (e.g., the fundamental hardware and software which enables bi-directional power flows). It is also crucial that utilities develop trust with households and businesses to:
 - Share the crucial data that digital and AI solutions rely on to make informed and accurate decisions.

- Allow utilities and grid operators to make decisions on how to optimise individual energy use (e.g., when to charge EVs and heat homes within defined preferences).
- Building the core digital literacy skills and citizen understanding of clean power systems (e.g., being able to interpret smart meter data) to empower individuals to take control of their own power consumption and production.
- Ensuring that individuals can share in the rewards of an AI-enabled clean power system by offering dynamic tariffs based on real-time prices that create incentives to shift demand and invest in rooftop solar, batteries and other distributed energy resources.

In doing so, policymakers and regulators can deliver transformative economic and social outcomes to citizens [Box C].

Exhibit - 6

CONSUMERS STAND AT THE HEART OF DIGITALLY AND AI-ENABLED POWER SYSTEMS



Source: ISA & Systemiq analysis (2025)

Box B

AI-enabled power systems from a prosumer perspective: Indian household, 2040

In 2040, a household in India has just installed solar panels on their roof, along with a battery. They have moved to a dynamic tariff, which offers real-time price incentives to shift power demand over the course of a day. They don't need to think about this though, as their smart home energy management system optimises their demand and electricity generation for them, within the bounds of the preferences set by the household.

For the household, the combination of rooftop solar, a battery, an EV, a smart home energy system and a dynamic tariff mean that in a typical day:

- Their solar panel generates the majority of their electricity needs, although not all of this generation occurs when they need it.
- During a typical day, when they are at work but the sun is at its strongest, their battery stores excess generation which is used to power their AC or charge their EV during the night.
- When their battery is at capacity, any further excess generation can be sold back to the grid, or to their neighbours. This is all automated by their peer-to-peer trading account, which works in combination with their dynamic tariff to optimise the most profitable times (i.e. when the grid is most constrained) to export excess generation.
- They aren't aware of this, but their utility company will aggregate all of the excess solar generation in a local area via prosumer aggregation models to effectively manage distributed energy resources in a single, coordinated portfolio. This helps to manage system peak demand and minimise the use of dispatchable fossil generation.
- The household has not only minimised their energy bills by reducing how much electricity they have to draw from the grid, but has also earned revenue by making their excess rooftop solar available to the wider power system.

Box C

The Sustainable AI Coalition

The Coalition for Sustainable AI is an initiative coordinated by France, the UN Environment Programme and the International Telecommunication Union, with the support of several international organizations and countries, including India as a founding member.³⁴ Launched at the Paris AI Action Summit, in February 2025, it aims at building a global community of stakeholders willing to contribute to initiatives for aligning AI development with global sustainability goals and fostering responsible AI that supports the environmental policies. The Sustainable AI Coalition has over 200 members as of January 2026.

To ensure AI contributes positively to environmental and climate objectives and can be deployed at scale, the Sustainable AI Coalition:

- Encourages AI Initiatives for the Planet: members commend inclusive and collaborative efforts to harness AI for the benefit of the local and global environment.
- Wishes to continue the work for an AI respectful of our Planetary Boundaries. To this end, members of the Coalition understand the need to focus on the following:
 - Standardised methods and metrics for measuring AI's environmental impacts.
 - Comprehensive Life Cycle Analysis of AI systems through multi-criteria analysis.
 - Frameworks for Reporting and Disclosure on the environmental impact of AI products and services.
 - Prioritisation of Research on Sustainable AI.
 - Efforts that ensure AI infrastructure and software aligned with global environmental commitments.
- Supports Collaborative Approaches: members of the Coalition recognise the essential role of multi-stakeholder collaboration—bringing together governments, academia, civil society, and the private sector.

Actions of the Sustainable AI Coalition focus on:

- Building a community of like-minded private and public organisations;
- Enhancing sustainable ai visibility with presence in all major international conferences;
- Sharing & scaling of initiatives and best practices through the initiatives hub; and
- Fostering & leading targeted initiatives and workstreams.

AI-Enabled Power Systems can Support Economic and Social Transformations

Digital and AI technologies not only solve the key challenges facing clean power systems, but also deliver tangible benefits to the power sector and society through two main sets of outcomes:

Efficient and optimised operation of the power system: as explored further in Chapter 3, AI-enabled power systems reduce losses, outages, and curtailment, and can deliver a fundamentally better use of renewable assets and storage. This lowers the total cost of building a clean power system.

Accelerated deployment of renewables: by optimising the integration of renewables, as well as lowering total system costs, AI-enabled power systems will support a faster deployment of wind and solar. This lowers the emissions emitted during the transition.

This has the potential to transform societies in 3 key ways: economic transformation, social inclusion, energy security.

Economic transformation

The overarching benefit of AI-enabled power systems is that they can reduce the required investments in renewables, grids, and storage by optimising planning and operations. And by enabling greater access to electricity and improving the reliability of grids, they can boost economic growth.

Investment

Building clean power systems requires a significant, but largely one-off, capital investment outlay. On average between now and 2050, around \$2 trillion a year of investment is needed globally:³⁵

- \$ 1100 bn of investment in renewable generation
- \$ 900 bn of investment in expanding and modernising grids
- \$ 120 bn of investment in storage.

These figures are not intended as precise forecasts, but rather as order-of-magnitude estimates designed to illustrate the scale of the investment challenge.

While on an aggregate global level, this investment accounts for a manageable 1.5-2% of global GDP, financing this investment in specific countries is a critical challenge – in particular, for middle- and low-income countries due to high cost of capital.³⁶ At a global level, investment in renewables is on track (although at a regional level, many countries are far behind targets), while for grids, even at a global level, investment is far off-track (\$400 bn was invested in 2025, compared to targets of \$580 bn a year).³⁷

Opportunities to reduce total system investment requirements are therefore important. AI-enabled power systems can deliver this through several levers:³⁸

- Increasing transmission capacity within the existing grid to support higher loads and avoiding the need for additional grid build out.³⁹
- Optimising demand and supply at a given point in time, reducing generation and storage requirements.⁴⁰
- Reducing technical losses across the system and making better use of existing renewable generation.
- Increasing the load factor of renewables due to better forecasting, predictive maintenance, and optimising their operation (e.g., angle of solar panels). This avoids the need for as much deployment of wind and solar.⁴¹

- Lowering demand for electricity – especially lowering peak electricity demand due to demand response – therefore lowering the required size of clean power systems.⁴²
- Increasing the lifetime of assets through better maintenance and therefore avoiding / deferring investment.⁴³

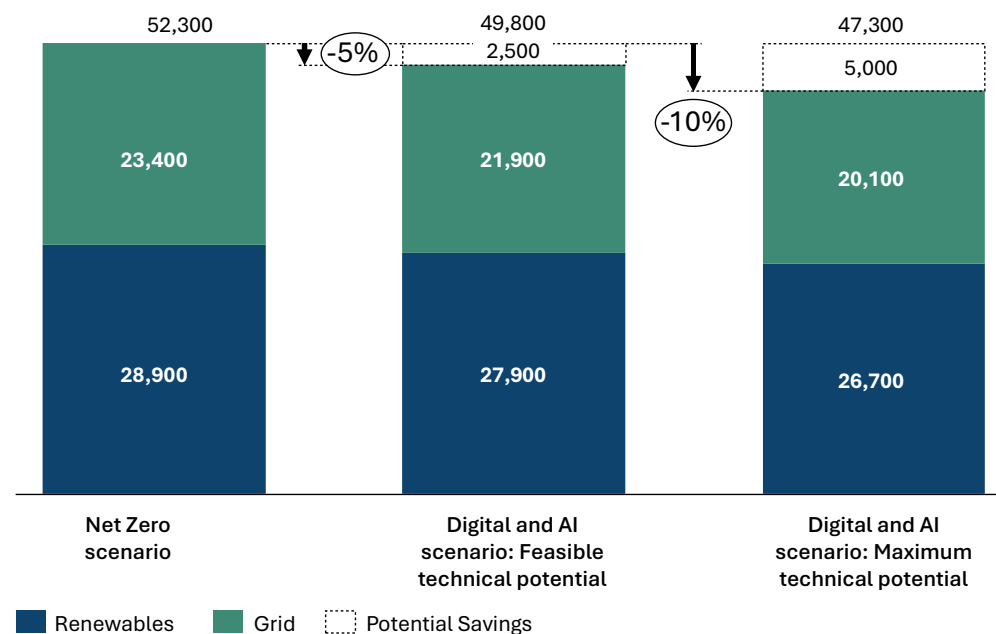
In total over the next 25 years, to build a net-zero aligned clean power system, high-level estimates suggest that the world needs to invest around \$50 trillion, cumulatively, in renewables and electricity grids.⁴⁴ By building AI-enabled power systems, the world could reduce this total net-zero investment requirement [Exhibit 7 and Annex 3]:

Exhibit - 7

THE MAXIMUM POTENTIAL BENEFIT OF A GLOBAL AI-ENABLED POWER SYSTEM WOULD BE TO REDUCE INVESTMENT IN A CLEAN POWER SYSTEM BY \$2.5 – 5 TRILLION

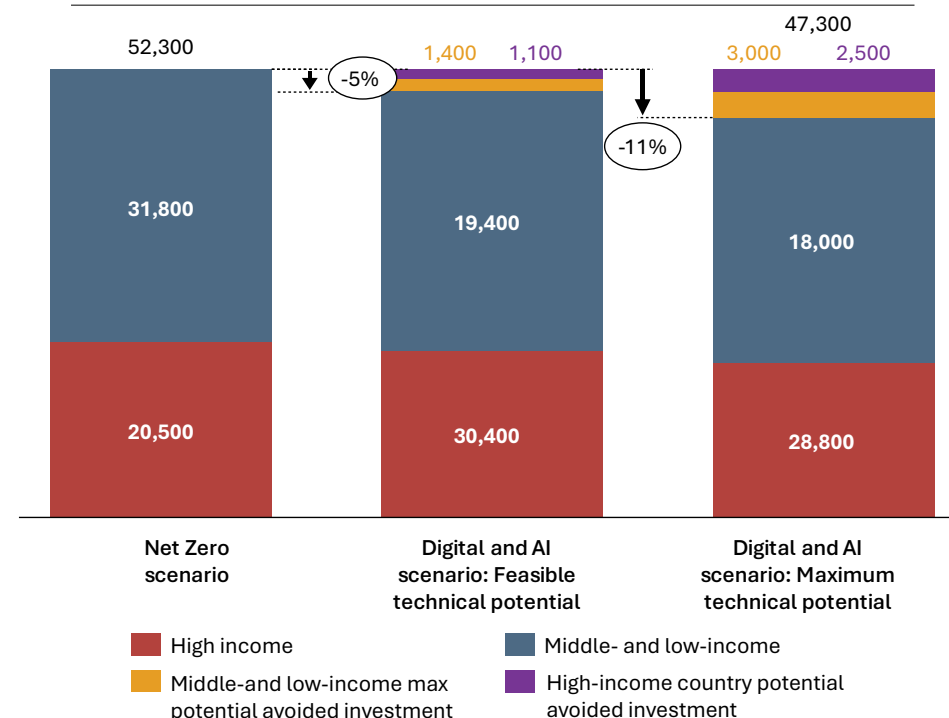
Total investment in to build a net-zero clean power system could in theory be reduced by 5-10%

Cumulative investment in renewables and grids and possible savings, global (2025 – 2050)
Trillion USD



~60% of the maximum possible prize could accrue to middle- and low-income countries

Cumulative investment in renewables and grids and possible savings, by country archetype (2025 – 2050) Trillion USD



Sources: ISA & Systemiq analysis (2025). Net Zero scenario estimates from IEA (2023), *Electricity Grids and Secure Energy Transitions*; IEA (2021), *Net Zero by 2050 – A Roadmap for the Global Energy Sector*.

Notes: The maximum potential benefit assumes that digital and AI technologies achieve their technical potential (feasible or maximum) and a reasonable phase in between now and 2050.

- The maximum potential benefit, if digital and AI technologies can realise their full technical potential and assuming a reasonable phase in over the next 25 years, is to reduce investment in renewables and the grid by \$2.5–5 trillion cumulatively, with almost 60% of this potential prize accruing to middle- and low-income countries.⁴⁵ These maximum possible savings would effectively knock-off 1-2 years of required annual investment in a net-zero power system. This means that \$450 bn of climate finance requirements in the power sector between now and 2035 could in theory be repurposed to support decarbonisation efforts in other sectors.⁴⁶
- It is unlikely that the world will be able to fully capture this potential benefit [see Chapter 4 for a detailed discussion of the barriers to deploying digital and AI technologies]. However, even if the world is able to capture 30-50% of this total prize, this would still reduce investment requirements by \$1–2.5 trillion – a significant outcome. The savings realised will ultimately depends on willingness and ambition of stakeholders.
- It is important to note that the maximum potential impact is likely to be somewhat offset by behavioural responses to a more efficient and/or lower-cost power system.⁴⁷ These effects mean that AI efficiency gains rarely translate 1:1 into demand reduction. However, there is significant uncertainty regarding the extent of a possible rebound effect:⁴⁸
 - **Direct rebound effect:** As power systems become more efficient and potentially cheaper (see Affordability section below), consumers demand more electricity. For households living in energy poverty, this delivers positive impacts for social inclusion and wellbeing. However, for higher-income households, this could lead to adverse behavioural responses (e.g., excessive running of AC).
 - **Indirect rebound effect:** As energy costs fall, savings are spent on other goods and services that require more power (e.g., households purchasing more appliances).
 - **Induction effects:** Where AI creates entirely new sources of electricity demand (e.g., always-on AI assistants, autonomous systems, generative AI).

Economic growth

As discussed in Chapter 1, accessible, affordable and reliable energy is central to social and economic development.⁴⁹ AI-enabled power systems have the potential to:

- Make electricity more affordable (see next section on social inclusion).
- Make electricity more accessible, due to a) the potential for lower consumer electricity prices, and b) optimising the use of solar home systems, especially in rural and remote areas.
- Make electricity more reliable by lowering outages and improving maintenance.

These outcomes can transform productivity and welfare, while avoiding costs of expensive back-up generators. With electricity access in high-income countries near universal and losses/outages already at very low levels, the biggest economic gains will be experienced by middle- and low-income countries.

Relative to a business-as-usual scenario, deploying AI-enabled power systems have the potential to increase GDP in middle- and low-income countries by 0.05-01 pp a year, on average, or \$1.4-1.8 trillion between now and 2050.⁵⁰

Social inclusion

An AI-enabled power system that places citizens and prosumers at the centre will deliver improved social outcomes if they can translate system-level improvements into everyday benefits for society. These outcomes range from improving disposable income to improving gender and rural equality; three of the most important, that this section discusses, are the opportunities for lower bills, lower emissions, and improved health and wellbeing.

Electricity affordability for households

While the exact impact of the energy transition on the price of electricity is uncertain, the following is clear:

01

Renewables are the cheapest source of new electricity generation in almost all markets globally.⁵¹

02

A highly electrified and renewables-based energy system is more efficient and cheaper to run compared to maintaining today's fossil-dominated system.⁵²

03

During the transition, near-term electricity costs are likely to be slightly higher due to the cost of significant investment in renewables and expanding and modernising the grid.⁵³

04

However, over the long-term, electricity prices in most regions are expected to be lower, and significantly more stable, in the 2040s under clean energy transition pathways, compared to maintaining today's system.⁵⁴ This reflects further reductions in the cost of renewables, a lower dependence on volatile fossil fuels, and fundamentally greater efficiency.

05

Realising the potential for lower long-term electricity prices relies on governments and regulators implementing appropriate power market design (e.g., ensuring market transparency and non-discrimination so that non-conventional assets such as energy storage and demand response can participate fully and fairly in energy markets).

AI-enabled power systems, have the potential to intensify or accelerate the downwards pressure on electricity prices, with key levers including:

- Lowering total investment requirements in renewables and grids.
- Maximising the use of low-cost renewables, especially at peak times.
- Greater efficiency and reliability of the power system (e.g., better detection of losses, predictive maintenance and lower outages) which reduces system operating costs.
- Exploiting opportunities for demand-side flexibility which, when combined with time-of-use pricing, enable consumers to realise lower energy bills.

It is important to note that large-scale deployment of AI across the economy also has the potential to exert upwards pressure on electricity prices due to the significant increase in power demand to run data centres [Box D]. While the exact increase is highly uncertain and will vary significantly across countries, the IEA estimates that global electricity requirements for data centres could increase from 1-2% of global electricity consumption today, to 3-4% by 2030, more than doubling to 950 TWh.⁵⁵ However, it is likely that many policymakers and regulators will act to moderate this increase and its implications for power systems, for example, through regulations requiring data centres to deploy on-site renewable generation and storage.⁵⁶

To conclude, the net impact of AI on electricity prices will be to create opportunities for lower consumer prices, but the average impact on aggregate is unclear.

Box D

Sustainability implications of the AI revolution: the central role of clean-powered data centres

It is crucial that the AI revolution occurs in a sustainable, efficient and resilient way; clean power is the critical enabler of that. There are currently several challenges facing the sustainable development of the AI revolution:

- AI data centres have a higher power density due to high-performance servers. Power demand is considered manageable at an aggregate level, with data centres expected to account for around 3% of global electricity demand in 2030 under a business-as-usual scenario⁵⁷
- However, data centres often cluster, with significant impact on local power demand. For example, data centres already account for up to 25% of local electricity demand in Virginia and Ireland.⁵⁸
- As part of corporate sustainability and net-zero targets, many technology companies have set commitments to use clean power in their data centres. However, grid connection delays have led some to explore gas turbines to expediate the deployment of data centers.
- Water consumption is also a growing constraint. Large data centres can consume up to 5 million gallons per day, equivalent to a town populated by 10,000 – 50,000 people.⁵⁹ In water-scarce locations, this can create significant challenges for the local population.

These impacts are, however, manageable – and addressing them is increasingly becoming part of the sector’s “license to operate”. Key actions to ensure a sustainable AI and data centre revolution include:⁶⁰

- **Accelerate the clean power revolution:** Low cost, clean, and reliable electricity is the critical enabler of sustainable AI. It keeps energy intensive data centres affordable to run and reduces exposure to volatile fossil prices. This urgent and large-scale demand for renewables and batteries in turn will accelerate further falls in their capex cost and enable faster deployment across the world.
- **Install on-site generation and storage:** On-site solar or wind, plus behind-the-meter energy storage can help reduce constraints on the grid, and expediate connection times, while providing low-cost power for data centres. Building flexible data centres also reduces potential regulatory risks in the future, as hotspots, such as Ireland and New Jersey, push to require AI data centres to either install on-site generation and storage or use power generated from clean sources.^{61, 62}
- **Implement water-efficient technologies:** Improved cooling solutions, heat reuse, and data-centre infrastructure management can materially reduce water intensity, enabling them to secure permits and local acceptance.

Health and wellbeing

AI-enabled power systems can improve public health and wellbeing by reducing potential emissions emitted during the decarbonisation of power systems:

- By supporting a faster deployment of renewables onto the grid, AI-enabled power systems can reduce potential cumulative emissions resulting from fossil fuel electricity generation during the energy transition. And as long as the increase in power demand resulting from AI is met by renewable electricity (as per the corporate clean power targets of most leading data centers), this increase in power demand will not have an undermining impact on emissions.
- By improving the load factor of renewable generation, AI-enabled power systems can further displace fossil fuel electricity generation.⁶³
- By improving the efficiency and reliability of the power system, digital and AI solutions can reduce the need for back-up diesel generation, which emit harmful pollutants (e.g., NO_x , $\text{PM}_{2.5}$, SO_x) and lead to severe respiratory and cardiovascular health risks.⁶⁴

The impact of the accelerated deployment of renewable generation – if the alternative was to produce this electricity via fossil fuels – would be to reduce potential cumulative emissions by 25-50 GtCO₂ – this equates to 70-130% of today's annual emissions.⁶⁵

Jobs

Building and getting the most out of an AI-enabled power system requires: a) the power sector to develop new digital skills, and b) the digital / technology sector to better understand the power sector. In doing so, the development of clean and AI-enabled power systems can create better jobs and stronger employment prospects for the power sector.

There is currently a huge disconnect between the two sectors and skills gaps are one of the most pressing barriers [see Chapter 4].

There are three key issues:

To what extent will digital / AI solutions complement or substitute jobs?

How to upskill workers within the power sector to unleash the potential of an AI-enabled power sector? [Discussed in Chapters 4 and 5]

How to attract workers with digital skills into the power sector? [Discussed in Chapters 4 and 5]

The impact of the accelerated deployment of renewable generation – if the alternative was to produce this electricity via fossil fuels – would be to reduce potential cumulative emissions by 25-50 GtCO₂ – this equates to 70-130% of today's annual emissions.



To what extent will AI solutions complement or substitute jobs?

The power sector is already undergoing a fundamental transformation as the world transitions to clean energy. On an aggregate level, it will create millions of additional jobs, although the impact will be unevenly distributed across countries.⁶⁶ A key element is a move away from highly specialised sector skills (e.g., mining and refining), to broader and cross-cutting skillsets (e.g., electrical and mechanical skills, data literacy, system design), with a greater focus on installation and maintenance. As a result, skills are more transferable across sectors (e.g., construction and manufacturing), creating fundamentally better employment opportunities for workers.⁶⁷

AI can augment this transition. In general, research suggests that generative AI is more likely to transform jobs by automating specific manual tasks and augmenting human work and productivity, as opposed to replacing jobs.⁶⁸ In the power sector, the main impacts are expected to be:

01

Transformation of manual tasks: AI can automate routine control, monitoring and data collection tasks which are typically very manual labour-intensive tasks. This changes the job content for many workers but, with the right training, enables them to engage in other higher-value tasks due to an increase in productivity.

02

Improvement in safety: digital tools can help identify faults, active lines, and prevent reverse flow from distributed generation, while drones can be used to replace dangerous inspection jobs.

03

Augmentation of skilled tasks: AI tools can enhance human abilities in forecasting, optimisation, and system planning. This requires workers to upskill into more analytical and strategic roles.

In all cases, humans still interpret results, make design and investment decisions, and exercise judgement in unfamiliar conditions. The net effect is that AI empowers traditional power jobs by shifting effort towards higher-value tasks: technicians work with safer, more automated field tools; engineers spend more time on optimisation rather than manual calculations; and operators focus on strategic system management rather than routine reporting [Exhibit 8].

At the system level, AI also pulls forward job creation in the manufacturing and installation of renewables by accelerating deployment. Better resource assessment, project design and grid integration planning shorten lead times for solar, wind and storage projects, bringing forward waves of engineering, procurement and construction (EPC) work and manufacturing of equipment.

Exhibit - 8

AI WILL HAVE AN OVERALL POSITIVE EFFECT ON THE POWER SECTOR WORKFORCE, WITH TRAINING TO ENABLE AI TO COMPLEMENT EXISTING JOBS

Energy system job	Traditional skills needed	Skills needed to engage with AI	How AI can complement job (headwinds)	How AI could substitute job (tailwinds)	Net effect on jobs
Renewable energy technicians	- Electrical training - Mechanical assembly - Engineering	- Operation of AI-assisted equipment - Digital literacy + ability to interpret digital analysis	- Reduces errors - Reduces maintenance time and cost; improves safety	Reduced need for maintenance	- Significant need for renewable energy installers - AI enables efficient and safe work
Grid technicians	- Electrical training - Construction capabilities - Technical knowledge of power system equipment and technologies	- Supervision of semi-autonomous machinery - Interpretation and understanding of digital planning & project tools	- Reduces errors - Reduces maintenance time and cost; improves safety - Safer work conditions with early hazard detection	- Autonomous equipment reducing need for routine machinery operation - Drone-based imaging reducing need for manual inspections	- Project labor intensity could drop, but total volume of projects is expected to rise - AI enables safe and efficient work
Grid engineers	- Electrical training - Technical knowledge of power system equipment and technologies - Grid infrastructure design	- Interpretation and understanding of digital planning & project tools, including complex AI-generated diagnostics - Use of digital twin / planning tools	- Reduces errors - Reduces maintenance time and cost; improves safety - Reduces time spent checking and monitoring equipment	- Reduces need for manual inspections - Reduces need for maintenance	Project labour intensity could fall for manual and routine tasks, freeing up time to spend on other value-add tasks
Grid operator	- Deep knowledge of power systems - Technical knowledge of power system equipment and technologies - Fault/outage handling	Ability to interpret the quality and implications of AI-enhanced analytics to make informed critical decisions	- Informed decision-making - Reduces errors and likelihood of outages - Enhanced forecasting and contingency planning	- Some automated management of power system; however, given criticality, it is unlikely that human decision making will ever be fully replaced - Automated reporting	- AI significantly improves and supports human decision-making - Replaces some manual tasks and frees up time for other value-add tasks
System planner	- Deep knowledge of power systems - Network planning - Understanding of demand and supply dynamics	- Data and model literacy for AI tools (e.g., digital twins) - Ability to interpret the quality and implications of AI-enabled analytics	- More accurate forecasts and demand modelling - Enhanced scenario analysis - Quicker modelling	Automation of some analysis and reporting	- AI significantly improves and supports human decision-making - Replaces some manual tasks and frees up time for other value-add tasks

Source: Systemiq analysis (2025)

■ Positive Impact
■ Significantly positive impact

Energy security

There are two key aspects to the relationship between energy security and digitalisation / AI: 1) how AI can help create independent and/or interconnected clean power systems, and 2) how greater digitalisation and connectivity can create new energy security challenges.

Digital and AI solutions can build energy security and independence by:⁶⁹

- Accelerating the integration of low-cost renewables onto the grid and reducing reliance on volatile fossil fuels and energy imports.
- Improving power system resilience by better forecasting, monitoring and management of risks, including enhanced weather forecasting.
- Enhancing reliability through predictive maintenance that reduces outages and downtime.

At the same time, digitalisation and AI will create new energy security challenges in the form of cybersecurity that must be managed. In 2024, a typical utility received over 1,500 cyberattacks, a threefold increase since 2020.⁷⁰ Greater digitalisation and connectivity opens the door to cyberattacks, with risks increasing with the more assets and parts of the system that are connected. There are two sides to the coin:⁷¹

- AI applications can provide real-time threat detection, automated responses to incidents and enhanced phishing defences.
- AI can also be used by cyber attackers to increase the sophistication of attacks, for example, to automate attacks and evade detection.

It is crucial that policymakers, regulators, system operators, and digital architects put in place the right frameworks, procedures and systems to build resilience and control.



Demystifying AI-Enabled Power Systems: Real World Case Studies

Technologies and Use Cases

There is no one-size-fits-all pathway towards an AI-enabled power system, or one technology. Instead, it will involve a suite of interconnected hardware and software deployed across the entire energy value chain [Exhibit 9 and Annex 1].

Digitisation: This is the core first step which underpins an AI-enabled power system. It involves collecting data, storing it, processing it, and transmitting it electronically. Without accurate and real-time data, digital platforms can't operate and AI can't learn. Key technologies include:

- **Sensing technologies to generate raw data:** Household meters, feeder-level meters deployed at transformers within the transmission network, and sensors along lines to collect data on weather, voltage and frequency.
- **Communications technologies to move data reliably:** Fibre, radio and cellular.⁷²

Digitalisation: The next step is to integrate this data within organisations and enable them to make operational decisions based upon it. This involves deploying digital technologies which utilise, analyse and action the data collected. By enabling “data-driven operations”, the system can improve efficiency, streamline operations, and optimise the system. Key technologies include:

- **Data platforms to store and organise data:** Outage management systems (OMS), meter data management systems (MDMS), and GIS spatial data platforms.
- **Analytics technologies to derive insights:** Forecasting software, digital twins, and loss detection systems.
- **Control technologies to take action based on insights:** SCADA systems, home energy management systems, and DER integration platforms.

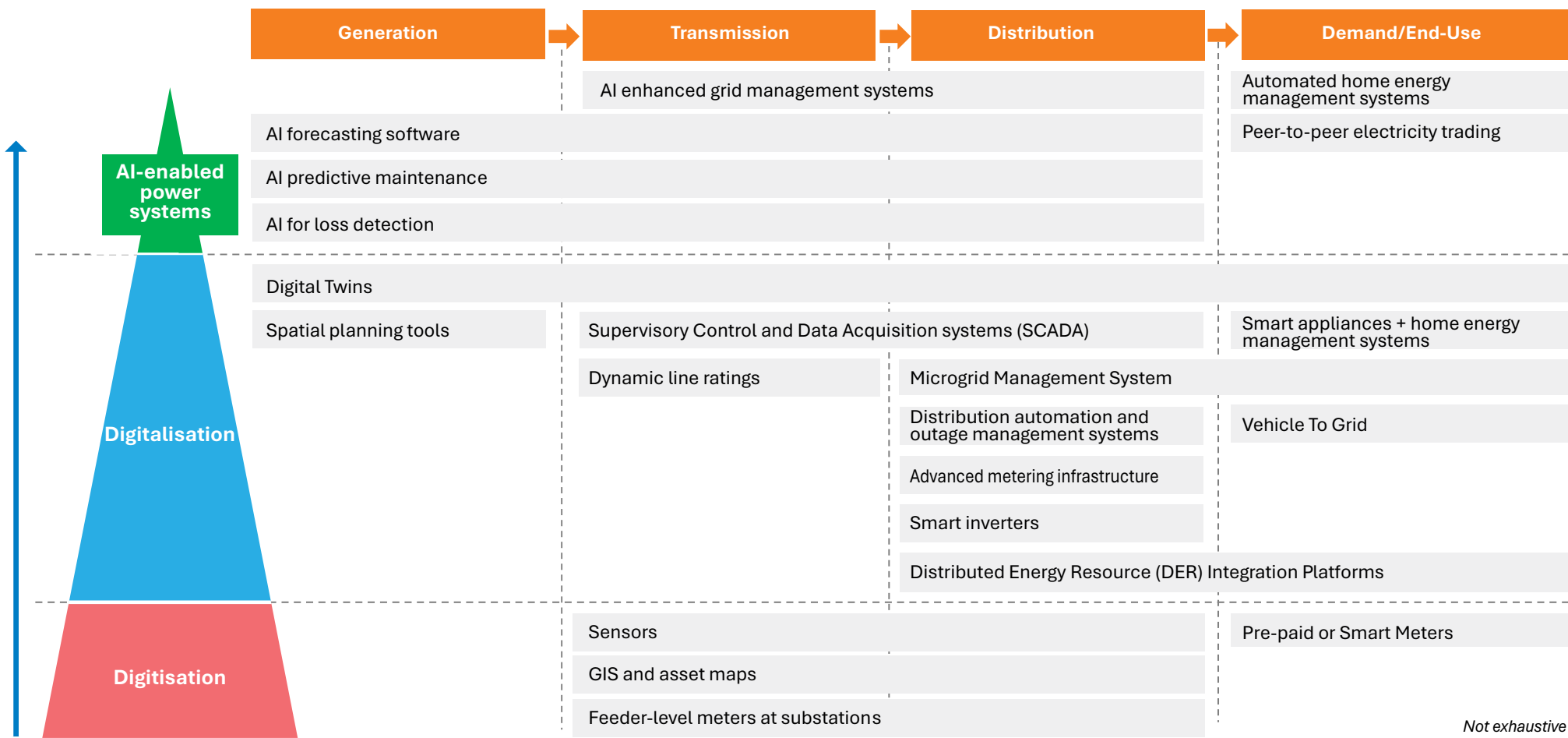
AI-enabled systems: The final step is to deploy AI to amplify the impact of digital technologies. Using machine learning, predictive algorithms and autonomous decision-making, AI can further improve the accuracy, efficiency and effectiveness of data-driven operations. Key AI technologies include:

- **Enhanced analytics:** AI forecasting and AI predictive maintenance.
- **Enhanced control and automation:** Automated grid or energy management systems.
- **Optimisation technologies which enable continuous improvement:** Smart building systems that learn and adjust energy consumption.

Annex 1 provides a glossary and summary of the key technologies within AI-enabled power systems.

Exhibit - 9

AN AI-ENABLED POWER SYSTEM INVOLVES A SUITE OF INTERCONNECTED HARDWARE AND SOFTWARE ACROSS THE ENTIRE ENERGY VALUE CHAIN



Source: ISA & Systemiq analysis (2025)

Not exhaustive

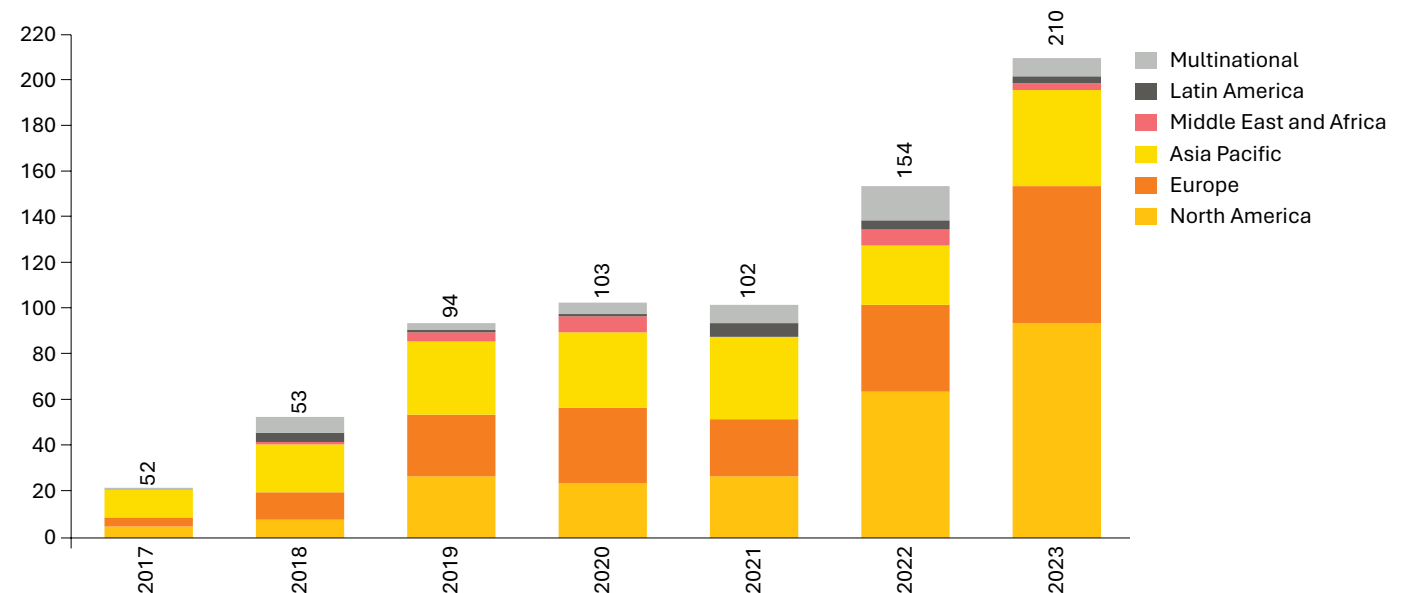
Real World Case Studies and Impact

Digital and AI technologies are already deployed today in various forms across the world, but very few countries have progressed completely up the digital readiness ladder to build fully AI-enabled power systems. While momentum is building, digital projects within the power sector are heavily skewed to high-income countries [Exhibit 10].

Exhibit - 10

DIGITAL PROJECTS IN THE POWER SECTOR ARE NOW INCREASING 30-50% A YEAR; EUROPE AND NORTH AMERICA ACCOUNT FOR 75% OF THESE

Number of digital projects and partnerships in the power sector
Number of activities



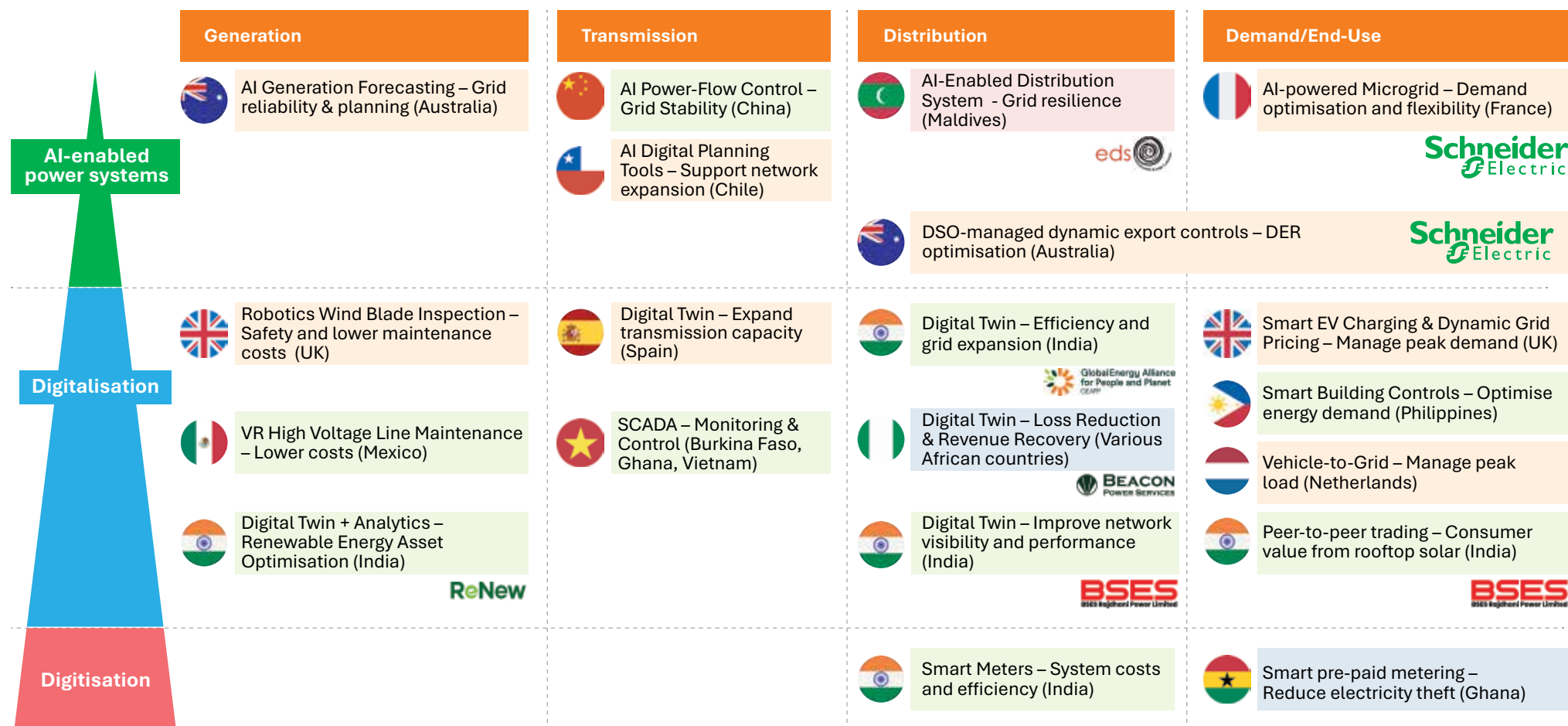
Source: IRENA (2025), *Digitalisation and AI for Power System Transformation*.

Note: counts digital projects and partnerships that are tracked by BNEF.

This report highlights examples of investments and projects which have already been implemented across the world and have delivered measurable value to power systems and societies. Exhibit 11 summarises the case studies which are described in this report – this section presents a selection of these, and the rest can be found in Annex 2. Box E summarises India's Energy Stack.

Exhibit - 11

THERE ARE ALREADY CLEAR USE CASES AND PROGRESS IN CREATING AI-ENABLED POWER SYSTEMS ACROSS THE WORLD



Source: ISA & Systemiq analysis (2025)

Country archetype

High income

Emerging markets

Low income

Small Island Developing States

How Jaipur's Digital Twin is Improving Network Efficiency and Supporting Grid Expansion



Global Energy Alliance
for people and planet



What was the problem?



Jaipur's distribution network consists of millions of physical assets (e.g., poles, transformers) spread across vast rural and urban areas. However, none had a digital identity, and operational data was siloed across ~40 unconnected legacy systems.

Grid operators lacked the information to address key challenges, such as:

- Rural areas with a 20% surplus of solar generation were feeding this back to the grid with huge transmission losses.
- High transformer stress (20,000+ failures/year).
- Permitting of new connections took 6 months due to manual inspections.

Due to the lack of integrated data, engineers could not run simulations, plan DER integration, or proactively manage overloaded assets.

What is the technology?



EDGE Industries, a technology company, created a full digital twin of the distribution network, mapping every asset with precise geolocation and technical parameters and enabling real-time visualisation, load-flow simulations, and AI-driven planning for integrating DERs. The digital twin enables utilities and grid operators to:

- **Improve network modelling:** accurate asset inventories and real-time load analysis supports demand forecasting and network planning, supporting DET integration.
- **Address grid inefficiencies:** load flow analysis and asset monitoring enables a better understanding of technical and non-technical losses and the health of assets.
- **Improve back-office efficiencies:** enables proactive task management and automated workflows, driving greater accountability and integrated operations.

How was it implemented?



- Began as a pilot with JVVNL, Jaipur's distribution company, under GEAPP's Digitalization of Utilities for Energy Transition programme.
- The process of digitising each asset initially began with on-the-ground teams walking along lines and physically mapping them, and progressed to using drones to film lines. Over time, AI will be used to automate the process.
- Asset data (like GIS coordinates, attributes) was consolidated into a single network model, and metering, billing, and sensor data were integrated into one platform.
- The approach became a repeatable playbook, rolled out across Jaipur, and adapted for other DISCOMs such as Delhi and Maharashtra.
- To date, ~80% of Jaipur's assets (~4.5M) have been digitised.

What was the impact?



Economic impacts:

- EDGE projects ~\$125M/year in total gross value, including improved forecasting (~\$27M), AT&C loss reduction (~\$29M), transformer failure avoidance (~\$14M), and DER integration including EV charging and rooftop solar (~\$7M).
- Expected \$32M/year of total savings for utilities.
- Permitting time to connect new industrial loads cut from **8-12 weeks** to less than a week.
- **15-20% reduction** in power procurement when battery energy storage systems are installed, due to optimisation of assets.

Social impacts: around 850 jobs were created through field and drone mapping.

Environmental impacts: 0.4 tCO₂e avoided during early rollout.

How Schneider Electric Used AI to Optimise a Microgrid for a Commercial Office in France



What was the problem?



- A commercial office in France sought to optimise energy costs and carbon performance. However, under fixed electricity tariffs, the grid provided weak signals to realise carbon or cost benefits from load shifting.
- As a result, the behind-the-meter microgrid (PV, battery, and loads) received weak signals for when the grid was using less carbon-intensive power, risking suboptimal battery operation.
- The core challenge was achieving both cost and carbon value simultaneously in a low-carbon grid, while respecting project constraints.

What is the technology?



- Schneider Electric installed an **AI-optimised microgrid control system** to manage the building's PV, battery storage, appliance loads, and time-of-use tariffs. It coordinates HVAC and load scheduling, battery dispatch, and temporal shifting of energy to minimize both cost and carbon.
- The system also uses the building's natural operating rhythm to improve self-consumption and reduce peak imports. Battery behaviour tracks time-of-use price signals, producing predictable charging and discharging cycles aligned with economic and environmental efficiency.

How was it implemented?



The microgrid pairs moderate PV generation with an AI-driven controller that manages distributed energy resources and grid interactions. The AI shifts battery charging to low-tariff nighttime periods and discharging to high-tariff daytime periods while respecting carbon constraints.

What was the impact?



Economic impacts:

- **€1,200** in net annual savings
- Achieved an abatement cost of **-€323/tCO₂**, meaning carbon reduction generated net savings and demonstrating that AI optimisation can reduce emissions while lowering costs, even in a clean-grid context

Social impacts: Improved indoor comfort and operational reliability by optimizing HVAC scheduling while avoiding peak-load stress

Environmental impacts: ≈ -3.8 tCO₂e net emissions reduction a year, mainly from reduced grid electricity use.

How India's Peer-to-Peer Pilot Unlocked Local Value from Rooftop Solar



What was the problem?



- Rooftop solar surplus is currently mainly monetised through net metering, a system that allows rooftop solar owners to export excess electricity to the grid, with the value later adjusted against their electricity bills, often through delayed settlement. This limited timely and local value for producers.
- Daytime solar surplus often coincided with local congestion and reverse power flows, while peak demand continued to rise outside solar hours.
- Consumers without rooftop solar had no direct access to local renewable power, and there was no feeder- or cluster-level price signal to value surplus energy.
- BRPL, Delhi's electricity distribution utility, had limited visibility of behind-the-meter generation and flexible demand, constraining local network management.

What is the technology?



A distribution-level peer-to-peer market mechanism that enables local matching between rooftop solar producers and nearby consumers, without changing physical power flows through the DISCOM network. This includes:

- Energy accounting in 15-minute time blocks, aligned with existing metering and settlement practices.
- Smart-meter-based validation of imports and exports, with commercial settlement separating peer-to-peer energy value from retail supply.
- Secure payments through fund blocking or escrow, settled after energy delivery is validated.

How was it implemented?



- Eligible rooftop solar producers and consumers were onboarded under defined participation rules.
- Trades were submitted one day ahead (T-1), with agreed prices and quantities for each 15-minute time block.
- Buyer funds were blocked in advance to eliminate payment default risk, while actual injection and draw were validated using smart meter data on T+1.
- Financial settlement was completed on T+2, with BRPL retaining full control over grid operations and billing integration.

What was the impact?



Economic impacts

- Solar producers earned 10–30% higher value for surplus energy than under net metering, while participating consumers saw 5–15% lower effective energy costs.
- Local matching reduced peak demand and helped defer feeder upgrades.

Social impacts: Consumers were given the choice to buy local clean energy, with clear settlement timelines reducing billing disputes and improving confidence in renewables.

Environmental impacts: Greater local use of rooftop solar reduced reliance on marginal grid generation, lowering carbon emissions.

Box E

India Energy Stack: An Interoperable Digital Public Infrastructure for an AI-Ready, Inclusive Power Transition

India's approach to building AI-enabled power systems offers a practical model for moving from pilot-based digitalisation to ecosystem-scale adoption. Building on lessons from national digital public infrastructure endeavours and ongoing utility digitalisation, the India Energy Stack (IES) is positioned as a common, interoperable digital layer for the power sector. It is not a single platform or product. It is a shared set of standards, specifications, and trust mechanisms that allow different systems to work together without centralising control. The intent is to create common rails for trusted interaction so that utilities, regulators, and service providers can scale services faster, reduce duplication, and strengthen governance outcomes.

IES is enabled by a small set of foundational digital building blocks that make interoperability practical at scale: shared identifiers for consumers and assets, registries to verify participation, standard protocols for data and service exchange, verifiable digital credentials to establish trust, and policy-as-code so regulatory rules can be applied consistently with auditability. Together, these reduce bespoke integration and enable plug-and-play participation for authorised actors, while providing regulators and utilities with traceable, enforceable workflows.

From energy access to energy agency

A distinctive contribution of IES is its explicit focus on enabling a shift from energy access to energy agency. Energy agency means consumers can choose services, participate in authorised programmes and markets, and monetise their assets or actions rather than remaining passive recipients of electricity. This matters because a high-DER, high-flexibility system requires participation that is trustworthy, measurable, and settleable at scale. Without such participation, system value is lost, network investments become more expensive, and consumer benefits remain uneven.

IES supports energy agency by reducing the practical friction that prevents most consumers from participating today. Standardised onboarding and verified digital credentials reduce repeated documentation and inconsistent verification across utilities and service providers. Consent-based data sharing enables consumers to selectively share data with providers of their choice, enabling competition in bill support, advisory, energy efficiency, EV charging, and demand response, while reducing vendor lock-in. Policy-as-code further strengthens consumer trust and regulatory confidence by applying eligibility, incentives, and settlement rules consistently and transparently, with clear audit trails.

Livelihoods and entrepreneurship as a design objective

The socio-economic impact becomes material when participation becomes monetisable at scale. Small distributed assets and flexible actions translate into income only when measurement, verification, and settlement are reliable, low-cost, and auditable. With the right market and programme designs, households, businesses, and agricultural consumers can monetise actions such as off-peak EV charging, reduced cooling loads, or temporary load curtailment. Over time, this supports a new class of energy micro-entrepreneurs who earn not only from generating power but also from providing flexibility and related services.

IES also creates conditions for last-mile energy service entrepreneurship. By standardising trusted workflows, it enables local intermediaries to support consumer onboarding, documentation and consent management, device installation and verification, bill optimisation advisory, grievance support, and participation in approved value streams such as export settlement, flexibility payouts, and performance-linked incentives. This expands participation beyond digitally sophisticated consumers, improves programme uptake and service outcomes, and creates livelihoods linked to a cleaner, more efficient power system.

These participation and settlement rails can align with women-led livelihood programmes through collective ownership and service delivery models. Women's self-help groups can aggregate demand for productive-use appliances, support pooled procurement and service delivery, manage shared assets where feasible, and participate in compliant incentive and flexibility programmes. Reliable and affordable electricity improves productivity and enterprise viability in activities such as food processing, tailoring, dairy, and agri-allied services. Participation in formal digital workflows can also strengthen financial inclusion, digital literacy, and local leadership.

AI readiness with regulatory confidence

IES is a practical pathway to AI readiness because it addresses the prerequisites for trusted automation: consistent identifiers, consented data access, standardised semantics, and verifiable transactions. This enables AI tools to scale across utilities and geographies rather than being rebuilt within each vendor environment. It also strengthens governance by enabling auditability and consistent application of regulatory rules, reducing the risk that AI improves narrow operational metrics without translating into system-level outcomes such as reliability, affordability, and inclusion.

Why the model is exportable

IES is exportable because it is a building-block approach rather than a monolithic platform. Countries do not need to replicate India's institutions or market design to benefit. They can adopt the concept of common rails for identity, trust, data exchange, and rule application, then adapt roles, governance, and market interfaces to local regulatory structures. This reduces time-to-implementation, avoids locking digital modernisation into a single vendor, and enables a competitive ecosystem of solution providers.

The model is also exportable because it supports phased adoption. Jurisdictions can start with foundational capabilities such as identifiers, registries, and standard exchange protocols, then layer on policy-as-code, settlement automation, consumer flexibility programmes, and AI-enabled operations. This makes it relevant for systems at different stages of maturity, from vertically integrated utilities to liberalised markets.

For countries navigating similar pressures from renewables, electrification, and distributed resources, the core challenge is coordination under constraint. An interoperable digital public infrastructure approach provides a credible pathway to scale solutions, de-risk innovation, and broaden benefits beyond early adopters through energy agency, livelihoods, and entrepreneurship.

The India Energy Stack (IES) is a flagship initiative of the Ministry of Power, Government of India, with REC Limited as the nodal agency and supported by FSR Global as the knowledge partner, under the guidance of a dedicated Task Force and expert working groups spanning technology, power system operations, markets and regulation.

Turning Ambition Into Action: How Should Different Country Archetypes Approach the Development of AI-Enabled Power Systems?

The previous chapters have highlighted the huge potential for improved economic, environmental and social outcomes from the deployment of digital and AI technologies. Realising this potential, however, requires significant policy/regulatory, capacity, technology and finance enablers to be in place. It will not be possible for all countries to move at the same pace or to realise all of the value from digital and AI technologies; indeed, many will have to pursue a pragmatic approach to a feasible scale-up of digital enablement which balances priorities. This chapter explores:

- Implications for scaling digital and AI technologies
- Feasible technology pathways for different country archetypes
- Barriers to the implementation of these technology pathways

Implications for Scaling Digital and AI Technologies

Chapter 3 set out some of the most important technologies within AI-enabled power systems. With no one size-fits-all pathway, it will be important for different countries, utilities, and grid operators to prioritise the implementation of different technologies over time [Table 1].



Table - 1

High-income countries		
Learning from case studies		Implications for scaling technologies
Key uses cases include: ▪ Making better use of existing network capacity ▪ Improving forecasting and grid planning ▪ Managing peak demand and unlocking demand-side flexibility ▪ Lowering energy costs ▪ Reducing emissions ▪ Improving safety and reducing the costs of maintenance	Grid operators, utilities and regulators are inherently risk averse, with a lack of incentives to lead digitalisation alone. <i>“You’re working decision-makers who are naturally risk-averse. Change only happens if you explain things very simply, speak their language, and build trust over time.” – Technology provider</i> <i>“One important thing is to bridge the gap between business and IT — they often don’t speak the same language.” – Distribution company</i> <i>“Capacity building within utilities and ministries is essential. The challenge is not the absence of solutions, but institutional inertia.” – International organisation</i> <i>“The hard part isn’t doing the analysis – it’s turning it into an application that works reliably in a mission-critical environment” – Distribution company</i>	Bring in private-sector partners early, especially for analytics, cloud, robotics, and managed service models. It is important to build trust in new technologies over time and ensure technology partners speak in terms and outcomes that resonate with the power sector. Build a business case for digital and AI investments around how these will form the backbone of a clean power systems, which can optimise efficiency, reduce emissions and deliver savings to prosumers.
Emerging markets		
Learning from case studies		Implications for scaling technologies
Key use cases include: ▪ Improving network efficiency and reducing losses ▪ Lowering energy costs ▪ Supporting grid planning and expansion ▪ Better managing assets (e.g., predictive maintenance) <i>“What the human eye can’t see – rusting, damage, micro-faults – that’s where AI adds value.” – Grid operator</i> You don’t need to implement technologies across the whole network — targeted deployments can deliver significant value. Digital solutions are most likely to succeed when they solve near-term reliability or financial problems. <i>“There is always a prioritisation fight, because there are so many initiatives and very limited capacity to change critical systems.” – Distribution company</i> <i>“The difficulty is not the lack of technology, but judging whether the operational efficiency gains justify the upfront capital cost.” – Financial institutions</i> It is crucial to build in visibility of distribution network assets early, avoiding the challenges now faced by high-income countries. <i>“Whatever we do, we will not increase energy costs. Digital and AI solutions have to deliver clear and tangible value.” – Distribution company</i> <i>“The challenge is to design systems that are modular, scalable, and affordable from day one – because tariffs are already under pressure.” – Financial institution</i>		Build a business case for digital and AI investments around how emerging markets can improve the efficiency and reliability of their grids and the commercial and consumer savings this can realise. Develop a prioritisation framework to sequence roll-outs (e.g., lines that are most congested, most unreliable, or have the highest losses). Prioritise use-cases that deliver quick wins (e.g. loss reduction, deferred capex, outage reduction) to build momentum and internal buy-in.

Low-income countries

Learning from case studies

Key use cases include:

- Reducing theft and commercial losses
- Improving network stability and reliability

“The idea that electricity systems can ‘leapfrog’ in the same way as telecommunications is flawed. Unlike telecoms, electricity still requires physical infrastructure – cables, substations, and transmission lines – so it is not the same kind of leapfrogging.” – International organisation

High-quality data is essential to get the full potential out of digital and AI technologies.

“If data quality is poor, AI doesn’t help — but if data exists and is locked away, it also doesn’t help.” – Distribution company

“There is a tendency to over-engineer solutions. In many cases, going back to basics is the right place to start.” – Financial institution

“If digital or AI solutions help deliver electricity at a reasonable tariff, we are open to them. But if they increase costs, they simply won’t work in these contexts.” – Financial institution

“There’s no incentive to be energy efficient when your electricity is already subsidised, so why would you invest in digitisation?” – International organisation

“Low-income countries cannot afford complex, capital-intensive SCADA or EMS systems at the outset. Instead, they need open, modular platforms that can grow over time.” – Financial institution

Implications for scaling technologies

Build a business case around digital investments they can improve the commercial viability of power grids and improve access and reliability.

Start by deploying sensors, feeder-level meters at priority substations and smart meters at key demand centers to build a reliable data foundation. This must be underpinned by interoperable and secure data standards and frameworks.

International collective action is needed to lower the upfront of digital technologies and to develop modular solutions that can realise economies of scale as they are deployed globally.

Small Island Developing States

Learning from case studies

Key use cases include:

- Improving grid stability and reliability
- Supporting the rapid integration of renewables

“In systems that already experience outages, experimenting with new digital solutions may actually be easier, because the risk tolerance is different.” – Distribution company

Implications for scaling technologies

Build a business case for digital and AI investments around how they can help manage high shares of renewables on the grid.

Run targeted pilots focused on demonstrating the potential benefits in lowering outages and improving reliability.



Feasible Technology Pathways

We can broadly think about countries falling into 4 different archetypes, which have different starting points in their digital / AI journey and have different priorities for their power systems [Table 2].

Table - 2

Archetype	Example Countries	Starting Point	Core Challenge
High-income Countries	EU, UK, US, Japan, Australia, South Korea. Significant heterogeneity exists regarding the integration of renewables and digital / AI solutions.	20-60% renewable integration 65-75% smart metering - Mature SCADA/EMS - Strong regulatory frameworks - EV sales 15-30% of new vehicles - Emerging DER congestion - Lacking visibility over distribution network.	- Optimising grid build out and managing congestion + curtailment - Integrating distributed renewables and EVs - Managing declining inertia in the system with renewables - Managing flexibility at scale and real-time optimisation across millions of assets. - Lack of interoperability
Emerging Markets	China, India, Brazil, Vietnam, South Africa, Indonesia, Thailand, Mexico, Saudi Arabia, Colombia. Wide variation in digital maturity within this group.	10-30% renewable integration, with rapid rooftop solar growth 20-50% smart metering - Basic SCADA, often no OMS - Transmission losses 10-20% - EV transition beginning.	- Scaling digital infrastructure while managing explosive DER/EV growth - Improving the reliability of the power system and reducing commercial losses - Preparing networks for electrification.
Low-income Countries	Sub-Saharan Africa (e.g., Nigeria, Kenya, Ghana, Tanzania) South and Southeast Asia (e.g., Myanmar, Bangladesh, Pakistan) South America (e.g., Bolivia). Mix of LICs and lower-middle-income with weak utility finances.	- Generally low electrification and renewable integration; although exceptions (e.g., parts of Sub-Saharan Africa with hydro power) - Limited metering (<20%) - Basic/no SCADA - Very high losses 25-40% - Weak utility finances and donor-dependent capex.	- Expanding access to electricity. - Reducing the cost to connect remote / rural households. - Building foundational grids and revenue collection while working with severe capacity, financing, and political economy constraints.
Small Island Developing States (SIDS)	Caribbean islands, (e.g., Jamaica, Barbados) Pacific islands (e.g., Fiji, Vanuatu, Tonga) Indian Ocean islands (e.g., Maldives, Mauritius, Seychelles).	60-90% diesel generation - High fuel costs (e.g., \$0.25-0.50/kWh) - Small isolated grids (1-200 MW) - High climate vulnerability - Limited technical capacity.	- Building climate resilience while transitioning away from diesel - Maintaining stability in small isolated systems - Reducing costs and import dependence.



Immediate priorities to implement digital and AI technologies vary across archetypes. Through expert interviews and analysis of case studies, this report suggests short- to medium-term priorities for different country archetypes, based on the following criteria:

Problem severity



Does the technology address a binding constraint for the archetype (e.g., losses, stability, congestion, resilience)?

Readiness



Are prerequisites in place, or achievable by 2028? Can the archetype realistically deploy this?

Value chain coverage



Does the technology portfolio span generation, transmission, distribution, and end-use?

Sequencing logic



Does this build foundations for more advanced technologies, or does it require foundations already in place?

These pathways focus on building the following over the next 3-5 years:



High-income countries:

In most developed systems, the binding constraint is not transmission but visibility of the low voltage distribution network. Utilities cannot assess hosting capacity for heat pumps and EVs without digitising networks that have operated 'blind' for decades. Priorities are therefore to:

- 1) Digitise and digitalise the distribution network to support end-use electrification and the integration of DERs.
- 2) Focus on optimising the energy system through AI-enhanced grid management, demand-side flexibility, and advanced analytics and forecasting.



Emerging markets:

The focus will be on scaling and integrating digital technologies across entire networks to drive coordinated and data-driven operations, with two key priorities:

- 1) Digitise and digitalise the distribution network and end-use to support electrification and the integration of DERs.
- 2) Begin developing the core capabilities and systems to digitally-enhance the operation of power systems.



Low-income countries:

The focus is on building the core sensing capabilities and data platforms, as well as communication and data sharing across the network. Priorities are therefore to:

- 1) Build a foundational visibility of network to support network planning.
- 2) Address technical and commercial losses and to improve the financial health of utilities.



SIDS:

The focus is on building resilient electricity systems which can maximise the potential of renewable generation and battery storage. Priorities are therefore to:

- 1) Develop the core digital capabilities to operate microgrids.
- 2) Make targeted investments in technologies which address specific problems (e.g., smart inverters to address the challenge of low inertia in the system).

Exhibit 15 summarises how different country archetypes should approach the digitalisation of their power systems and technology choices through three types of investment:

01
Building foundational technologies and digital capabilities, which look very different for low- and high-income countries.

02
Quick wins that can be relatively cost effective and can quickly deliver a return in terms of efficiency or avoided investment.

03
Strategic bets which have a high potential impact, but are uncertain or costly.

Exhibit - 15
FOUNDATION BEFORE OPTIMISATION: COUNTRIES SHOULD PRIORITISE FOUNDATIONAL TECH FIRST, THEN OPTIMISE QUICK WINS AND STRATEGIC BETS

Archetypes Vs Prioritisation	Foundation Essential infrastructure that enables other technologies; must be in place before advancing	Quick Win Proven technology with clear ROI; can be deployed relatively quickly with vendor partnerships	Strategic Bet High potential but uncertain; requires experimentation, may not reach scale in all contexts
Archetype: High-income countries and some emerging markets	- Digital substations - Network-wide digital twins - Smart home energy management systems	Dynamic line ratings	AI-enhanced grid management
Archetype: Emerging markets, low-income countries and Small Island Developing States	- DER integration platforms - Distribution automation systems - GIS and asset mapping - Feeder-level metering - Basic SCADA and Outage management systems - Pre-paid/Smart meters (AMI at scale) - Microgrid EMS - Smart inverters	AI generation forecasting	- Digital twins - AI for loss detection

Sources: ISA & Systemiq analysis (2025)

Table 3 summarises the specific technologies within each archetype's pathway, and Table 4 provides a detailed description of targets, pre-requisites, and enablers.

Table - 3

High Income Countries

01	02	03
Install dynamic line ratings , prioritising the most congested corridors, to increase the capacity of the transmission network, support greater electricity demand and peak loads, and lower the overall build out.	Digitise, digitalise and automate the distribution network , starting with low voltage monitoring sensors at substations to understand capacity and constraints, and completing smart meter rollout. Full distribution visibility will then come with the integration of AMI, SCADA/DMS, and DER platforms. Digital substations can then be automated, with real-time monitoring and control systems replacing manual voltage checks.	Build network-wide digital twins , which focus first on the medium voltage network, progressing to low voltage areas with high DER integration. Digital twins will enhance scenario planning, investment optimisation, and system operation.
04	05	06
Drive rollout of smart energy management systems in homes and businesses to realise opportunities for demand-side flexibility and to empower citizens to participate in electricity markets.	Build DER integration platforms which support visibility and optimisation of rooftop PV, batteries, and EVs. These can be led and owned by either DSOs and utilities, TSOs, or third party aggregators.	Invest in AI-enhanced grid management , piloting in key control rooms to build real-time optimisation capabilities and explore where AI can be afforded greater control and automation over some decisions.



Emerging Markets

01	02	03
Install smart meters at scale across households and businesses; in the short-term, this enables utilities to address technical and commercial losses through more accurate visibility and billing, and over the long-term, sets up utilities and prosumers to realise opportunities for demand-side flexibility, placing citizens at the centre. This relies on dynamic time-of-use pricing being in place	Deploy distribution automation and outage management systems which can better detect faults and speed up maintenance to improve the reliability of the grid, while also addressing low visibility of the low voltage network and supporting DER integration.	Build DER integration platforms which support visibility and optimisation of rooftop PV, batteries, and EVs. These can be led and owned by either DSOs and utilities, TSOs, or third party aggregators.
04	05	
Invest in AI generation forecasting capabilities which supports system planning, reduces reserve procurement, and avoids curtailment. It can also improve the load factor of renewables (i.e. due to modifications in solar panel and turbine angles).	Build network-wide digital twins , which begin focusing on the most congested parts of the network to enhance scenario planning, investment optimisation, and system operation. Key use cases are to better understand how to manage losses and excess solar generation.	

Low-income Countries

01	02	03
Develop GIS and asset maps of the network , providing grid operators with a clear registry of the age, health and physical characteristics of lines, poles and substations. This supports system planning, maintenance, and network optimisation.	Large-scale deployment of feeder-level meters to provide visibility of substation activity, load and losses – this is important for grid operators and utilities to address commercial losses and provide a foundation level understanding to optimise operations and investment decisions.	Deploy basic SCADA and outage management systems , to drive coordinated and efficient operation of power systems (e.g., communication across substations and control centers, digitalising outage tracking, digital records to enhance planning).
04	05	
Install prepaid and smart prepaid meters , prioritising large loads and parts of the network with the biggest commercial losses to address revenue collection failures, billing disputes and lower connection costs, with the ultimate objective of improving the financial health of utilities.	Invest in AI for loss detection capabilities , as a strategic bet to better understand where technical and commercial losses are occurring, and prioritise investment and upgrades. This relies on feeder meters being installed.	

Small Island Developing States

01	02
Deploy energy management systems to manage microgrids and battery storage , to realise the full potential of small-scale distributed renewable energy generation and build resilient microgrids which support remote and rural access, reducing dependence on expensive and emissions-intensive diesel generation.	Install smart inverters , which can support frequency and voltage stability, addressing the unique grid stability problem facing small island states. The combination of small isolated grids of 1-200 MW with very low inertia, high renewable integration targets (50-100% by 2035), and a lack of interconnection to larger grids that could absorb frequency and voltage swings creates a key investment need for smart inverters.
04	05
Deploy basic SCADA and distribution / outage management systems , to drive coordinated and efficient operation of power systems (e.g., communication across substations and control centers, digitalising outage tracking, digital records to enhance planning).	Invest in AI generation forecasting capabilities which supports system planning, reduces reserve procurement, and avoids curtailment – crucial for small, isolated and renewable-dominated grids. It can also improve the load factor of renewables (i.e. due to modifications in solar panel and turbine angles).

This table details the key technology priorities across archetypes for the next 3-5 years. Please refer to Annex 1 for more information on each technology.

Stack layers: L1 = sensing; L2 = communications; L3 = data platforms; L4 = analytics; L5 = control; L6 = optimisation.

Type: Quick win (proven technology with clear ROI; can be deployed relatively quickly with vendor partnerships); Foundational investment (essential infrastructure that enables other technologies; must be in place before advancing); Strategic bet (high potential but uncertain; requires experimentation, may not reach scale in all contexts).

Table - 4

Value chain	Technology	Stack	Type	Problem / Use Case	Prerequisites	2028	2031	2035	Enablers	Support required
High Income Countries										
Transmission	Dynamic Line Rating (DLR)	L3-L4	Quick Win	Transmission congestion; RE curtailment; deferring new line CAPEX (\$2-5M/km)	SCADA/EMS operational; weather data feeds; line sensors; regulatory approval for dynamic limits	20-30% of congested corridors enabled; regulatory framework approved	50-60% coverage; 10-15% average capacity gain; integrated into dispatch	70-80% coverage; up to 20-25% capacity increase on favourable corridors	Weather APIs; sensor vendors; regulatory trust; grid code updates	Regulatory twinning + sandbox templates for DLR approval frameworks
Distribution	Distribution Automation & Digital Substations	L2-L5	Foundation	Automation gap in MV/LV networks; slow fault restoration; manual switching; limited DER hosting	Basic SCADA/DMS; communications infrastructure; protection coordination studies; trained field crews	30% of urban feeders automated; digital substations standard for new-build	50% coverage; self-healing on critical feeders; adaptive protection deployed	70%+ automation; sub-second fault isolation; full DER visibility at substation level	IEC 61850 adoption; vendor interoperability; cybersecurity frameworks; workforce training	Digital Academy modules on protection engineering; procurement templates
Transmission and distribution	Digital Twins (Network-wide)	L4	Foundation	DER hosting capacity uncertainty; investment optimisation; scenario planning under high uncertainty	Complete GIS/asset data; SCADA/DMS integration; computing infrastructure; modelling expertise	Urban MV network twins operational; hosting capacity automated; planning cycle reduced 25%	Full MV network coverage; real-time synchronisation; investment optimisation live	LV network extension in high-DER areas; AI-driven scenario generation	GIS data quality; vendor platforms; model governance; cross-functional teams	Reference architectures; data quality standards; Academy modules
End-use	Smart Building Energy Management Systems	L4-L6	Foundation	Lack of demand response in residential sector; significant demand growth; high peak demand	Smart meter installation across homes and businesses, DER integration platforms	All homes with rooftop solar + EVs on a dynamic tariff + EMS system installed	Full coverage across the 25% biggest commercial buildings	Over half of all buildings with a smart energy management system	Dynamic, time-of-use tariffs, often deliver the best returns in homes with rooftop solar, batteries and/or EVs	Regulatory push for smart meter installation, regulatory frameworks which enable flexible energy markets

Value chain	Technology	Stack	Type	Problem / Use Case	Prerequisites	2028	2031	2035	Enablers	Support required
Distribution and end-use	DER Integration Platforms	L3-L5	Foundation	Visibility gap (millions of rooftop PV, batteries, EVs); local congestion; flexibility procurement	Smart meter rollout complete; communication standards (IEEE 2030.5); aggregator frameworks; API infrastructure	60-70% DER registered; visibility dashboards; flexibility procurement pilots	80% registered; active dispatch for grid services; local flexibility markets operational	90%+ registered; automated coordination; real-time optimisation	Interoperability standards; aggregator licensing; data sharing rules between utilities, aggregators and customers; power market design for flexibility; dynamic tariffs	Interoperability standards development; aggregator framework templates
Transmission and distribution	AI-Enhanced Grid Management	L5-L6	Strategic Bet	Real-time optimisation under high RE uncertainty; reserve over-procurement (est. 8-12% of system cost); slow contingency response	Modern SCADA/EMS; 3-5 years quality historical data; data science team; cyber security framework	Pilots in 5+ control rooms; AI-assisted contingency ranking; 3-5% reserve reduction demonstrated	AI co-pilot in 25-30% of control rooms; automated security assessment	40-50% adoption; near-real-time re-dispatch; 10-12% reserve optimisation; explainability standard	Talent pipeline; academic partnerships; model governance; vendor ecosystem	Twinning placements for AI/ grid ops; model governance guidance notes
Emerging markets										
End-use	Smart Meters (AMI at Scale)	L1-L3	Foundation	AT&C losses 10-20% (est. \$2-5B/year in large markets); no customer-level visibility; manual billing errors	Utility financial stability; procurement capacity; IT/OT integration capability; consumer communication strategy	50-60% coverage (urban priority); MDMS operational; loss hotspots identified	75-80% coverage; ToU tariffs enabled; 5-7 pp loss reduction achieved	90%+ coverage; prepaid/postpaid flexibility; losses <10%; DR-ready	DFI financing; MDMS vendors; consumer acceptance campaigns; regulatory cost recovery	Financing facility access; MDMS procurement templates; consumer engagement toolkits
Distribution	Distribution Automation & Outage Management Systems (OMS)	L2-L5	Foundation	Manual fault location (crews search for hours); long restoration times; no outage analytics; weak network visibility	Communications to substations (cellular/fibre); RTUs at key points; control center upgrade; operator training	Urban substations monitored; OMS operational; fault indicators on critical feeders	Automated fault isolation on 30-40% of urban feeders; restoration time halved	60%+ urban automation; predictive outage analytics; crew dispatch optimisation	Vendor partnerships; standardised turnkey solutions; O&M contracts; regional training hubs	Procurement templates; regional training programs; O&M contract frameworks

Value chain	Technology	Stack	Type	Problem / Use Case	Prerequisites	2028	2031	2035	Enablers	Support required
Distribution and end-use	DER Integration Platforms	L3-L4	Foundation	Rooftop solar explosion (India: 10→100+ GW by 2030); reverse power flows; no registry; grid stability risk	Basic SCADA/ DMS operational; net metering policy clarity; interconnection standards; utility buy-in	National registry operational; 40-50% rooftop PV registered; feeder-level visibility	70% registered; local trading pilots; active curtailment capability for critical feeders	85%+ registered; automated dispatch; flexibility markets in pilot states	Policy clarity (net metering evolution); grid code updates; data standards; aggregator frameworks	Grid code technical assistance; registry platform reference architecture; policy guidance
Generation	AI Generation Forecasting	L4	Quick Win	RE forecast errors 15-25% (day-ahead); reserve over-procurement; curtailment 5-15% in high-RE states	Weather data access (NWP, satellite); plant telemetry; 2+ years historical data; dispatch system integration path	AI forecasting for 40-50% of utility-scale RE; 25-30% error reduction; pilot integration with dispatch	70% coverage; embedded in scheduling; reserve optimisation live	90% coverage; 35-40% error reduction vs baseline; probabilistic forecasts standard	Weather service partnerships; model localisation; operator training; vendor ecosystem	Weather data partnerships; Academy modules; vendor pre-qualification
Transmission and distribution	Digital Twins (Planning)	L4	Strategic Bet	Investment prioritisation blind spots; hosting capacity unknown; slow planning cycles (12-18 months)	GIS data digitised (>80% network); SCADA/DMS feeds operational; planning team capacity; computing infrastructure — requires Digital Maturity Level 3+	Twins for 2-3 major urban networks with good data quality; hosting capacity pilots	5-8 urban networks; real-time sync with SCADA where available; investment optimisation pilots	Major urban networks covered; AI-driven scenario generation in advanced utilities	GIS data cleanup programs; vendor platforms (cloud-based); training; cross-functional coordination	GIS data quality standards; reference architectures; Academy planning modules
Low-income countries										
Transmission and distribution	GIS and Asset Mapping	L3	Foundation	Unknown network topology; no asset register; planning blind spots; crew inefficiency; connection backlog	Satellite imagery access; field survey capacity; basic GIS software; data entry team	MV network mapped; primary assets registered; mobile access for field crews	LV network in urban areas; asset condition added; planning integration started	Complete network GIS; digital asset register; work order integration; planning foundation	Satellite imagery (free/low-cost); survey contractors; GIS training; data quality processes	GIS data standards; survey methodology; training programs; quality assurance
Distribution	Feeder-Level Metering	L1	Foundation	No visibility beyond substation; losses 20-40% (cannot segment); no performance metrics; theft unlocatable	Feeder identification/ mapping; communication backhaul (cellular); basic data collection system	50% of feeders metered; loss segmentation initiated; high-loss feeders identified	80% coverage; monthly loss reports by feeder; targeted intervention on top 20% loss feeders	100% coverage; real-time monitoring; losses reduced 8-12 pp from baseline	Simple robust meters; cellular operators; basic analytics platform; management accountability	Meter specifications; procurement templates; analytics platform reference

Value chain	Technology	Stack	Type	Problem / Use Case	Prerequisites	2028	2031	2035	Enablers	Support required
Transmission and distribution	Basic SCADA/OMS	L2-L5	Foundation	Paper-based outage tracking; no fault location (crews search manually); restoration hours-days; no data for planning	Control center facility; communications to key substations; basic computing; operator training	Primary substations monitored; centralised outage logging; dispatch coordination	Secondary substations added; fault indicators on critical feeders; 30-40% faster restoration	Urban network coverage; basic crew dispatch; outage analytics; 50% restoration improvement	Vendor partnerships; standardised turnkey systems; regional training; O&M support contracts	Turnkey specifications; vendor pre-qualification; regional training programs
End-use	Prepaid / Smart Prepaid Metering (LV)	L1-L3	Quick Win	Revenue collection failure; billing disputes; disconnection/reconnection costs; working capital strain	Vending infrastructure; customer registration; tariff structure compatible with prepaid; field teams for installation	30% of LV customers on prepaid; vending network established; revenue improvement visible	50% prepaid; mobile vending dominant; 15-20% revenue uplift vs baseline	70%+ prepaid; smart prepaid with AMI features in urban areas; sustainable utility cash flow	Prepaid meter vendors; mobile money integration; customer communication; regulatory support	Prepaid system specifications; vendor pre-qualification; customer engagement toolkits
Transmission and distribution	AI for Loss Detection (Targeted)	L4	Strategic Bet	Non-technical losses (theft); no targeting capability; enforcement resources wasted; political protection of theft	CRITICAL: Feeder meters installed (6-12 months data); basic analytics capability; AND political will + enforcement capacity + judicial support. Without political economy alignment, technology alone will fail.	Anomaly detection on metered feeders; top 10% loss feeders flagged; enforcement pilots in politically-supportive areas	Automated weekly flagging; success rate >40% on inspections; revenue recovery measurable in pilot zones	Scaled to all metered feeders; integrated with billing; losses reduced 5-8 pp; model refined continuously	PRIMARY: Political commitment at ministerial level; enforcement agency capacity; judicial fast-track. SECONDARY: Feeder data; simple ML models (cloud-based)	Political economy assessment tools; enforcement capacity building; success case documentation
Small island developing states										
Distribution and end-use	Microgrid EMS + Battery Storage	L3-L5	Foundation	Diesel dependence (60-90%); fuel cost \$0.25-0.50/kWh; supply chain risk; climate vulnerability	Grid assessment; RE resource assessment; storage sizing study; O&M capacity plan; concessional finance secured	25-30% RE penetration; 2-4 hour storage; EMS controlling solar + battery + diesel	40-45% RE; 4-6 hour storage; black-start capability; diesel run-hours reduced 30-40%	50-60% RE; 6-8 hour storage; near-autonomous operation. Note: Upper targets assume continued concessional/grant finance	Concessional finance (GCF, CIF, bilateral); standardised designs; regional O&M support; technology partnerships	Standardised procurement packages; O&M contract templates; financing facility access

Value chain	Technology	Stack	Type	Problem / Use Case	Prerequisites	2028	2031	2035	Enablers	Support required
Distribution	Smart Inverters (Grid-Forming)	L2-L3	Foundation	Frequency instability (± 2 -5% swings); voltage fluctuations; high RE curtailment (20-40%); no rotational inertia	Updated grid code; inverter certification process; installer training program; utility technical acceptance	Grid code updated; 40-50% new installations grid-forming capable; synthetic inertia pilots	70% new installations compliant; retrofit program for critical sites; curtailment reduced to <20%	Grid-forming standard for all new; synthetic inertia operational; stable at 50%+ RE	Grid code technical assistance; certification labs (regional); installer training; vendor engagement	Grid code templates; regional certification support; training programs
Transmission and distribution	Basic SCADA/DMS + Resilience Hardening	L2-L5	Foundation	Manual operation; long restoration (hours-days post-storm); no fault location; limited resilience investment	Communications infrastructure (cellular/radio/satellite); substation RTUs; control center; trained operators	Main island substations monitored; fault indicators deployed; post-event assessment protocol	Automated fault isolation on critical feeders; restoration time halved; hardening of critical corridors	Full main-island coverage; self-healing priority feeders; resilient design standard for new build	Vendor partnerships; regional shared services; training programs; resilience financing windows	Turnkey system specifications; regional training hubs; resilience finance facility
Generation	AI Forecasting (Solar + Wind + Demand)	L4	Quick Win	Small system volatility; spinning reserve 20-30% of peak; dispatch optimisation; fuel planning uncertainty	Basic SCADA data; weather station or satellite feed; 1+ year historical data; cloud connectivity	Day-ahead forecasts operational; reserve sizing improved 10-15%; cloud-based solution live	Intra-day updates; 15-20% reserve reduction; fuel planning optimised	Probabilistic forecasts; automated dispatch recommendations; regional forecast hub participation	Cloud platforms; satellite weather services; regional centers of excellence; vendor partnerships	Regional forecasting hub; weather data partnerships; vendor pre-qualification

Barriers to Implementation

Realising these technology pathways, however, requires countries to address barriers and bottlenecks across five key areas:

01

Policy and regulation: Fundamental challenge of power markets lacking competitiveness, transparency and flexibility to sufficiently incentivise digital investments.

02

Capabilities: Persistent gaps in digital skills within the power sector to plan, procure, and operate digital and AI-enabled technologies.

03

Data governance and infrastructure: Legacy IT systems, poor cybersecurity, and unclear data policies that make it hard to collect, share, and effectively use high-quality energy data.

04

Innovation and ecosystem creation: Underdeveloped innovation ecosystems and weak collaboration between energy, digital and finance communities slow the testing and scale-up of new solutions.

05

Finance and de-risking: High capital costs, stressed utility finances and limited finance tools hold back investment in digital and AI solutions.

This section summarises the key challenges facing the development of AI-enabled power systems across different country archetypes.

Policy and regulation

Policy and regulatory frameworks fail to sufficiently incentivise investment in digitalisation and innovation. While specific challenges vary country-to-country, there are some common issues. In high-income countries, this typically reflects:⁷³

- Mandates for regulators to keep consumer prices low creates a risk for network operators of potentially over-investing in technologies and infrastructure; if regulators exclude investment from a company's regulated capital base, they can't earn a return on this investment.
- The revenue that regulators are permitted to recoup is often linked to costs, as opposed to outcomes and impact, and risk-taking is often discouraged.
- Regulatory frameworks have a bias towards capex investments, which is remunerated via regulatory cost of capital and scrutinised less compared to opex. However, many digital and AI investments are treated as opex-based solutions that drive operational efficiency (creating perverse incentives for digitalisation).

In middle- and low-income countries, where regulatory frameworks are much less mature, challenges typically relate to: regulators lacking legal independence, capacity, and enforcement power; politically constrained tariffs which, in some cases, set tariffs below cost-recovery levels; and the fundamental challenge of uncompetitive power markets meaning there are few clear mechanisms that reward investment in electricity grids.⁷⁴

Regulators and grid operators are generally risk averse and can be slow to adopt new technologies. In all countries, regulators and grid operators are incentivised and motivated by one key priority: keeping the lights on.⁷⁵ While in high-income countries, regulators are beginning to incentivise other priorities such as system efficiency, guaranteeing security and reliability of supply remains the central principle. This means the investment doctrines of network operators often include a bias towards predetermined solutions, rather than taking a technology-neutral approach to address system needs.⁷⁶ Regulatory frameworks do not sufficiently incentivise a focus on outcomes or have mechanisms to appropriately reward risk-taking and innovation. Added to this is the challenge of high project costs and long asset lifetimes of 20-50 years.

This limits the willingness and ability of regulators and grid operators to pilot new technologies and innovate. For example, the biggest barrier to the deployment of dynamic line ratings – which enable lines to operate above typical capacities under certain conditions – is that regulators are slow to adjust regulatory limits to allow lines to be run at higher capacities.

Power markets do not sufficiently reward flexibility, transparency or innovation. To underpin the digitalisation of the entire value chain – from generation to T&D to end-use – power markets need to be competitive, transparent and have appropriate mechanisms to reward storage and flexibility. In high-income countries, while power markets are typically competitive, legacy design for centralised and predictable generation still persists, with inadequate incentives for flexibility.⁷⁷

Value is fragmented across different markets (e.g., capacity, ancillary, and arbitrage markets), with returns often being uncertain and inadequate.

Poor price volatility and signals, for example, due to a lack of real-time or locational price signals (e.g., hourly settlement rather than every 15 minutes, static tariffs rather than time-of-use prices).

Unclear role and rules for aggregators, who often face inconsistent compliance requirements and face challenges to accessing data.

In the rest of the world, the biggest challenge is the lack of competition within power markets. In most of middle- and low-income countries, power systems are dominated by a state-owned, vertically integrated, single utility that procures power through long-term power purchase agreements (PPAs).⁷⁸ This limits incentives for flexibility as systems operate based on contractual obligations, as opposed to real-time needs, with weak or non-existent short-term markets to value storage and flexibility. Electricity tariffs are also often politically-controlled, subsidised and do not reflect time, location or scarcity.





Capabilities

As introduced in Chapter 2, there is currently a huge disconnect between the power and digital sectors, with skills gaps one of the most pressing barriers to the digitalisation of the power sector.

The power sector lacks the fundamental digital skills to unleash the potential of an AI-enabled power sector. Unlocking the productivity benefit of AI depends on a major digital upskilling push within the existing power workforce. The skills required to work effectively with AI build on, rather than replace, traditional engineering and operations capabilities, but do require capabilities in five key areas:

- **Data and model literacy:** understanding how operational data are collected, cleaned and used in models; reading AI-generated insights and knowing their limitations.⁷⁹
- **Use of advanced digital tools:** from predictive maintenance dashboards and grid-analytics platforms to digital twins and optimisation software.⁸⁰
- **“Human-in-the-loop” decision-making:** integrating AI recommendations into operational decisions, knowing when to override algorithms, and documenting decisions for regulators and customers.⁸¹

- **Cybersecurity and digital safety:** basic cyber-hygiene for all staff, and specialist skills for those working on critical control systems.⁸²

- **Interdisciplinary collaboration:** the ability for power engineers, IT specialists and data scientists to work together on shared platforms and projects.⁸³

Today, digital skill gaps are already a binding constraint on the digitalisation of the power sector:

- Demand for AI and digital skills is growing in the energy sector but has grown more slowly than in other sectors.⁸⁴ A possible explanation for this is that use cases and applications of digital and AI solutions are unclear.
- Almost 90% of energy professionals report skills gaps as the main challenge to accelerating the adoption of digital technologies.⁸⁵

In recent years, utilities in high-income countries have moved from a focus on database skills to greater emphasis on data analysis and scripting languages, but a focus on AI and machine-learning skills is still very low.⁸⁶ For utilities in middle- and low-income countries, which often have limited in-house IT capacity and legacy systems, this creates a dual challenge: catching up on foundational digital capabilities while also preparing for more advanced AI-enabled applications.

At the same time, the power sector struggles to attract new digital talent. In addition to upskilling the current power sector workforce, AI-enabled power systems will not function without a significant inflow of workers from digital and technology backgrounds. AI-rich grids need specialised workers, echoing past digitalisation waves that expanded IT employment at a rate two times faster than the rest of the economy and six times faster than the global job-creation rate.⁸⁷

The power sector will need to create new jobs in the following key categories:

- 01 **Digital and AI power system design:** Workers required to design the underlying digital architecture of AI-enabled power systems, including data models and platforms, control algorithms, and interoperable data standards. These jobs require digital and tech experts to be equipped with a core understanding of how the power system works.
- 02 **Installation and integration of digital / AI technologies:** Roles to deploy software within and across organisations (e.g., internal technology transformations to incorporate SCADA and energy management systems), as well as the physical installation of hardware (e.g., dynamic line ratings and smart meters).
- 03 **Operation of digital / AI solutions:** Some additional jobs may also be required to support in the running and operation of new digital platforms and technologies, or in the initial stages, to upskill the existing workforce to utilise these.

However, competition for digital talent is a key challenge for the power sector. The prevalence of workers with AI skills in the energy sector ranks lower than other sectors; between 2018 and 2024, the concentration of AI talent was 40% lower than in education, finance and professional services.⁸⁸

Weaker pay and career structures are a major challenge, with studies indicating that digital roles within the energy sector are paid less than other sectors; for example, salaries offered by US utilities for cybersecurity positions are at least 20% lower than in finance and insurance.⁸⁹ This salary gap is compounded by perceptions that utilities offer slower innovation cycles and less flexible working conditions than technology firms, even though the underlying mission of providing clean, reliable power is highly attractive to many digital workers.⁹⁰

To close this gap, governments, utilities and regulators will need deliberate strategies to embed digital skills and decision-making across organisations.

There are currently several cross-cutting challenges that hinder progress:

- ✓ Short-term and fragmented skills planning within organisations, with short planning horizons and constrained training budgets.
- ✓ Weak coordination between government ministries, regulators, utilities and education providers means there is no joined-up approach to building AI-ready energy skills.
- ✓ Engineers and operators are cautious about delegating decisions to algorithms, especially in safety-critical grid operations.

Data Governance and Infrastructure

Foundational digital infrastructure is lacking in most middle- and low-income countries, making advanced data use difficult. While high-income countries debate data standards and AI governance, many utilities in middle- and low-income countries still lack the foundational digital infrastructure required to collect, store, and use grid data.⁹¹ Asset registers are incomplete or paper-based, network connectivity is unreliable or absent in rural areas, and metering coverage remains limited.⁹² Without the basic digitisation of network assets and installation of sensors, meters, and communications infrastructure, more advanced digital applications remain out of reach. In high-income countries, the challenge is different: legacy systems and siloed data architectures create integration barriers even where infrastructure exists, requiring significant investment to modernise and connect disparate systems.⁹³

Data governance frameworks are underdeveloped and misaligned with energy sector needs. Effective data use requires clear rules on data ownership, access, quality, and sharing. In high-income countries, fragmented regulatory authorities often mean that energy data governance falls between existing frameworks: telecommunications regulators address network issues, data protection authorities focus on privacy, and energy regulators lack explicit mandates or expertise on data matters.⁹⁴ This creates uncertainty for utilities, technology providers, and new market entrants. In middle- and low-income countries, the challenge is more fundamental: data governance frameworks for the energy sector often do not exist, leaving utilities without guidance on how to manage sensitive operational and customer data, share data with third parties, or comply with emerging cybersecurity requirements.⁹⁵

Cybersecurity requirements create additional barriers, particularly for resource-constrained utilities. As grid digitalisation increases attack surfaces, cybersecurity has become a critical concern. High-income countries are developing sophisticated operational technology security frameworks, but implementation remains uneven and costly.⁹⁶ For utilities in middle- and low-income countries, cybersecurity presents a dual challenge: they must meet international standards to access technology and finance, yet often lack the technical capacity, trained personnel, and financial resources to implement comprehensive security programmes.⁹⁷ Geopolitical concerns around technology suppliers add complexity, with some utilities caught between competing standards regimes and procurement restrictions that limit their options and increase costs.

Low levels of consumer participation in digital energy services reflect these shortcomings in data infrastructure and governance.

In many countries, households and businesses are wary of sharing granular consumption data with utilities or third parties, given past experience of poor service, opaque billing practices, and limited recourse if data are misused.⁹⁸ Even where privacy laws exist, consumers often lack clear, simple rights to access, port and authorise use of their data, and consent processes are long, technical and difficult to navigate.⁹⁹ At the same time, the value proposition is weak: potential bill savings or service improvements from smart tariffs and demand response are unclear relative to the perceived hassle and risk. In middle- and low-income countries, these issues are compounded by low awareness and limited digital literacy, meaning only a small, higher-income segment can realistically engage with app-based services.¹⁰⁰ As a result, most consumers remain passive users of electricity rather than active participants in data-driven power systems.

Innovation & Ecosystem Creation

Energy–AI innovation ecosystems are fragmented, with pressing gaps between digital and power communities. Across most high-income countries, innovation ecosystems are fragmented, with innovators being disconnected from the rest of the value chain, citing establishment of corporate – start-up collaboration as a challenge.¹⁰¹ This compares to the landscape in China, where industries are vertically-integrated, meaning the process from idea generation to deployment and scaling is connected and coordinated.

The deployment environment for digital innovations is fractured, making replication and scaling across utilities and countries costly. The distribution network – which will be responsible for managing the vast majority of new renewable generation and demand – is characterised by more than 40,000

different components in Europe alone, with significant differences in equipment standards.¹⁰² This means the scaling of digital solutions is complex, requiring interoperability across tailor-made equipment and software.

Data fragmentation in energy systems is a structural barrier to digital and AI-driven innovation. Across the EU, data on power demand and supply is governed through a patchwork of national rules, heterogeneous technical standards, and across thousands of distribution system operators.¹⁰³ Similar challenges are evident in the US, where a highly decentralised energy system and state-level regulation limits data sharing and system-wide optimisation. This results in siloed datasets and limited interoperability across the value chain and countries. Inconsistent data access procedures and non-standardised formats increase transaction costs for innovators and make it difficult to scale AI solutions beyond pilot projects.

In middle- and low-income countries, innovation is constrained by structural weaknesses in the innovation ecosystem. These include:

01

Weak and fragmented links between research institutions, startups, utilities, regulators, and financial institutions, especially in least-developed countries.¹⁰⁴

02

Innovation is frequently driven by donor-funded pilots and external support, without clear routes to scale or procurement and high likelihood of failure once funds are discontinued.¹⁰⁵

03

The absence of shared energy data infrastructure, innovation testbeds and structured sandboxes raise barriers to entry for AI developers.

04

Financing gaps across the innovation value chain, in particular for early-stage and growth, with financing for pilots concentrated in North America, Europe, and China.¹⁰⁶

04

International collaboration is often required to bring in technology, finance and know-how, but current initiatives remain fragmented and under-resourced, with the majority of R&D expenditure highly concentrated in the G20.¹⁰⁷ Many countries have limited access to global R&D networks, open datasets and partnerships.



Finance & De-Risking

In high-income countries, while capital is broadly available, specific financing challenges prevent sufficient flows. This largely relates to insufficient policy and regulatory frameworks (see “policy and regulation”), but also reflects the following:

01

Most network companies cannot fund the required investment levels from retained earnings. Analysis of Europe’s transmission system operators (TSOs) suggests a €250 billion gap between expected operating cash flows and required capex to build out and upgrade grids through to 2030.¹⁰⁸ Balance sheet health creates challenges securing finance. Analysis of 15 of Europe’s largest TSOs shows the majority have very low to moderate credit risk ratings, with ~20% at a substantial to very high risk of defaulting on their financial obligations.

02

A mismatch in the risk/return and size of many digital / AI projects (i.e. the “missing middle” problem in climate finance).¹⁰⁹ Investments often fall between traditional infrastructure finance and high-risk and return growth finance; yet risk-tolerant private capital has been shrinking due to higher interest rates, while the growth investment community has become more conservative. This is aggravated by the fact that TSOs and DSOs are expected by policymakers to behave like growth companies – fast, scalable, and flexible – while many investors value them as low-risk, dividend-paying entities.

03

Challenges creating a clear business case for digital investments, with unclear use cases, responsibilities and value proposition for specific stakeholders.

In lower-income countries, the cost of capital significantly limits investment potential. For example, in 2022, the weighted cost of capital for solar PV investments was at least twice as high in middle- and low-income countries (excluding China), averaging 9–12% compared with 5–6% in high-income economies.¹¹⁰ While digital and AI technologies vary in their finance and capital structure (e.g., hardware vs asset-light software), significant capital outlays are required, meaning the cost of capital is a significant determinant of the overall cost of investments.

Across middle- and low-income countries, the financial position of utilities creates significant financing challenges. It is estimated that only 40% of utilities can cover their operating and debt service costs, with challenges due to high costs but below-cost tariffs, system losses, inefficient payment collection, and poor planning.¹¹¹ This limits the ability of utilities to make invest in digital technologies.

Across middle- and low-income countries, but in particular in low-income countries and small island developing states, keeping the cost

of connecting new customers low is the critical priority. In countries where household power consumption is low, the cost to connect them is often prohibitively high as the cost of new connections may not be recouped through electricity bills within viable time frames.¹¹² Making digital and AI investments – even if they have the potential to lower costs and increase revenues over the long-term – can further challenge the financial viability of expanding access to additional customers.

Access to development finance for digital and AI investments in the power sector remains limited. While expanding access to clean electricity is a fundamental priority of multilateral development banks, investments are typically focused on traditional infrastructure investments (e.g., half of the World Bank’s and ADB’s energy supply portfolio investments are geared towards T&D accounts).¹¹³ Similarly, while digitalisation is a key priority of many MDBs today, this is largely focused on telecommunications and digital public services.¹¹⁴ There is a limited availability of facilities focused on de-risking and providing catalytic finance for the digitalisation of the power sector specifically.

A Global Mission for AI for Energy: How to Accelerate Progress Towards AI-Enabled Energy Systems

This report has outlined the significant opportunity to develop AI-enabled power systems globally: the clean energy revolution cannot scale without digitalisation and AI. However, there is a critical window of opportunity. As the share of renewable electricity generation in power grids reaches ever higher levels, there is an urgent need to demonstrate the currently untapped potential that AI can bring to clean power systems and to address the 5 barriers, outlined in the previous chapter.

Our last chapter outlines the broad actions that are required in all countries, at different stages in their digital and AI journey, to tackle the challenges within each barrier. But it also goes further and argues that there is an urgent need for global coordination and formalisation of efforts to digitalise and AI-enable power systems through a Global Mission for AI for Energy.

A Global Mission for AI for Energy

This report highlights the value that a Global Mission for AI for Energy can bring to unleash the potential of digitally- and AI-enabled power systems across the world. A government-backed Global Mission is needed to do four critical things:

- 01 **Institutionalise delivery.** Today, AI-for-energy efforts are scattered across pilots and one-off technical assistance with no single accountable owner. Establishing a dedicated mission supported by a directorate would provide a permanent mandate, governance, and operating power to drive delivery with roadmaps, standards alignment, and partner management.
- 03 **Create a coordination mechanism that spreads best practice.** Progress is uneven, with most countries constrained by capability, data access, interoperability, and financing. The mission would provide a platform for peer-learning and coordination that enables shared best practices and lessons learned, builds trust in new technologies that have delivered measured outcomes, and ensures faster diffusion and reduced risk.

- 02 **Bring speed and urgency through focus and specialisation.** With utilities and regulators focused on reliability, bespoke projects move slowly and innovative technologies fail to scale. The mission would focus resources on a set of priority products and technologies, enabling countries to apply proven building blocks quickly, rather than re-inventing solutions, running bespoke pilots, or waiting for innovations to be validated one project at a time.
- 04 **Bring a core focus on the democratisation of clean power systems.** A clean power system cannot function effectively without the participation of people. Establishing a Global Mission is needed to set a clear global vision for citizen-centric electricity markets and translate this into action.

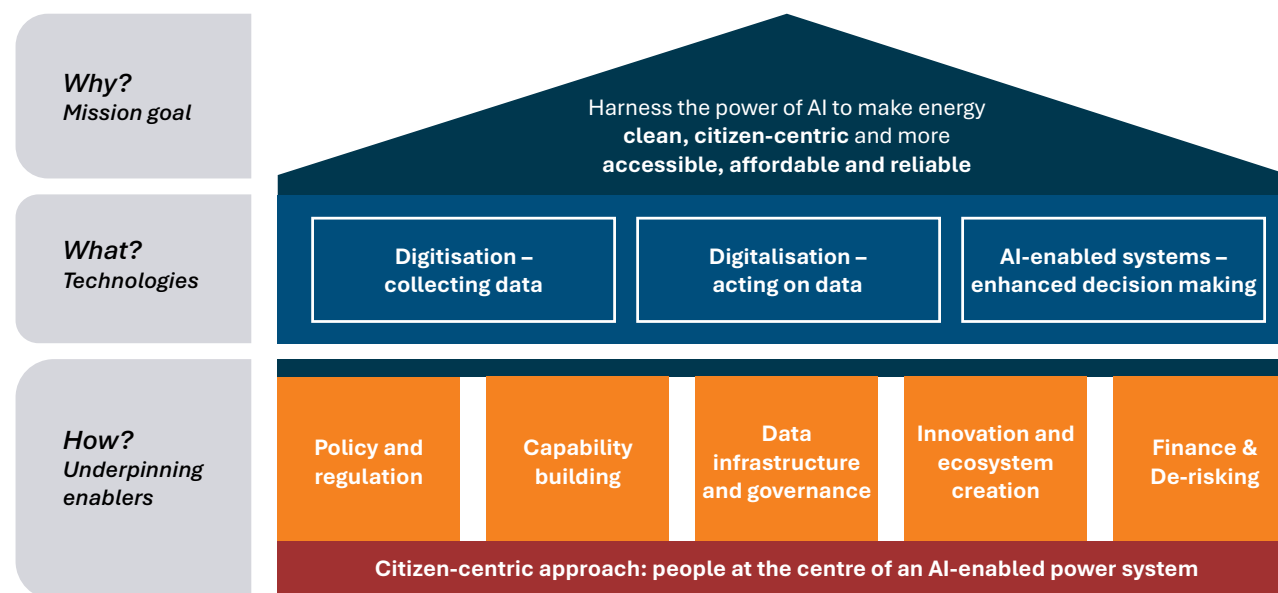
The International Solar Alliance, with 125 Member Countries representing some of the highest solar potential globally, is uniquely positioned to harness this convergence at scale and drive this Mission forward.

Under ISA's leadership, a Global Mission can help countries convert AI potential into real-world outcomes: faster renewables integration, lower system costs, improved reliability, and improved citizen participation. It would do this through coordinated action across policy and regulation, capability building, data infrastructure and governance, innovation and ecosystem creation, and finance to de-risk early deployments.

The mission will be structured around these five interconnected pillars to build supply side capacity and deliver impact over the next 3-5 years.

Exhibit - 16

THESE CHALLENGES REQUIRE A COORDINATED APPROACH, DEMANDING A GLOBAL MISSION TO UNLOCK AI FOR ENERGY



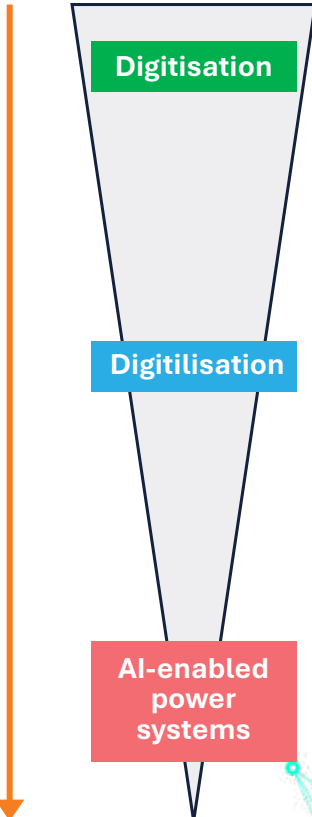
This chapter summarises the action needed globally across these 5 pillars to unlock progress along the digitalisation and AI ladder, and discusses how such a Global Mission would provide a clear backbone for progress.

Pillar 1: Policy and Regulation

Well-designed policy and regulation are critical to determining the pace, the ambition and ultimately the delivery of AI-enabled power systems. Exhibit 17 sets out the five priority actions that are needed at global level.

Exhibit - 17

POLICY AND REGULATION: KEY ACTIONS



Key Action	Leading Actors	Supporting Actors
1. Set a clear national vision and roadmap to create clean and AI-enabled power systems, with the citizen at the centre	Polymakers / regulators	Grid operators and utilities
2. Create transparent and competitive power markets, which incentivise flexibility and innovation	Polymakers / regulators	Grid operators, utilities, and technology companies
3. Directly incentivise investment in digitalisation through well-designed regulatory frameworks that reward outcomes for efficiency and flexibility and enable the adoption of new technologies	Polymakers / regulators	Grid operators, utilities, and technology companies
4. Set the core parameters for digital power systems through mandates for key technologies: - Installation of smart meters at key load centres and, over time, in all households - Installation of key technologies across the T&D network (e.g., SCADA systems)	Polymakers / regulators	Grid operators, utilities, technology companies, and end-users
5. Create secure data sharing between system operators and utilities to unleash the power of AI: - Mandate the implementation of secure and interoperable data sharing frameworks between system operators and utilities - Require utilities to publish open datasets to support system-wide planning (e.g., demand profiles, flexibility performance)	Polymakers / regulators	Grid operators, utilities, technology companies, and end-users

Sources: ISA & Systemiq (2025).

A Global Mission could accelerate change towards AI-enabled power systems by:

01

Exploring new ways of sharing best practice policy and regulation across countries, for example organising formal workshops, field trips and hackathons with policymakers and regulators across the world, and unlocking the potential for AI to inform data-driven policies.

02

Through this sharing, developing consensus on how to best design regulatory frameworks for digitally- and AI-enabled power systems (e.g., how to design outcomes and performance-based frameworks to incentivise investment in digital and AI technologies).

03

Bringing regulators and technology providers across the world together to share learnings and their experience with new digital and AI technologies to build trust in the outcomes that can be achieved (e.g., allowing grid operators to run transmission lines to a higher capacity than current regulated limits as guided by dynamic line ratings).

This Pillar would build an “AI for Energy Policy Hub” which would provide the following products:

01

Policy and regulatory library, providing examples that have driven measured outcomes in other countries, and guidance notes for governance, interoperability, cybersecurity, etc.

02

Community of practice and a twinning pool, bringing policymakers + regulators across the world together through workshops, clinics, and peer reviews

03

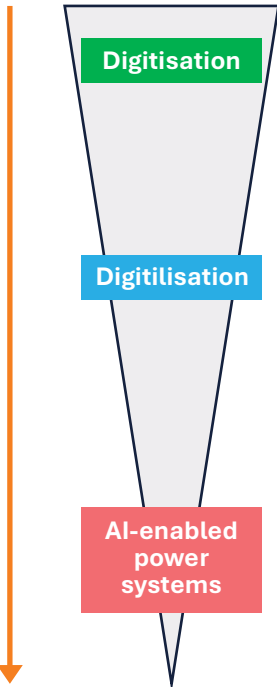
Country adoption packages with a diagnostic tool, a reform roadmap, and draft policy / regulatory instruments

Pillar 2: Capability Building

The development of an AI-enabled power system cannot reach its full potential without a long-term and joined up approach to building digital literacy across society, to building targeted digital and AI skills within the power sector, and to attracting digital experts who understand energy into the sector. Exhibit 18 sets out the five priority actions that are needed at global level.

Exhibit - 18

CAPABILITY BUILDING: KEY ACTIONS



Key Action	Leading Actors	Supporting Actors
1. Build digital literacy across society and within the power sector to enable individuals to productively engage with digital technologies: ▪ Ensure local communities have the basic digital literacy skills to be able to understand their energy use and opportunities to reduce bills, targeting in particular, women and rural communities. ▪ Upskill regulators, grid operators and utilities in data analysis and AI modelling to ensure they can interpret the outputs and insights from digital and AI technologies.	Policymakers / regulators, grid operators, utilities, end-users	Technology companies
2. Build a nexus of energy x AI, with targeted training programmes and sandboxes to develop digital experts skilled in how the power sector works, enabling them to develop solutions to sector-specific challenges.	Policymakers / regulators, grid operators, utilities, end-users	Technology companies
3. Attract digital experts to the power sector by developing long-term career opportunities and invest sufficiently in reward packages. Bring digital experts in through immersion programmes, secondments, and joint hackathons	Grid operators, utilities	Policymakers / regulators
4. Create peer learning and guidance for regulators and utilities to use digital technologies (e.g., twinning, handbooks, workshops). Use demonstrations and sandboxes as learning labs on how to deploy and govern AI tools.	Policymakers / regulators	Policymakers / regulators
5. Take a long-term, joined up approach to building digital x energy skills through collaboration across policymakers, education providers and the power sector to design education programmes and embed digital grid skills in vocational and university curricula with continuing education options.	Policymakers / regulators, utilities, grid operators and education providers	End-users

Sources: ISA & Systemiq (2025).



A Global Mission could accelerate change towards AI-enabled power systems by:

01

Addressing skills gaps by sizing the gaps and opportunities related to the digital / AI transformation of power systems, developing global or cross-country careers opportunities; pooling demand, creating portable career pathways, and running cross-border training pipelines (e.g., shared fellowships, secondments, certification).

02

Developing common competency frameworks (e.g., safety, risk management, data governance) that enable engineers and operators trained in one system to reliably and easily work across others, creating a fluid international labour market and overcoming existing silos.

03

Enabling grid operators and utilities in countries with underdeveloped digital power systems access to real datasets, technologies and operating systems through cross-country sandboxes, peer-to-peer learning and practical training.

This Pillar would build a “Digital X Energy Academy” which would provide the following products:

01

Online role-based training catalogue with courses in key areas such as foundational digital literacy and interpreting AI analytics, AI for power systems, AI governance, etc.

02

In-person training courses, with workshops for utilities and grid operators delivering case study practice sessions with digital platforms and simulations

03

Twinning / mentorship programme consisting of global mentor roster, twinning pool, and case study workshops

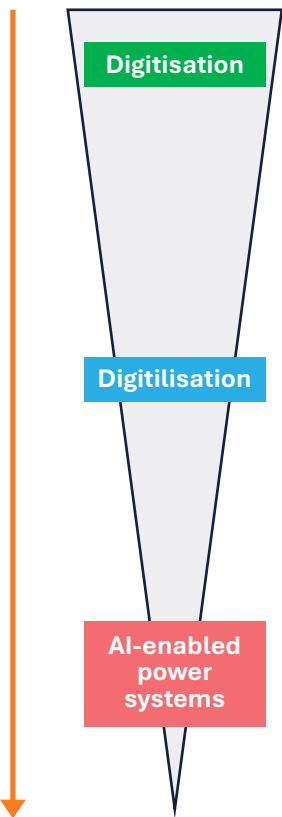


Pillar 3: Data Governance and Infrastructure

Addressing barriers in data governance and infrastructure requires coordinated action across the digital maturity ladder, from establishing foundational hardware standards through to enabling AI-specific data frameworks. Unlocking the value of grid data for AI applications requires frameworks that balance legitimate concerns around security and privacy with the benefits of data access. In high-income countries with active energy data ecosystems, the focus should be on removing barriers to responsible innovation. In middle- and low-income countries, the priority is building the institutional capacity and regulatory frameworks to manage data sharing safely. Exhibit 19 sets out the five priority actions that are needed at global level.

Exhibit - 19

DATA GOVERNANCE & INFRASTRUCTURE: KEY ACTIONS

	Key Action	Leading Actors	Supporting Actors
	1. Establish hardware specifications and procurement standards for sensors, meters, and communications infrastructure - In high-income countries, standards bodies and regulators should accelerate harmonisation of existing specifications across jurisdictions to reduce complexity and support economies of scale. - In the Global South, the priority is developing simplified, tiered specifications that define minimum requirements for basic grid visibility while enabling progressive enhancement as capabilities mature.	Polymakers / regulators, and technology companies	Grid operators and utilities
	2. Develop cybersecurity standards and protocols for grid devices and communications networks from the outset, recognising that retrofitting security is far more costly than building it in.	Polymakers / regulators, and technology companies	Grid operators and utilities
	3. Develop and implement interoperable data architectures based on proven models: - Develop interoperable data standards and open APIs that enable integration across existing systems without requiring wholesale replacement of legacy infrastructure (e.g., building on India Energy Stack architecture) - Implement data governance frameworks that define data ownership, access rights, and sharing protocols - Support development of reference data architectures for AI-enabled grid applications	Polymakers / regulators, and technology companies	Grid operators and utilities
	4. Create enabling frameworks for data sharing and AI applications - Establish data quality standards and validation processes for meter and grid data that enable innovation while protecting sensitive information - Create data-sharing platforms between utilities, aggregators, and third-party service providers, creating access to anonymised data - Require utilities to publish anonymised datasets for AI training and research (e.g., load profiles, generation patterns) – and create sandboxes where new AI applications can be tested under regulatory supervision - Develop AI-specific data governance frameworks addressing algorithm transparency and accountability	Polymakers / regulators, and technology companies	Grid operators and utilities

Sources: ISA & Systemiq (2025).

A Global Mission could accelerate change towards AI-enabled power systems by:

01

Convening technical working groups that include both high- and low-income country perspectives to develop reference specifications and ensure low-income countries have the technical assistance to help regulators adapt standards to local contexts.

02

Adapting reference architectures to different contexts, developing implementation roadmaps that sequence investments appropriately, and provide hands-on technical assistance to utilities undertaking digital transformation. A Global Mission should ensure success stories from early adopters are documented and disseminated to accelerate learning across countries.

03

Facilitating peer-to-peer learning between jurisdictions and support the development of template agreements and governance frameworks that countries can adapt to their circumstances.

This Pillar would build the core digital power system architecture, which would consist of the following:

01

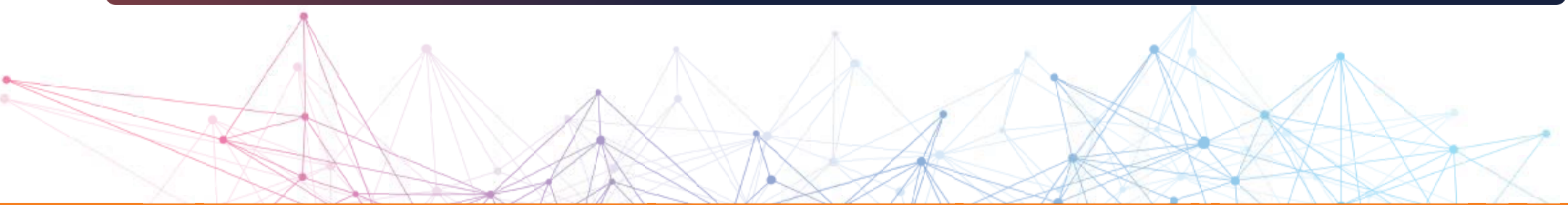
Digital energy grid reference architecture and the minimum data backbone, defining core principles and minimum viable data infrastructure [Box F]

02

Interoperability standards that consists of practical standards guidance and conformance approach

03

Implementation roadmap and pilot toolkit with a maturity assessment, migration plan, and secure-data sharing processes. Convene the best digital energy system architects.



Box F

What is Digital Energy Grid (DEG)?

In February 2025, Beckn Labs¹¹⁵ a mission under Networks for Humanity¹¹⁶ released the [Digital Energy Grid paper](#)¹¹⁷, setting out a shared vision for digital coordination in decentralised energy systems. As energy becomes more distributed, digitised and participatory, digital foundations remain fragmented, proprietary and poorly interoperable. The paper proposes a thin, open coordination layer as Digital Public Infrastructure (DPI) framework for energy – that works alongside existing grids, markets and regulation, enabling interoperability, verification and value exchange without centralising control or replacing incumbents. DEG¹¹⁸ provides common infrastructure building blocks which allow utilities, aggregators, asset and resource owners and consumers to interact while retaining visibility and control.

DEG as a framework for foundational “digital rails” include building blocks such as:

- **Universal addressability for assets, actors and transactions:** A consistent, sector-wide scheme to uniquely identify energy assets, DERs, prosumers, metering and verification instruments, retailers, aggregators and other actors and resources.
- **Verifiability and portability of proofs and credentials:** Cryptographically verifiable proofs of metering, flexibility delivery, asset performance, consent, green attributes, etc., that can move safely between platforms. This is central to enabling trustable interoperability across DSI, FMAR, smart metering and future smart-data schemes.
- **Universal value exchange protocol:** A decentralised, sector neutral protocol for initiating and completing value exchanges (e.g., flexibility activation, settlement events, energy trading, DER services, EV charging sessions, etc.) enables composability and avoids platform lock-in.
- **Universal discovery and trust infrastructure:** Registries, decentralised directories, and credential services (e.g., sector directories, agent registries, CDS/DeDi patterns) allow actors to discover each other, establish trust, prove identity, and validate information without centralising control. This reduces onboarding friction, supports real time claim verifications, reduces fraud and manual verification, and enables small, distributed participants to join markets with confidence.
- **Machine-readable policies:** Common, authoritative, machine-readable representations of regulatory, operational, and program rules-covering eligibility, tariffs, constraints, limits, and program conditions-expressed in structured formats. DEG frames this as “policy-as-a-code”; a verifiable rule layer that can be uniformly evaluated and adopted enabling consistent enforcement, low-discretion governance, transparent verification, and dynamic policy updates without system rewrites.

These rails turn the currently “unified electrically but fragmented digitally” grid into one where any compliant actor can integrate once and interoperate broadly.

Architectural Principles of DEG led Digital Public Infrastructure:

DEG's DPI playbook shows that how the sector build matters as much as what it builds. Architectural coordination should therefore embed design principles as first-class elements:

- **Unbundle to foundational elements:** Separate common rails from vertical applications to reduce lock-in.
- **Build only minimal, interoperable building blocks:** Favour small, reusable components over monoliths.
- **Design to unify, not to make everything uniform:** Allow diversity while enforcing open interfaces and schemas.
- **Trust-by-design:** Privacy-by-default, policy-as-code, strong authentication/authorisation and cryptographic commitments.
- **Ecosystem first:** Patterns that lower barriers for smaller players (DEG-compatible APIs, sandboxes, open reference implementations).

Since the inception of the concept of DEG, we are seeing momentum across a host of use cases and geographies, translating the conceptual framework into applied initiatives and real-world collaborations.

Across countries, significant efforts are already in play—cutting across national, sub-national, and utility-scale initiatives:

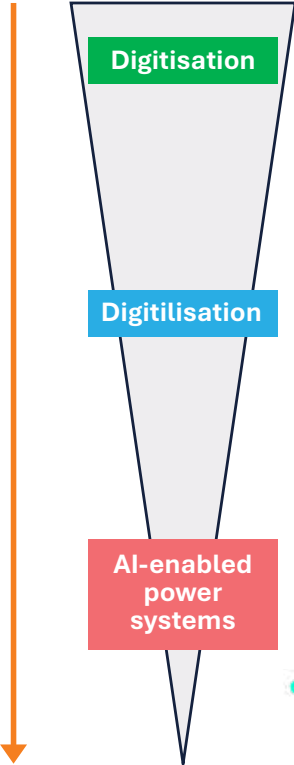
1. **India Energy Stack (IES):**¹¹⁹ A national, open energy infrastructure anchored by the Ministry of Power with Rural Electrification Corporation as nodal agency, built on India's DPI playbook. It enables public and private innovation on shared digital rails. Dr. Pramod Varma (Chief Architect) and Sujith Nair (IES Task Force) are leading the architecture and early lift-offs, with Nandan Nilekani as Chief Mentor.
2. **Unified Bharat e-Charge (UBC):**¹²⁰ An open, national EV charging network with NBSL and the Ministry of Heavy Industries under the PM E-drive scheme to reduce fossil dependence.
3. **Peer-to-Peer Trading:** A P2P trading use case with multiple India utilities (namely Tata Power and UPPCL) enabling prosumers (residential and C&I) to sell surplus energy in an open market; pilots are running in parts of UP and Delhi.
4. **Unified Energy Interface (UEI):**¹²¹ A consortium of 90+ startups, think tanks, not-for-profits and corporations collaborating on energy solutions; it has processed 6 million+ orders and delivered 32+ GWh.
5. **International momentum:** Grid flexibility and interoperable EV charging are being explored with partners in the United Kingdom, Brazil and Germany.

Pillar 4: Innovation and Ecosystem Creation

The potential for AI technologies to transform power systems is a largely untapped opportunity. The world must therefore unleash innovation that is anchored in addressing real utility problems and operational constraints. Exhibit 20 sets out the five priority actions that are needed at global level.

Exhibit - 20

INNOVATION AND ECOSYSTEM CREATION: KEY ACTIONS



Key Action	Leading Actors	Supporting Actors
1. Define a shared digital power innovation agenda and identify priority use-cases to address the most pressing system needs (e.g., reliability, decarbonisation, flexibility).	Policymakers / regulators, grid operators, utilities, and technology companies	Universities and research institutions
2. Unlock testbeds space for experimentation: ▪ Enable low-risk data access (e.g. anonymised / aggregated historical data sets) for early-stage innovation [see Pillar 3] ▪ Create regulatory sandboxes and testbeds for digital and AI pilots	Policymakers / regulators, grid operators, utilities, technology companies, and universities and research institutions	Financial institutions
3. Catalyse solution development through utility–tech collaboration, for example, by running challenge funds and hackathons between digital / tech experts and utilities/grid operators to co-develop solutions.	Policymakers / regulators, grid operators, utilities, technology companies, and universities and research institutions	Grid operators and utilities
4. Build regional Digital x Power innovation ecosystems: ▪ Establish power-sector focused incubators / accelerators, with a targeted focus on emerging markets ▪ Develop regional AI-for-energy hubs and communities of practice	Policymakers / regulators, grid operators, utilities, technology companies, universities and research institutions, and financial institutions	
5. Support innovations to scale and reach global markets: ▪ Facilitate demonstrations and de-risking of pilots ▪ Provide scale-up finance and procurement pathways for proven solutions ▪ Connect innovators to global value chains, and facilitate cross-jurisdiction sharing of learnings and experience with new technologies	Policymakers / regulators, grid operators, utilities, technology companies, universities and research institutions, and financial institutions	

Sources: ISA & Systemiq (2025).

A Global Mission could accelerate change towards AI-enabled power systems by:

01

Overcoming fragmented and siloed markets by developing a collaborative global innovation ecosystem, with a targeted focus on power systems which brings together utilities, start-ups, academia, and funders to crowd-source ideas to global and local grid challenges.

02

Creating standardised innovation playbooks for scaling solutions by aligning interoperability standards, reference architectures, and certification pathways to ensure that solutions can scale across utilities and jurisdictions.

03

Unlocking sufficient finance and varied testbeds across jurisdictions by opening innovations up to larger markets and shared de-risking facilities.

This Pillar would build a “AI x Energy Accelerator” which would provide the following products:

01

Standing convening mechanism bringing together utilities, start-ups, academia, and funders to crowd-source ideas to grid challenges

02

Standardised playbooks + templates with problem definition packs, data sharing agreements, and pilot scopes / KPIs

03

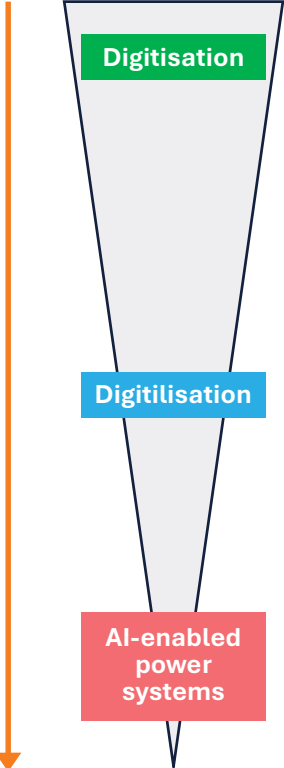
A managed portfolio that delivers paid pilots and follow-on scale mechanisms by convening start-ups with investors and growth finance providers



Pillar 5: Finance and De-Risking

Without sufficient, accessible and low-cost finance, investment to develop AI-enabled power systems will not happen at the scale or pace required. Exhibit 21 sets out the five priority actions that are needed at global level.

FINANCE AND DE-RISKING: KEY ACTIONS



Key Action	Leading Actors	Supporting Actors
1. Mainstream digital grid investment into power-sector planning and finance - Quantify digital grid investment needs (including type of finance) and integrate them into national / utility plans - Embed digital-grid and resilience criteria in green finance frameworks	Grid operators, utilities, MDBs, policymakers / regulators, and financial institutions	
2. Stabilise utility finances and enable cost recovery for basic digitalisation by securing large, creditworthy offtakers, tackling theft and non-payment, and re-design of tariffs / subsidies	Utilities, grid operators, policymakers / regulators, financial institutions	
3. Reposition the T&D network as a value creator rather than a cost center with business models that reward connection - Regulatory reform which rewards networks for efficiency, flexibility, reliability, and data-enabled energy services [Pillar 1] - Position digitalisation as an enabler of system value, as opposed to a cost line	Policymakers / regulators, grid operators, and utilities	
4. De-risk early deployments of digital and AI power technologies, and crowd in private capital: - Convene VC/growth equity and infrastructure funds with start-ups - Develop blended funds with VCs to enable start-ups to move from pilot to scale. - Deploy blended finance and guarantees for pilots and initial rollouts of new technologies - Standardise business cases and procurement templates for digital projects	Financial institutions, policymakers, philanthropies, and start-ups	Grid operators and utilities
5. Build scalable capital markets for digital power solutions: - Aggregate small digital investments into investible portfolios - Create outcome-based and service-based financing models for AI-enabled grid services - Provide concessional finance to build a “product” which can be scaled to other emerging markets	Financial institutions, policymakers, philanthropies, start-ups, MDBs, grid operators, and utilities	Technology companies

Sources: Systemiq (2025).



A Global Mission could accelerate change towards AI-enabled power systems by:

01

Sufficiently lowering the cost of capital of investing in digital and AI technologies – especially in low-income countries – by bringing stakeholders and different types of finance together to pool risks and develop shared de-risking tools and facilities.

02

Developing standardised and repeatable digital / AI “products” through common procurement and contracting standards, which can then unleash capital due to lower transaction costs across jurisdictions.

03

Building a bankable pipeline of investments through global portfolios which overcome the small and distributed transaction sizes of most digital power investments today; in doing so, this creates stronger global demand signals.

This Pillar would build an “AI x Power Product Fund” which would provide the following:

01

Mission-aligned investment blueprint and eligibility criteria that defines qualifications (e.g. business cases, MRV) and scoring to screen projects

02

Build scalable technology products, by providing the core capital for digital products (e.g., digital twins or SCADA), which can then be scaled and tailored

03

A coordinated facility that combines grants + concessional capital to crowd in finance and a project preparation pipeline to get deals to bankability



Realising a Citizen-Centric Vision

Embedded within each pillar will be a core focus on how to build citizen participation and engagement within electricity markets. Exhibit 22 illustrates what the Global Mission will look from a citizen perspective – how it will enable them to do three key things:

01 Understand their energy use: consumers must trust and allow their utility to install a smart meter, and, crucially, have the digital literacy skills to be able to interpret the insights on digital platforms and make decisions based on this. Pillar 2 is critical.	02 Optimise their energy use and their bills: consumers must be incentivised to flex their energy demand in response to price signals, and to trust their utilities to optimise and automate their energy use (e.g., smart EV charging). Pillars 1 and 3 are critical.	03 Actively participate in electricity markets and to earn revenues via peer-to-peer trading and exporting power back to the grid: prosumers must be incentivised to invest in generation and storage technologies, must have trust and transparency over transactions, and be able to easily share data and participate across different vendors. Pillars 1, 3 and 4 are critical.
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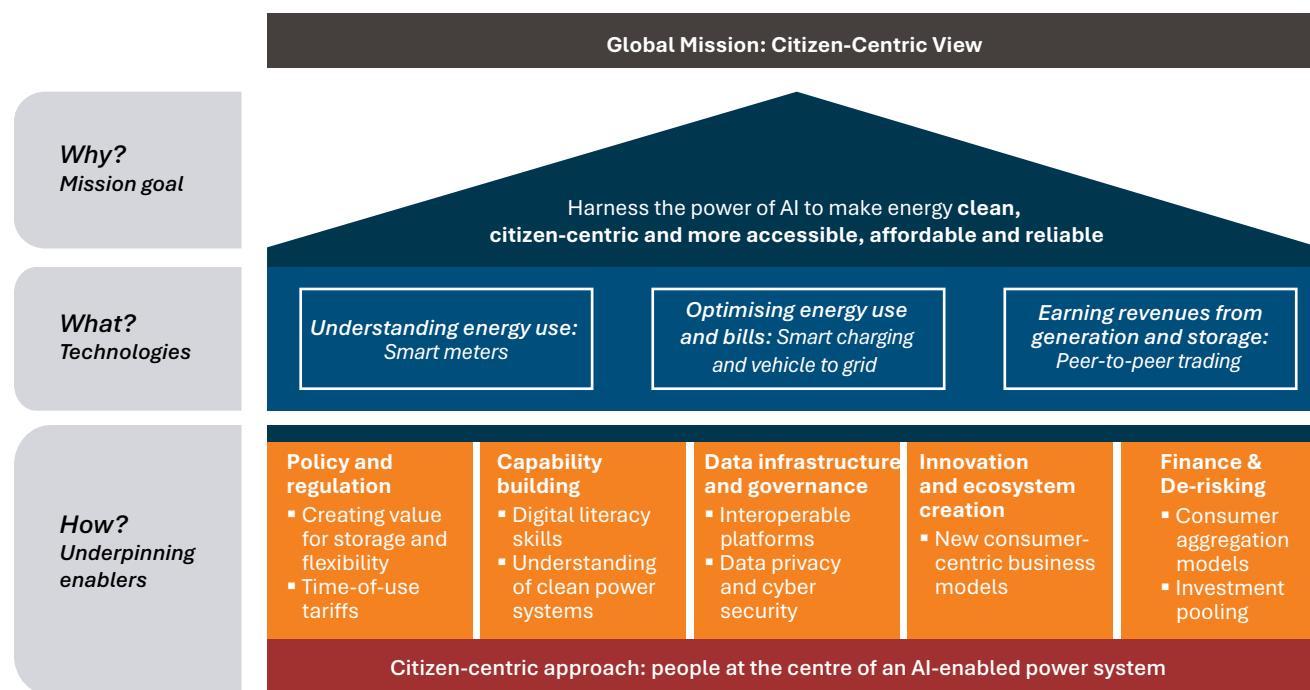
A Global Mission will formalise a global vision for citizen-centric power systems, clearly articulating the economic and social case for people and ensuring the right enablers are in place across the Pillars:

01 Building consensus on the policy and regulatory frameworks which will enable prosumers to productively participate in electricity markets (e.g., creating clear revenue streams for storage and flexibility, and time-of-use tariffs).	02 Building core digital literacy skills across society, especially with women and in rural communities, and an understanding of how clean power systems work (e.g., understanding the concept of grid congestion and price signals).	03 Building interoperable and secure data frameworks which enable transparent transactions, data sharing, and competition.	04 Unlocking innovation on new prosumer-focused solutions, such as peer-to-peer trading and consumer aggregation models.
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In doing so, citizen-centric power systems can be more efficient, cost-effective, and fair by:

01 Providing accurate and real-time data on demand profiles and supply to fuel AI technologies and improve forecasting and system planning.	02 Utilising the potential of distributed energy resources and demand-side flexibility to manage and lower peak demand – therefore lowering the overall investment requirement in clean power systems.	03 Strengthening system resilience and reliability by providing local generation and storage.	04 Unlocking social and political buy-in for the clean energy revolution as citizens share in the value and rewards.
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HOW THE GLOBAL MISSION WILL PLACE CITIZENS AT ITS CORE



Sources: Systemiq, ISA and GEAPP.

Conclusion

We believe that investing in AI-enabled power grids is essential to delivering electricity that is affordable, reliable, and resilient in an increasingly complex energy landscape. Digital intelligence applied to grids can unlock efficiency, accelerate integration of clean energy, and strengthen system stability at scale.

The actions taken in the coming decade will be decisive. Meeting this challenge will require unprecedented international coordination among grid operators, policymakers, investors, technology innovators, energy producers, buyers, and the broader public and private sectors. No single actor or region can achieve this transformation alone.

We see a clear opportunity for a global mission—one that aligns goodwill, capital, and innovation to modernize power systems worldwide. Collaboration today will determine the affordability, security, and sustainability of energy for generations to come. We invite stakeholders who share this vision to engage with us and help shape this collective effort.

Glossary and Summary of Digital/AI Technologies

Table - 5

Technology	Description	TRL	Current deployment	Cost	Key use cases and impacts	Specific implementation barriers
Sensors	Devices which measure temperature, loading and environmental conditions on feeders and assets.	9	High-income: High Rest of world (RoW): Low - medium Common in high-income systems; RoW scaling from pilots to targeted critical feeders.	Low: costs have fallen significantly over recent years.	➤ Visibility and monitoring of assets: faster fault detection, reduces outages and extends asset life	➤ Poor integration within system: relies on digital and operational capacity to analyse and act upon the data collected
Smart Meters+ Meter Data Management Systems (MDMS)	Devices which record electricity use at short intervals and send data to utilities MDM Systems. improving billing accuracy,	9	High-income: Medium – High RoW: Low - medium Coverage nearing 60-75% in some high-income countries; uneven, but often rapid, rollout across RoW (e.g., India and Ghana).	Medium: India benchmarks indicate (\$90–200 per meter)	➤ Billing accuracy and electricity theft reduction ➤ Enables demand-side response and opportunities for households to lower their energy bills ➤ Provides rich data for grid planning	➤ Significant upfront capex cost across all households + businesses ➤ Logistical deployment challenges ➤ Unclear business case for utilities to bear all of the cost ➤ Data governance, privacy and consumer trust ➤ Interoperability across vendors
Feeder-level Meters at Substations	Devices which measure all electricity flowing into distribution feeders.	9	High-income: High RoW: Low - medium Most high-income utilities have some form of measurement at primary substations and feeders; in RoW, often deployed in loss-focused programmes and pilots.	Low: \$300–2,000 per feeder	➤ Provides first level of network visibility to support investment planning and network efficiency improvements. ➤ Enables loss segmentation: identifies which feeders have high losses (technical vs commercial).	➤ Requires feeder identification and mapping (many utilities don't have accurate network topology) ➤ Relies on reliable communications network ➤ Poor integration within system: relies on digital and operational capacity to analyse and act upon the data collected.
GIS and Asset Maps	A system for collecting, managing, analysing and visualising spatial data, such as network topology and asset locations.	9	High-income: High RoW: Low - medium Widely embedded in network planning in high-income countries; increasing use in RoW through donor-backed planning and smart-grid programmes.	Low – medium; main cost is labour to analyse and interpret insights	➤ Support grid expansion planning ➤ Optimise efficiency of system through optimal siting of renewables + storage (e.g., reduce transmission losses) ➤ Reduce the time required to connect new loads	➤ Poor connectivity between asset maps and wider systems (e.g., OMS, billing SCADA) ➤ Weak governance and accountability to keep asset maps updated ➤ Skill gaps, organisational silos, and time constraints to complete surveys

Technology	Description	TRL	Current deployment	Cost	Key use cases and impacts	Specific implementation barriers
Dynamic Line Ratings	Real-time sensors on lines which use weather data to monitor conditions that impact the line's ability to dissipate heat and dynamically adjust the line's power transfer capability accordingly.	9	High-income: Medium RoW: Low Steady rollout across Europe + US; in RoW, DLRs are mainly at pilot stage; studies in India and Vietnam have established that DLRs can significantly increase capacity in hotter climates.	Medium: \$10,000 – 50,000 / km	➤ Increase in the capacity of existing lines (e.g., 10-45% increase in transmission capacity - varies depending on weather condition. ➤ Avoid the need for significant grid build out and investment. ➤ Better manage peak loads.	➤ Regulators currently lack trust in DLRs to run lines above typical capacity – use is therefore limited by regulated constraints ➤ Evolving business case, with current difficulties quantifying financial benefit to grid operators
SCADA (Supervisory Control and Data Acquisition) and Outage Management Systems (OMS)	SCADA is the core operational backbone to power systems, allowing grid operators to monitor, control and supervise the network in real time. OMS use network topology, fault indicators and customer outage reports to locate faults, coordinate switching and manage restoration.	9	High-income: High RoW: Medium Standard backbone of most high-income systems; extensive deployment and modernisation programmes underway across RoW, although progress is partial and uneven.	High: Ranges from ~\$10,000–100,000 for small or basic systems to multi-million-dollar national platforms.	➤ Improves grid reliability: reduces outages, improves restoration times, and fault detection. ➤ Operational efficiency through remote monitoring and digital control and loss detection ➤ Safe network operation ➤ Improves asset utilisation and planning ➤ Provides the foundation for automation and advanced control systems	➤ High upfront capital and ongoing opex (e.g., cybersecurity) ➤ Requires strong communications infrastructure ➤ Challenges integrating legacy infrastructure and lack of interoperability ➤ Requires strong digital skills for complex control-room decision-making.
Digital Twins	Virtual representations of grid assets (e.g., solar, batteries, demand, poles and wires) that use network data (e.g., voltage, load) and exogenous data (e.g., weather, topography) to mirror real-time system status and performance.	6-9	High-income: Medium RoW: Low–Medium Increasingly used by TSOs and DSOs in Europe and other high-income markets; RoW deployment is growing through targeted pilots at transmission and distribution level (e.g., Jaipur, India).	Medium – high	➤ Optimise operation of the power system (e.g., can deliver 10–25% of additional capacity) ➤ Support grid expansion planning (e.g., better forecasting and simulations) ➤ Lower maintenance costs (e.g., 20–40% lower inspection costs)	➤ Fragmented datasets/systems and complex integration across GIS, SCADA, AMI ➤ Large upfront effort with benefits spread across functions, making business case unclear ➤ Practical/logistical challenges of mapping assets (e.g., labour-intensive)

Technology	Description	TRL	Current deployment	Cost	Key use cases and impacts	Specific implementation barriers
Smart Inverters	Hardware which converts direct current from DERs into grid-compatible alternating current and automatically adjust voltage and frequency to maintain grid stability.	9	High-income: High RoW: Medium Common in new solar PV installations in high-income markets; in RoW, rollout is growing, but setup and enforcement remain uneven.	Low – medium	➤ Supports grid stability via frequency and voltage control. ➤ Network efficiency: reduces losses and outages ➤ Reduces PV curtailment by up to 50% when all PV systems on the feeder use smart inverters + battery storage.	➤ Technical challenges aligning settings across different inverter types and old equipment. ➤ Utilities may lack skills and confidence to manage advanced settings. ➤ Unclear business case – who pays for communications and setup costs.
DER Integration and Management Platforms	Software platforms that register, monitor and dispatch distributed energy resources (e.g., rooftop PV, batteries and EVs) as grid assets.	7-9	High-income: Medium RoW: Low - medium Growing use in high-DER markets in Europe, North America and Australia; early pilots in RoW such as India.	Medium – high Cost driven by platform licensing and integration with utility and market systems.	➤ Full visibility of all assets within system ➤ Utilisation and optimisation of DER assets: reduces curtailment, enables demand-side flexibility, and avoids renewables + grid investment ➤ Unlocks new value streams and enables households to be active participants in clean power systems	➤ Lack of common device and data standards create challenges integrating with utility systems. ➤ Data-sharing constraints between utilities, aggregators and customers. ➤ Immature market design and regulatory frameworks for DER participation in many jurisdictions.
Microgrid Energy Management Systems	Control platforms that optimise local generation, storage and loads within islanded or grid-connected microgrids (e.g., commercial building complexes), often serving rural communities, or islands.	8-9	High-income: Medium RoW: Low – medium Pilots and commercial deployments exist in high-income and emerging markets.	Low – medium Cost depends on microgrid size, control sophistication and degree of automation.	➤ Energy independence and security: cuts diesel generation back-up ➤ Boosts electricity access ➤ Control and optimisation of energy costs	➤ Interoperability between microgrid controllers, DERs and utility systems – this limits integration at scale ➤ Limited local technical capabilities to operate advanced controllers. ➤ High upfront costs of tailoring software to individual systems + unclear who the benefits accrue to ➤ Weak communications infrastructure
Smart Building Energy Management Systems + Smart Appliances	Software that monitors, controls, and optimises energy use in a building by coordinating HVAC, lighting, on-site generation, storage, and flexible loads in real-time.	9	High-income: Medium RoW: Low Mass-market availability in many high-income countries, although deployment is below where it needs to be; deployment in RoW is fundamentally held back by limited price signals and smart meter rollout	Low – medium Cost varies depending on sophistication of system. Challenge is deployment across millions of households	➤ Core to a citizen-centric power system – it provides consumers with the data and ability to take control of their energy use. ➤ Enables and automates demand-side flexibility ➤ Critical tool for grid operators to manage peak demand	➤ Lack of harmonized standards and interoperability across utilities and platforms. ➤ Lack of consumer engagement and trust to share data. ➤ Relies on smart meters and time-of-use tariffs being in place

Technology	Description	TRL	Current deployment	Cost	Key use cases and impacts	Specific implementation barriers
Smart Charging and Vehicle-To-Grid (V2G)	Smart EV chargers schedule charging at low-cost or off-peak times, while V2G systems allow EVs to both charge and export power back to the grid or buildings.	7-9	High-income: Medium – high RoW: Low Smart charging is widely deployed across EV owners, while V2G deployment remains at an earlier stage, with emerging commercial fleet applications and early residential offerings in Europe, Japan and North America, and large-scale pilots under development in China.	Low - medium for smart charging Medium - high for V2G, with indicative additional costs of ~US\$4,000 for a V2G-ready charger	➤ Smart charging reduces peak load on local grids by around 20–30% ➤ Improves utilisation renewables ➤ Enables prosumers to earn revenues and minimise energy bills	➤ Limited coordination and interoperability between utilities, OEMs and charge-point operators ➤ Consumer concerns over battery degradation. ➤ Unclear allocation of value between drivers, fleet operators, aggregators and system operators. ➤ Lack of granular price signals and clear market-access rules and incentives
AI Forecasting Software	Machine learning forecasting systems that use weather and past performance data to learn relationships and provide short- and long-term generation forecasts to inform dispatch and reserve procurement.	9	High-income: Medium - high RoW: Low Forecasting is a fundamental capability in most high-income countries; the use of AI to enhance forecasts is growing. Adoption across the RoW is expanding as renewable generation grows.	Low – medium	➤ AI can improve typical forecast accuracy by around 20–45% ➤ Reduces reserve needs and improves system planning ➤ Optimises renewable and storage assets and supports higher renewable penetration	➤ Relies on high-quality weather and plant data, with forecasting systems having to be tailored to specific climates. ➤ Integration into legacy dispatch workflows and building operator trust in AI outputs. ➤ Unclear how savings from lower reserves and imbalances are shared between operators and plant owners.
AI-enhanced Grid Management Systems (including Automated Monitoring & Decision-Support Systems)	Modern platforms that use AI to build on existing EMS and DMS platforms to enhance decision-making and to monitor, operate and optimise aspects of the network automatically, or with minimal human input.	7–8	High-income: Low–Medium RoW: Low Early-stage deployments and pilots in a limited number of utilities, typically implemented as software layers on top of existing SCADA/EMS/DMS platforms.	Medium – high Costs are driven by upgrades to control platforms, integration of additional data sources, and advanced software deployment.	➤ Improves the speed and consistency of operational decisions ➤ Reduces reserve requirements by improving confidence in system conditions ➤ Shortens outage duration by supporting faster fault assessment and restoration ➤ Supports efficient operation of clean power systems	➤ Ensuring reliability and transparency of decisions and strong cybersecurity. ➤ Building trust in AI-assisted decision-making and understanding where human input is / is not required ➤ Limited regulatory recognition of where AI can automate / support decision-making and operations.

Technology	Description	TRL	Current deployment	Cost	Key use cases and impacts	Specific implementation barriers
AI Predictive Maintenance	Monitoring and analysis of network assets, using sensors and operational data to spot early signs of equipment problems, estimate failure risk and guide maintenance teams to assets at the right time.	6-8	High-income: Medium RoW: Low Increasingly layered onto SCADA and DMS systems in high-income countries; RoW deployment is at pilot level, often focused on critical transformers and lines.	Medium	➤ Reduces unplanned outages and catastrophic failures ➤ Improves maintenance efficiency by shifting work onto higher-risk assets ➤ Reduces overall investment need by extending asset's service lives.	➤ Inconsistent or sparse historical failure and condition data ➤ Integration with legacy systems. ➤ Changing maintenance culture from time-based to risk-based practices ➤ Building trust in model outputs. ➤ Misaligned incentives where regulations remunerate capital investment more readily than O&M efficiency.
AI for Loss Detection	Machine-learning systems that analyse smart-meter, feeder-meter and network data to identify patterns of technical losses, electricity theft, meter tampering and billing irregularities, enabling targeted field inspections and revenue recovery.	6-8	High-income: N/A (losses generally not material) RoW: Low Deployed mainly through pilots and early commercial implementations in high-loss electricity systems where AMI or feeder-level metering data is available.	Low – medium	➤ Significantly improves theft detection compared with random inspections, enabling targeted enforcement ➤ Supports revenue recovery in high-loss areas ➤ Reduces unnecessary field visits by focusing on high-probability cases.	➤ Interoperability challenges across appliances, vendors and communication protocols ➤ Data privacy concerns
Automated Building Energy Management Systems	Energy-management systems that monitor and automatically control building electricity use by controlling appliances (e.g., lighting which responds to sensors), optimising appliances (e.g., heating and AC in response to weather and occupancy) in response to prices or grid signals while maintaining user comfort.	9	High-income: Low - medium RoW: Low Commercial products and pilots are established in several high-income markets, with emerging deployments in RoW where smart appliances, rooftop PV or storage are bundled.	Low – medium, depending on scale and sophistication (e.g., individual flat vs high-rise office building)	➤ Reduce peak demand through automated load shifting (e.g., EV smart charging) ➤ Improve utilisation of rooftop solar and batteries ➤ Enable participation in demand-response and local flexibility programmes ➤ Support grid stability on congested feeders and help defer distribution network reinforcement.	➤ Interoperability challenges across appliances, vendors and systems. ➤ Customer trust, data-privacy concerns and acceptance of automated control. ➤ Limited incentives where retail tariffs lack time-varying or flexibility-based signals.

Key sources include: ETC (2025), *Power Systems Transformations*; IRENA (2023), *Artificial Intelligence and Digitalisation in Power Systems*; ISGF (2025), *Case studies on AI-enabled grid operations, robotics, asset analytics and VR-based training*; CurrENT (2024), *Prospects for innovative grid technologies*; IEA (2025), *ETP Clean Energy Technology Guide*. Please also refer to the sources listed in Annex 2 – Case Studies.

Case Studies of Digital and AI Technologies within Power Systems



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How Australia is Leveraging AI Generation Forecasting to Improve Grid Planning and Reliability



What was the problem?



- Accurate forecasting of wind and solar electricity generation is essential for maintaining grid reliability, reducing system costs, and avoiding reliance on fossil-based backup.
- Traditional forecasting tools often deliver only **60–70%** accuracy and struggle with rapid cloud cover changes, wind variability and Australia's highly diverse climate regions.
- This makes it challenging for grid operators to integrate high renewable shares while keeping the system stable and affordable.

What is the technology?



- AI and machine-learning forecasting systems analyse satellite imagery, weather-station data, atmospheric sensors and historical performance in real time. The models predict cloud movements, solar radiation and wind-pattern changes with hour-ahead and day-ahead precision.
- At the Hornsdale Wind Farm, these models also incorporate turbine data, wind behaviour and atmospheric conditions to optimise output and dispatch.
- As a result, the models achieve forecasting accuracy levels of roughly 90%.

How was it implemented?



- AI forecasting has been deployed at solar and wind farms across Australia. The results connect to grid-management systems, helping operators plan ahead, balance supply and demand, and use batteries at the right time. This enables better scheduling of dynamic reserves and more efficient dispatch.
- Real-time alerts prepare operators for sudden drops in solar or wind output, while automated controls (e.g., panel positioning or turbine adjustments) help increase generation and support grid stability.
- These tools are already in use across multiple regions and sites, with demonstrated results at Hornsdale (South Australia), Gannawarra (Victoria) and the Sunshine Coast Solar Farm (Queensland).

What was the impact?



Economic impacts: A **20–30%** improvement in forecasting accuracy boosts renewable utilization and reduces curtailment. Key examples include a **~25%** increase in renewable electricity generation at Hornsdale and **45% fewer forecast** errors at Gannawarra.

Social impacts: Improved forecasting strengthens reliability for communities by helping keep the grid close to its safe operating range. At the Sunshine Coast Solar Farm, this meant the grid stayed within safe limits **98%** of the time.

Environmental impacts: Better forecasting allows more clean energy to be used rather than curtailed, this also reduces reliance on fossil-fuel backup

How China's State Grid Uses AI for Real-Time Power-Flow Control to Improve Grid Stability



What was the problem?



- Large provincial grids in China frequently experienced transmission line overloads and voltage violations, worsened by high shares of intermittent renewables.
- Traditional optimisation methods were too slow to compute system-wide generator redispatch in real time.
- Operators lacked tools to detect and resolve violations within operational timeframes, risking stability and higher system costs.

What is the technology?



- Grid Mind, an AI-driven real-time grid-control platform built with Deep Reinforcement Learning (DRL), analyses grid conditions and recommends redispatch actions, adjusting generator outputs up/down to keep the grid stable in under 30 milliseconds, fast enough for real-time correction.
- A built-in safety layer ensures every recommended action is physically feasible and meets grid constraints before execution. The platform integrates directly with the energy management system (EMS) for seamless real-time data and control.

How was it implemented?



- A DRL agent was trained offline using a large set of historical EMS snapshots, then deployed online to continue learning under real operating conditions. Required building a smooth AI-EMS interface to support high-frequency data exchange and automated decision execution.
- It was jointly delivered by the State Grid Corporation of China (SGCC) and DAMO Academy in 2019, following a successful demonstration. It has been fully operational since

What was the impact?



Operational impacts:

- AI resolved **100%** of **810 operational snapshots** containing grid violations during the one-week trial.
- Delivered decisions in **<30 milliseconds**, enabling real-time corrective action.
- Reduction in operating costs.

Economic impacts: ~4% reduction in system losses by improving power-flow efficiency and optimisation.



How Australia Used AI-Powered Flexible Exports to Turn Grid Constraints into System Value



What was the problem?



- South Australia has one of the world's highest rooftop-solar penetrations, with **1 in 3 homes** generating electricity, creating variability the electricity grid must manage.
- High daytime solar output causes reverse power flows (electricity flowing back into the grid), triggering voltage swings and feeder congestion because the network was not designed to carry large upstream flows. As a result, the grid could only allow **1–2 kW** of export per home despite **10 kW** system capacity.
- As rooftop solar generation surged, SA Power Networks (SAPN), the state's distribution network operator, began classifying many substations as congested, signaling the need for grid upgrades unless solar could be better managed.

What is the technology?



SAPN deployed Schneider Electric's EcoStruxure™ Distributed Energy Resource Management System (DERMS), a platform for forecasting and controlling distributed energy resource (DER) exports, which introduced Dynamic Operating Envelopes (DOE), flexible, real-time solar export limits across a highly solar-saturated grid. This included:

- **Real-time export-limit calculations**, updated every 15 minutes, based on forecast and actual grid conditions
- **AI-enabled optimisation** to safely maximize solar exports while preventing voltage and thermal congestion
- **Cloud-based communication to smart inverters** (devices that connect solar systems to the grid), using secure online protocols so updated export limits are applied automatically at scale

How was it implemented?



- The project investigated, tested, and verified the integration and automation of flexible exports in areas with high DER penetration, enabling greater dispatch of rooftop solar and unlocking existing network hosting capacity without physical upgrades.
- SAPN set up real-time Dynamic Operating Envelopes (DOE) so that flexible export limits are automatically calculated and updated every 15 minutes.
- Manual and emergency overrides were retained so operators can apply emergency limits or correct DOE values when calculations are not appropriate.

What was the impact?



Economic impacts:

- Customers can export up to **10 kW (v/s ~1.5 kW/0)**, increasing value of rooftop solar.
- Projected to save South Australian customers more than **\$100 million** in avoided distribution network upgrades over the next decade.
- Avoidance or deferral of costly network augmentation.

Social impacts: Dynamic Operating Envelopes give customers greater choice and clarity in managing rooftop solar exports.

Environmental impacts: By enabling dynamic export limits, SAPN can significantly increase solar hosting capacity, reduce curtailment, and displace fossil-fuel generation.

How the Netherlands Used Smart Energy Management and Vehicle-to-Grid to Manage Peak Demand



What was the problem?



The Johan Cruijff Arena, an events venue in the Netherlands, faced several energy-related challenges:

- High electricity use (**~8.6 GWh/year**) with high peak demand (**3 MW+**)
- Heavy reliance on diesel backup generators because the Arena's rooftop solar covered only **~8%** of demand and the site was constrained by a **3.4 MW** grid-connection limit, leaving insufficient power during major events.
- Rising EV adoption risked exceeding the 3.4 MW grid connection limit.

The arena sought a strategy involving energy storage and smart controls to reduce emissions, increase energy autonomy, and access flexibility services.

What is the technology?



- A 3 MW / 2.8 MWh battery system, 14 smart 22 kW EV chargers and a 10 kW Vehicle-to-Grid (V2G) charger were installed alongside the existing 1 MWp rooftop PV system, all coordinated by an **Energy Management System (EMS)** from The Mobility House, a technology company.
- The EMS uses real-time data to **manage power flows between PV, the battery, EV chargers and the grid**, keeping total demand within the 3.4 MW grid-connection limit while supporting peak shaving and grid-stability services.
- Smart-charging and **V2G software** continuously monitor key battery metrics, and automatically adjust charging or discharging. This allows vehicles to support the grid when helpful, while ensuring they still leave with sufficient charge for the driver.

How was it implemented?



- Delivered by a multi-partner consortium (Arena, AUAS, Eaton, Nissan, The Mobility House, Liander, Tennet).
- During the pilot phase, 148 Nissan Leaf batteries installed (**40%** were second-life batteries reused from EVs).
- The pilot successfully demonstrated measured outcomes and is now part of day-to-day stadium energy management, with plans to scale similar capabilities across the **2,000-space car park**.

What was the impact?



Economic impacts: **~€0.4M/year** in extra revenue from the **3 MW battery** providing grid stability services, additional savings from a **10% peak-demand reduction** during major events, and **€15k/year** saved via smart EV load management. This means the initial investment of of **~€1.8–2.0M (3 MW / 2.8 MWh at ~€650k/MWh)** will pay back in 10 years.

Environmental impacts: **~2,012 tCO₂/year reduction**, higher energy autonomy, and **178,204 zero-emission km** enabled via EV charging.



How Dynamic Grid Pricing Can Reduce Peak Loads and Manage EV Demand



What was the problem?



- Distribution grids in the UK are seeing demand growth from EVs, with demand patterns also becoming more complex.
- This rising, and increasingly dynamic, demand is outpacing existing network capacity, creating risks such as higher losses, reduced efficiency, and potential damage to both the network and consumer devices.
- A major driver of new load is customer-owned distributed energy resources (DERs) such as EVs and heat pumps. If usage isn't managed, they can strain local grids.
- Despite this, pricing remains static – most households in the UK have a fixed day/night tariff that does not adjust to real-time or location-specific supply/demand changes.

What is the technology?



- SSEN (Scottish and Southern Electricity Networks), a UK Distribution Network Operator, partnered with Octopus Energy using Kraken's grid-management platform. The platform used grid topology and telemetry data to build real-time visibility around four substations in Dundee. Kraken trained a forecasting model to predict power flow and congestion at each substation.
- Forecasted load was turned into a day-ahead dynamic grid price, with low prices when substations had spare capacity (**below 80%**), rising prices as they neared limits (**80–120%**), and very high prices once they exceeded safe capacity (**>120%**).
- EV drivers were placed on a bespoke automated charging tariff, allowing the time of charging to shift in response to these prices.

How was it implemented?



The SSEN trial tested whether automatic price signals could shift EV charging away from busy times on the grid:

- 4 monitored primary substations were included (**around 10 EVs each**), plus an aggregated group of **72 EVs** and a control group of **110 EVs elsewhere** in the **UK**.
- Each treatment group received a dynamic price signal based on local conditions forecasted by Kraken; the control group stayed on the standard tariff.
- Kraken's flexibility engine automated EV charging, shifting load away from constrained periods while still meeting customer charging preferences.

The success of the trial led Octopus Energy to roll out the same automated smart-charging approach nationwide through its flexible EV tariff.

What was the impact?



Operational impacts:

- EVs avoided high-congestion periods and cut local load by **~50%** in some cases, while still meeting driver's EV needs.
- If applied across the wider network, dynamic pricing could defer grid-capacity upgrades by **10+ years**, reduce peak load by **25%**, save **£1 billion**, and shift over **100 GWh** of energy off-peak each year.

Social impacts: To date, 2 million Octopus customers have participated in some form of demand shifting and are making average savings of up to £415 / year on an EV tariff.

Environmental impacts: Over 100 GWh/year of EV charging can be shifted to times of surplus renewable generation, reducing the need for dispatchable fossil generation.

Modelling a “Smart Distribution Island” Approach for Small Island States



What was the problem?



- The Maldives' electricity systems are small and geographically dispersed, with no interconnection between islands. Heavy dependence on imported diesel exposes utilities to fuel price volatility and supply risks.
- Rising demand for electricity is driven by cooling needs and urbanisation, while tourism increases system stress. Growing deployment of rooftop and ground-mounted solar PV creates operational challenges, including variability and voltage stability, and there is currently limited system visibility.
- Without early digitalisation, utilities risk inefficient operations and costly retrofits.

What is the technology?



- Environmental Design Solutions, a consultancy, developed a model AI-enabled smart distribution system to demonstrate how smart metering deployed as core digital infrastructure with AI can serve as the backbone of a smart, resilient, and renewable-ready distribution system suited to island power networks.
- The model uses an AI analytics layer that uses meter, network, and weather data to:
 - Forecast demand and solar generation
 - Support voltage and frequency stability in small island grids
 - Enable predictive maintenance, loss detection, and operational optimisation
- Designed to support renewable integration, energy efficiency, and demand-side flexibility from the outset.

What is the model's approach?



- Designed as a model “smart distribution island” with universal smart metering across residential, commercial, and public consumers to establish real-time system visibility.
- Smart meter data is integrated with meter data management, billing, outage management, and utility IT systems to create a single digital view of network operations.
- AI analytics configured using local conditions, including island-specific load behaviour, weather patterns, and tourism-driven demand cycles.
- Selective, high-impact AI use cases identified, such as cooling load optimisation, solar-aligned desalination and water-pumping schedules, and AI-supported peak demand management.
- Structured explicitly as a replicable model, enabling lessons learned to be adapted and scaled across other Maldivian islands and Small Island Developing States (SIDS).

What are the potential impacts?



Economic impacts: Projected to reduce diesel fuel consumption through higher renewable utilisation and optimised dispatch, lower operational costs via AI-driven automation, loss reduction, and predictive maintenance, and defer generation and network investments through demand optimisation.

Social impacts: Projected to improve reliability and speed up outage detection and restoration, increase transparency and consumer control through smart metering and digital services, and enhance service quality on tourism-dependent islands.

Environmental impacts: Projected to enable higher renewable energy integration in island systems, reduce emissions from diesel generation, and provide a scalable digital foundation supporting Maldives' long-term clean energy transition.

How Digital Twins Help African Utilities Reduce Losses and Improve Revenue Collection



What was the problem?



- Many African electricity utilities lose over 40% of revenue due to inaccurate customer and asset data and poor visibility of their distribution networks.
- Utilities are unable to determine supply points - which lines, or substations electricity is flowing through, which customers are paying, or where outages and losses are.
- Manual network accounting is slow and error-prone, with limited knowledge of customers, assets, and grid topology.
- Sector investment focused heavily on generation and transmission, while distribution challenges remain largely unresolved.
- Furthermore, significant revenue severely impact ability to invest in grid infrastructure, leading to poor grid reliability.

What is the technology?



Beacon Power Services (BPS) deployed a GIS-based digital twin of the distribution network, linking customers, meters, and physical assets into one integrated system:

- A digital asset and customer mapping platform creates an accurate grid map that shows how every customer connects to poles, transformers, and feeders.
- A real-time grid management platform connects to smart meters and field devices to monitor energy flows, outages, and losses.
- A consumer mobile app enables visibility into consumption, billing, and payments, improving transparency and engagement.

These tools give utilities a single, accurate, real-time view of distribution networks.

How was it implemented?



- Beacon Power Services (BPS) combined GIS-based mapping, mobile data collection, and drone imagery with AI based image detection and field verification to digitally map customers and grid assets. Where smart meters were not already in place, BPS supported utilities with meter deployment and system integration to enable real-time monitoring.
- Customer and asset data were digitally validated with on-the-ground checks, and the platforms were rolled out alongside utility staff training and workflow digitization to embed them into daily utility operations.
- Implementation began in Nigeria, where BPS now works with 6 of the country's 11 distribution utilities, and later expanded across Ghana, Tanzania, Togo, Zambia, typically starting in high-loss areas to deliver early impact.

What was the impact?



Economic impacts

- Around \$70M in additional annual revenue generated across BPS's utility deployments by identifying customers connected to the grid but previously unbilled.
- Improved billing efficiency and revenue collection from 30% to 90% through accurate customer and asset data and simpler loss identification.

Social impacts

- Faster outage detection and restoration, improving service reliability and trust.
- Greater transparency for customers through accurate billing and digital tools.

Environmental impacts: Reduced technical and commercial losses, improving overall system efficiency.

How Digital Twins Improved Visibility and Performance in Low-Voltage Distribution Networks



What was the problem?



- BSES Rajdhani Power Limited (BRPL), Delhi's electricity distribution utility, had limited visibility of its low-voltage network beyond the substation. Once power left the substation, it was often unclear which feeders, transformers, cables, or groups of customers were affected by overloads, faults, or poor power quality, as data from GIS, billing, and SCADA systems was fragmented and not time-aligned.
- Low-voltage network issues were mainly identified through customer complaints, delayed fault reports, and occasional manual inspections, making it difficult to pinpoint problems quickly or plan upgrades efficiently.
- As electricity demand grew and new loads such as electric vehicles, air conditioning, and rooftop solar expanded across Delhi, these visibility gaps increasingly threatened reliability, customer experience, and long-term network planning.

What is the technology?



The solution combined low-voltage network monitoring with existing utility systems:

- **GIS-based network mapping** to create an accurate digital model of feeders, transformers, and downstream connections
- **Feeder-transformer connectivity cleanup** using GIS and billing data to correctly link customers to the assets supplying them
- **SCADA** to combine substation data with visibility from the low-voltage network
- **Monitoring & Analytics** to track loading, voltage, and quality closer to end users

These elements converted fragmented data into a coherent digital view of the distribution network.

How was it implemented?



- The utility began by cleaning up feeder and transformer connectivity, reconciling GIS records with billing data to ensure customers were correctly mapped to network assets.
- Low-voltage network data was then integrated with existing SCADA systems and visualised through GIS-based network models, allowing engineers to relate operational conditions to specific locations and customer groups.
- Deployment focused first on areas experiencing higher load growth and operational stress, enabling targeted analysis and gradual scale-up.

What was the impact?



Economic impacts

- Reduced technical losses across pilot areas: 0.1% in low-loss neighbourhoods, and 2% in high-loss neighbourhoods within one year.
- Approval times for new electricity connections dropped from 5 days to within 2 days.

Social impacts

- Average power restoration time after outages fell from 56 to 30 minutes (46% improvement).
- Voltage-related customer complaints declined in high rooftop solar areas.

Environmental impacts: Improved network visibility and performance supported higher rooftop solar adoption.



How Spain's Digital Twin Improves Transmission Capacity in Ibiza

What was the problem?



- Spain's transmission operator, REE, needed a more accurate estimate of how much power Ibiza's transmission lines could safely carry, so it could plan future investments and ensure the network could meet the island's rising summer electricity demand.
- Existing methods for estimating line capacity weren't reliable enough, creating uncertainty about where upgrades were genuinely required. Key challenges included:
 - Highly seasonal, peaky summer demand driven by tourism
 - A mix of line types (400 kV, 220 kV, 66 kV) with different characteristics
 - Lines running through dense vegetation and urban areas, making conventional thermal-capacity calculations difficult

What is the technology?



- Enline, a grid-analytics technology company, deployed Enline Live View, a digital-twin platform that estimates transmission-line behaviour in real time without installing any sensors or field hardware.
- The platform uses existing substation electrical measurements, combined with physical and virtual weather data, to model line temperature, sag and capacity under changing conditions.
- Its AI-based algorithms simulate how each line responds to load and weather, enabling REE to calculate maximum safe power flow much more accurately than traditional static rating methods.

How was it implemented?



- Enline applied the digital twin to four transmission lines in Ibiza, using REE's existing electrical data and meteorological inputs.
- The model continually assessed how environmental and operational conditions affected thermal limits and remaining headroom.
- REE used these real-time and historical outputs to support planning decisions and identify where upgrades were actually needed.

What was the impact?



Economic impacts: The digital twin revealed an average ~20% increase in usable transmission capacity, enabling the TSO to defer or better target future investments and make more efficient use of existing assets. It also reduced the need for near-term build-out and improved the quality of long-term planning decisions.

Social impacts: Better visibility of real capacity lowers the risk of summer supply issues and helps avoid disruptive construction works for local communities.

Environmental impacts: More efficient use of existing lines delays the need for new transmission infrastructure and reduces reliance on carbon-intensive backup generation during peak periods.

How the Philippines uses Smart Building Controls to Optimize Energy Demand



What was the problem?



- Office buildings in the Philippines face high cooling demand because of the hot, humid climate, and they often waste energy because ventilation, cooling, and lighting systems run at fixed settings that do not adjust to real-time occupancy or daylight.
- These inefficiencies lead to higher electricity use and emissions, even in buildings equipped with efficient HVAC and lighting hardware.
- Arthaland, a real-estate developer, wanted its flagship office tower to meet the highest global green-building standards and achieve net-zero operational carbon through reduced energy demand and renewable electricity.

What is the technology?



The building installed a coordinated control system that links the ventilation, cooling, and lighting so all equipment runs only when needed and at the right level.

This works with:

- Smart ventilation that uses sensors in occupied rooms to tell the fans how fast they should run, so the system only brings in the fresh air that is needed. A second system reuses the cool air leaving the building to help cool the fresh air coming in.
- Smart lighting that brightens, dims, or turns off automatically based on daylight occupancy.

How was it implemented?



- Arthaland first reduced heat entering the building with high-performance windows and cooling zones tailored to how each area is used. These passive features were paired with the smart control systems.
- The ventilation, cooling, and lighting systems were then installed and connected through one control setup so they could operate together throughout the day.
- Because the systems use built-in sensors and automated controls rather than field hardware, they were straightforward to incorporate during construction.
- After reducing overall energy demand, the building sourced 100% renewable electricity from a hydro plant to reach zero operational carbon.

What was the impact?



Economic impacts: The smart control systems helped deliver part of the building's 45% reduction in energy use per square meter.

Social impacts: Sensor-based ventilation and automated lighting improve indoor comfort by ensuring fresh air and appropriate lighting only when required.

Environmental impacts: lower energy demand from smart controls enabled the building to operate with zero operational carbon when paired with clean electricity.



How Ghana uses Smart Prepaid Metering to Reduce Electricity Theft

What was the problem?



- NEDCo (Northern Electricity Distribution Company, Ghana's distribution utility) faced high non-technical losses (NTLs) from electricity theft, meter bypassing and tampering, incorrect readings, and defective or aged postpaid meters.
- Post-paid meters were installed at customers' premises, making tampering easy, while theft detection relied on manual inspections that were costly, slow, and often ineffective.
- These issues contributed to around 30% loss of electricity supplied by utilities in Ghana, weakening the utility's finances and making reliable power supply harder to maintain.

What is the technology?



- Anti-tamper, anti-fraud, anti-theft smart prepaid meters that require customers to purchase electricity units (kWh) before use were installed.
- Meters were mounted on service-pole tops to keep the metering unit out of reach and reduce tampering. Customers buy credit at vending points; if the meter is not auto-loaded, they enter a purchased token on a keypad installed at their home.
- The meters provide daily consumption information and low-balance alerts, removing the need for monthly meter reading and paper billing, helping customers track use.

How was it implemented?



- In May 2019, NEDCo launched a smart prepaid metering pilot in Berekum after a customer education campaign.
- About 1,000 smart prepaid meters were installed for residential customers, selected randomly across the area, with no targeting based on theft or consumption levels.
- Meters were mounted on service-pole tops and initially loaded with 10 kWh to keep supply on until customers made their first purchase.
- After installation, all consumption for treated customers was recorded through NEDCo's smart prepaid vending system, while customers from the treatment group remained on postpaid meters.
- Since the pilot, NEDCo have scaled their rollout of pre-paid meters to almost 100,000.

What was the impact?



Economic impacts:

- For households that switched to smart prepaid meters, reported electricity use rose by about 12.7 kWh per month, ~13% more than their previous recorded consumption, revealing previously unbilled energy and recovering non-technical losses.
- By cutting NTLs, the programme eases pressure on generation and improves NEDCo's revenue position, supporting more sustainable and reliable electricity service.

Social impacts:

- Daily usage notifications helped customers plan and manage their electricity use.
- Smart meters improved the reliability and fairness of electricity supply by ensuring households received and were billed for the power they actually used.

How Chile uses Digital Planning Tools to Make Faster and Strategic Decisions About Where and how to Connect New Assets



What was the problem?



- Chile aims to reach 70% renewable energy by 2030 and net-zero by 2050, but its 130-year-old transmission grid and legacy planning tools were not designed for highly variable wind and solar resources spread across a 3,100 km system.
- Coordinador Eléctrico Nacional (CEN), Chile's national electricity system operator, could run only one simulation at a time, making long-term planning slow, manual, and limited in scope. Planners had restricted ability to test multiple future scenarios, evaluate extreme-weather conditions (e.g., drought, low-wind days, heat waves), or assess coal-retirement pathways with confidence.
- Manual workflows required parsing dense tables and custom scripts, slowing planning during a period of rapidly expanding variable renewable energy.

What is the technology?



The project deployed advanced digital grid-planning tools with Google tapestry:

- **Tapestry Grid Planning Tool:** An AI-enabled platform for large-scale transmission planning, simulating grid performance up to 20 years ahead.
- **Scenario-based planning and “what-if” analysis:** Allows planners to quickly compare different futures (e.g. where demand grows, where renewables connect, and how the grid performs under extreme events such as heatwaves and droughts).
- **High-resolution forecasting integration:** Incorporates advanced wind and weather forecasts, with ongoing development toward hourly simulations to better capture renewable variability and support better generation and transmission decisions.

How was it implemented?



- CEN partnered with Tapestry in 2021, initially running the Grid Planning Tool alongside legacy systems to build confidence.
- Planners moved from manual, file-based workflows to a centralised data environment, enabling easier updates and scenario management.
- Tapestry customised its AI wind-forecasting model for Chile, using local wind data and enhanced weather inputs, then integrated it into CEN's planning tools.
- After two years of piloting, CEN adopted the tool for Chile's 2025 national transmission planning, becoming the first national operator to deploy it at scale.

What was the impact?



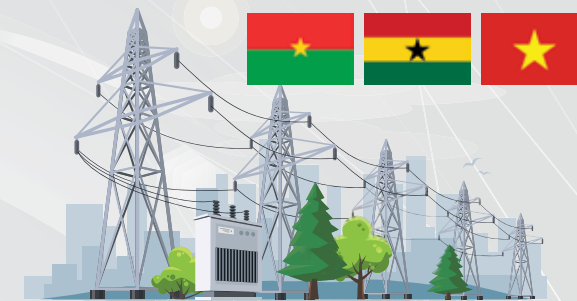
Economic impacts:

- 85%+ faster simulation runs, dramatically reducing planning time and staff hours.
- Ability to run 30 scenarios in parallel (up from one), with a roadmap to 100× faster planning by end-2024, enabling faster and more confident infrastructure decisions.

Social impacts: Faster, more accurate planning improves future grid reliability for 20 million electricity users in Chile.

Environmental impacts: Earlier and more confident integration of renewable energy, helping Chile meet its net-zero targets.

How SCADA Systems Strengthen Transmission Grids in Burkina Faso, Ghana, and Vietnam



What was the problem?



- Across Burkina Faso, Ghana, and Vietnam, fast-growing electricity demand was hitting the limits of old transmission systems and weak grid control. Transmission grids were operating with limited real-time visibility and control, relying on aging equipment and manual processes.
- Burkina Faso faced ~130 hours of outages/month, poor cross-border control with Ghana, and high tariffs.
- Vietnam experienced frequent faults and congestion on its 500 kV/220 kV network, driven by 10–15% annual demand growth and legacy, paper-based operations.

What is the technology?



- SCADA/EMS (Supervisory Control and Data Acquisition/Energy Management Systems) are digital control platforms that collect real-time data from substations and transmission lines and allow operators to remotely monitor, analyse, and control grid operations.
- SCADA is used to give operators real-time visibility and control of high-voltage transmission assets. It creates a single digital view of the transmission system, showing the status of substations, lines, and power flows.
- This enables faster fault detection, remote switching, and more stable, coordinated system operations.

How was it implemented?



- These challenges were addressed through World Bank-supported grid-modernisation programmes implemented during the 2010s, using proven and mature digital tech.
- **Burkina Faso & Ghana:** SCADA/EMS was installed to monitor and control the new Bolgatanga–Zagatouli interconnection, covering the cross-border transmission corridor, enabling operators in both countries to manage the line digitally and maintain grid stability.
- **Vietnam:** Key 500 kV and 220 kV substations were modernized and connected to a unified SCADA platform, covering the backbone transmission network, replacing legacy equipment and allowing digital monitoring, switching, and coordinated operation across the backbone network.

What was the impact?



Economic impacts:

- **Burkina Faso:** Along the Bolgatanga–Zagatouli transmission link connecting Ghana to Ouagadougou, outages are expected to drop from ~130 to ~8 hours/month, benefiting ~20,400 customers and enabling ~4% tariff reductions.
- **Vietnam:** capacity across 500 kV and 220 kV transmission network expected to rise by ~80%, with 5 GWh/year of load shedding avoided and ~25% fewer system faults.

Social impacts: More stable and predictable electricity supply for households, businesses, and public services across all three countries.

Environmental impacts: Reduced wasted generation from faults and outages, and a more robust transmission system able to support greater renewable integration.

How Virtual Reality Transforms High-Voltage Line Maintenance Training in Mexico



What was the problem?



- CFE (Comisión Federal de Electricidad), Mexico's state-owned national electricity utility responsible for generation, transmission, and distribution, relied on traditional field-based training for high-voltage line maintenance, where mistakes can be fatal.
- Inexperienced recruits learned directly on live equipment, exposing them to serious safety risks, while training required travel to specialised centres across Mexico, creating high logistical and financial costs. Maintenance tasks were highly complex, varying by structure type, tools, and techniques, making standardized training difficult.
- With thousands of workers across 16 regions, CFE struggled to maintain consistent safety standards, certification, and technical procedures, especially as rising electricity demand required rapid onboarding of new staff.

What is the technology?



- CFE deployed ALEn^{3D} AT, a non-immersive (i.e. running on standard desktop computers) Virtual Reality Training System (VRTS) for high-voltage line work.
- The system includes:
 - A Virtual Warehouse with 371 interactive 3D tools and components.
 - 31 simulated high-risk maintenance procedures across real-world structures. Three training modes (Learning, Practice, Evaluation) for competency-based certification.
 - A web-based learning management system (AdminWeb) for course creation, exams, and progress tracking.

How was it implemented?



- The system was developed using a user-centred design process, with CFE linemen, foremen, and engineers translating real maintenance procedures into accurate digital simulations.
- Over 20 months, the team digitised 31 manoeuvres and built hundreds of detailed 3D models.
- Following a controlled pilot comparing VR training to traditional methods, CFE rolled the system out nationally, training instructors across all regions.
- Between 2011 and 2015, the system was installed on 3,700 computers, delivering 1,100 courses to 4,600 workers.

What was the impact?



Economic impacts:

- Training time reduced by 33% (from 6 weeks to 4 weeks).
- \$950 saved per trainee, generating \$4.37 million in direct savings

Social impacts:

- Workplace accidents reduced by 59%.
- Working days lost due to accidents reduced by 93%.
- Health-related and lost-workday expenses reduced by 94%.
- VR-trained workers scored 14–22% higher in practical field tests.



Using Robotics to Improve the Safety and Cost of Wind Turbine Blade Maintenance

What was the problem?



- Wind turbine blades degrade over time due to cracks, erosion, and internal defects, reducing performance and increasing failure risk, especially offshore.
- However, manual blade inspections rely on rope-access technicians working at height, which is dangerous, weather-dependent, and costly.
- Operations and maintenance account for 10–25% of the levelised cost of electricity, driven by specialist labour, vessels, and downtime.
- Drone inspections are faster but limited: they mainly detect surface damage and cannot identify hidden internal defects.

What is the technology?



BladeBUG, a UK-based robotics company, developed a six-legged crawling robot for wind turbine blade inspection:

- The robot performs in-situ inspections, meaning blades are inspected directly on the turbine without removing or dismantling them.
- It uses non-destructive testing (NDT) sensors, which assess blade condition without causing damage, enabling detection of both surface and internal defects.
- Automated scanning paths allow consistent, repeatable inspections along long blade sections.
- Inspection data is captured digitally to support condition-based maintenance.

How was it implemented?



- BladeBUG developed the robot through multi-year collaboration with industry and research partners. ORE Catapult, an offshore renewable energy research centre, supported testing and validation in controlled and offshore environments.
- EDP Renewables, a global wind farm operator, GE Renewable Energy, a turbine manufacturer, and Imperial College London supported trials, sensor integration, and performance validation.
- A major milestone was achieved when BladeBUG completed the world's first 50-metre robotic "blade walk" on a live offshore turbine.
- By 2021, the system progressed from feasibility testing to full field validation on operational turbines.

What was the impact?



Economic impacts:

- Robot deployment takes ~35 minutes, significantly faster than traditional rope-access setup, reducing turbine downtime.
- Inspecting long blade sections in a single pass lowers labour needs, follow-up visits, and offshore vessel time.
- Lifetime maintenance costs are estimated to be up to 30% lower, with potential savings of up to 50% for next-generation turbines.

Social impacts: Dramatically improves worker safety by reducing the need for technicians to work at height in hazardous offshore conditions.

Environmental impacts: Earlier defect detection prevents major blade failures, improving turbine reliability and energy output.

How Smart Metering Transforms Distribution Operations in India



What was the problem?



- India's distribution sector has faced persistent financial stress due to high technical and commercial losses, inefficient billing and collection, and limited operational visibility.
- Most distribution companies (DISCOMs) rely on manual meter reading and fragmented IT systems, leading to billing inaccuracies, delayed outage detection, and weak customer trust. This lack of granular, real-time consumption data constrains utilities' ability to improve service quality, manage demand growth, and prepare networks for higher renewable energy integration.
- These challenges have reduced DISCOM creditworthiness and slowed broader power sector reform and investment.

What is the technology?



- Smart metering deployed as part of an Advanced Metering Infrastructure (AMI), which enables two-way communication between meters and utility systems.
- Smart meters provide real-time data on electricity consumption, voltage, and outages, replacing manual meter reading.
- AMI integrates with billing systems, customer information systems, and outage management systems to create a digital backbone for distribution operations.
- The technology enables remote connect/disconnect, prepaid and postpaid billing, time-based tariffs, and net metering where applicable.

How was it implemented?



- India adopted a phased rollout approach, starting with pilots from 2012 onward to test technologies, standards, and business models. The National Smart Grid Mission provided institutional coordination, policy guidance, and capacity building across states. Standardised technical specifications and bidding documents reduced procurement risk and supported large-scale deployment.
- Public-private partnership models attracted private investment and technical expertise while aligning performance incentives.
- Smart metering was integrated into broader distribution reform programmes, enabling scale-up across multiple states.

What was the impact?



Economic impacts:

- Improved billing accuracy and collection efficiency, alongside lower operational costs and reduced losses through automated meter reading and better energy accounting.

Social impact

- Improved reliability and transparency for consumers through faster outage detection and restoration, and access to accurate, timely consumption and billing information.

Environmental impact

- Greater readiness of distribution networks to support renewable energy, net metering, and future efficiency, demand management, and smart grid applications.

Using Digital Twins and Analytics to Improve Renewable Asset Performance

ReNew



What was the problem?



- India's rapid scale-up of wind and solar has increased operational and commercial pressure on large renewable portfolios spread across remote and diverse sites, such as those of ReNew.
- Maintaining high asset availability so plants consistently generate electricity when expected, minimising unplanned outages, and meeting grid schedules that specify how much power must be delivered and when became increasingly complex at scale.
- Reactive maintenance, siloed operations, and manual coordination between asset teams and commercial functions has reduced predictability and exposed ReNew to penalties and revenue leakage - especially as hybrid, storage-linked, and merchant assets expanded.

What is the technology?



ReNew built an integrated, in-house digital and analytics stack which included:

- Analytics platform:** Combines operational, equipment, and site data to enable predictive maintenance, anomaly detection, and monitoring across assets.
- Digital twins:** Data- and physics-based models used to test operating scenarios, maintenance strategies, and hybrid or storage dispatch options before deployment.
- Forecasting and virtual dispatch systems:** AI-driven generation forecasting with centralised control of hybrid and battery-backed assets.
- Digital trading platform:** A workflow-based system that automates electricity market participation, integrating forecasts, approvals, and audit trails.

How was it implemented?



- Deployed across more than 2,400 wind turbines and 26,000 solar inverters, integrating all monitoring and operational data into a single analytics layer.
- Predictive maintenance models were trained on historical failures, operating conditions, and site characteristics to prioritise interventions and reduce unplanned outages.
- Computer vision (image-analysis software) applied to drone and field imagery to automate inspections of blades, panels, and balance-of-plant assets.
- The insights from digital twins were embedded into engineering and planning workflows, feeding directly into forecasting, scheduling, and centralised dispatch.
- Capabilities were owned by operating teams and supported by a dedicated Digital Lab, ensuring scalability and continuous improvement.

What was the impact?



Economic impacts:

- ~25% reduction in unplanned downtime across the renewable portfolio
- 1–1.5% annual energy generation gains from continuous performance optimisation
- ~1% revenue uplift from improved forecasting and automated market participation
- Lower penalties and operating costs through better dispatch discipline

Social and operational impacts: More reliable renewable power delivery through safer, faster inspections and stronger coordination between asset operations and commercial teams.

Environmental impacts: Higher renewable energy output with reduced water and material use.

How Gradyent's Digital Twin is Helping Assure Investment Decisions for Decongestion



What was the problem?



- A region in the North East of the Netherlands is experiencing grid congestion, severely slowing down the energy transition (e.g., EVs, heat pumps, renewable production, electrification of industry).
- The hardware investments in the electricity system needed to resolve this have a 10-year future horizon, which would slow the economic prospects of the region. Other investments, like a district heating grid to reduce the reliance on electric heat pumps, are under discussion.
- The DSO, Municipality, Province and Dutch companies are teaming up to accelerate the investment decisions to help reduce congestion and enable economic growth.

What is the technology?



- Gradyent's physics-based Digital Twin technology, coupled with AI & ML methods, is being implemented to help simulate and design potential investment decisions.
- The Digital Twin of the power grid, gas network (and potential district and industrial heat network) creates an e2e detailed and dynamic model of the behaviour of the networks, at high frequency time intervals going into minutes where required.
- The high accuracy and trust enables decision makers in the consortium to make the best possible investment decision. Examples of investment decision are:
 - Accelerating/changing investments in the grid to focus on urgent bottlenecks
 - Implementing a district heating network to reduce the grid impact of electric heating
 - Introducing new policies (e.g., advanced pricing schemes) based on in-depth grid impact analysis

How was it implemented?



The Digital Twin was built by combining 4 critical elements:

- The network layout from the local DSO, mapping out the geospatial layout of the networks, incl. substations, gas valves, etc.
The historic network data from all sensors in this network
 - Gradyent's proprietary physics models, modelling out all behaviours between sensors
 - Gradyent's data platform and interfaces, built across dozens of network and nearly a decade of modelling energy infrastructure
- Integrated by Gradyent's engineers in several months to build the Digital Twin

What was the impact?



The project is currently still ongoing but is expected to deliver a broad impact for the region:

- **Economic impacts:** Improving the economic attractiveness of the region as companies & industries are not hindered by net congestion in electrifying their equipment, vehicles, etc.
- **Social impacts:** Enabling the construction of more homes to attract more talent to the region, which is currently hampered by net congestion.
- **Environmental impacts:** Above all, the accelerated electrification of heating & mobility in the region will reduce the reliance on natural gas.

Technical and Modelling Appendix

This report presents high-level estimates of the potential impact on key economic and environmental indicators to build a global case for action for digital- and AI-enabled power systems. This annex sets out our approach and assumptions for estimating:

- The extent to which the investment to build a global net-zero power system can be reduced (“avoided investment”).
- The extent to which potential global cumulative emissions between now and 2050 could be reduced (“avoided emissions”).
- The potential boost to GDP in middle- and low-income countries (“GDP boost”).

Avoided Investment

As this report explores, digital and AI technologies for power systems have the potential to reduce the size of the overall clean power system required for net-zero, avoiding global investment needs. Our approach presents a maximum potential prize, assuming that technologies are able to achieve their full technical potential. These numbers should not be interpreted as forecasts, but as high-level estimates of the potential order of magnitude savings that could be realised from digital and AI technologies. These are also gross savings; we do not model the investment required in digital and AI technologies, but assume this is largely already captured in the IEA’s estimates of net-zero investment in building out and modernising grids.

We followed a three-part approach:

1. We used the IEA’s Net-Zero scenario to understand pathways for installed renewable capacity and investment need and disaggregated the global pathway into high-income and middle- and low-income countries, which we corroborated against the International Solar Alliance’s SHINE scenario – an ambitious scenario in which solar adoption is accelerated well beyond current trajectories.¹²² From this, we derived estimates of the annual build out of renewables and the grid.
2. We assumed a reasonable phase in of digital and AI technologies across the entire network in high-income countries and middle- and low-income countries.¹²³
3. We modelled the impact of digital and AI technologies across four levers, with low and high scenario assumptions:
 - A reduction in grid losses: this better utilises existing renewable generation and avoids future investment in additional renewable capacity.
 - An increase in the load factor of wind and solar generation: this increases the efficiency of installed capacity and avoids future investment in additional renewable capacity.
 - An increase in the transmission capacity of the existing grid: this better utilises the existing grid and avoids future investment in building out the grid.
 - A reduction in electricity demand: this reduces the overall size of a future clean power system and avoids future investment in both additional renewable capacity and building out the grid.

Modelled levers	Assumption	Source
Reduction in grid losses [note – this is not modelled for high-income countries as transmission losses are already less than 5%]	Reduction from 15% today, to 10% (low scenario) and 5% (high scenario)	Systemiq analysis. We assume that middle- and low-income countries are able to realise grid loss rates seen in high-income countries (~5%) – see World Bank, <i>Electricity grid loss rates</i> .
Increase in load factor of renewable generation	10 – 20% increase in load factor	Stern et al. (2025), <i>Green and intelligent: the role of AI in the climate transition</i> .
Increase in transmission capacity of the grid	15 – 30% increase in capacity	CurrENT (2024), <i>Prospects for innovative power grid technologies</i> . ETC (2025), <i>Power system transformations</i> .
Reduction in electricity demand	1 – 5% reduction in demand	ETC (2025), <i>Achieving Zero-Carbon Buildings</i> . There is significant uncertainty in the size of this lever, given the potential for rebound effects (see Chapter 2). We take a moderate assumption, moderating the estimates in the ETC's report, which suggest there is an opportunity to reduce demand by 5-10% through smart energy management.

Avoided Emissions

As this report explores, digital and AI technologies for power systems have the potential to a) enable the integration of higher shares of renewables in power systems, and b) accelerate the deployment of renewables. In doing so, they can avoid fossil fuel generation and avoid potential future emissions. At the same time, they can improve the reliability of power systems, reducing outages and the need for back-up diesel generation which is very emissions intensive.

We followed a three-part approach:

1. We used the IEA's Net-Zero scenario for pathways for renewable/fossil generation, which we disaggregated into pathways for high-income and middle- and low-income countries.¹²⁴
2. We assumed a reasonable phase in of digital and AI technologies across the entire network in high-income countries and middle- and low-income countries.¹²⁵
3. We then modelled two questions, using three levers:
 - For a given year between now and 2050, to what extent is it possible to increase renewable generation within AI-enabled power systems? If the alternative was for this electricity to be generated by fossil fuels, what are total avoided emissions? We use two levers:
 - Accelerated deployment of renewables
 - Increase in load factor of renewable generation
 - To what extent do AI-enabled power grids reduce outages? How much avoided diesel generation back-up power could be avoided? We use one lever:
 - Reduction in grid outages (System Average Interruption Duration Index, SAIDI)

Modelled levers	Assumption	Source
Accelerated deployment of renewables	Assume that the world reaches the IEA's net-zero target for installed capacity 2 years earlier.	Systemiq assumption based on expert interviews
Increase in load factor of renewable generation	10 – 20% increase in load factor	Stern et al. (2025), <i>Green and intelligent: the role of AI in the climate transition</i> .
Reduction in SAIDI [note – this is not modelled for high-income countries as grid outages are already very low]	Reduction from an average of ~20 hours/year today, to 10 (low scenario) and 5 (high scenario)	We assume that middle- and low-income countries are able to realise grid outages seen in high-income countries (~5 hours/year) – see IEA, <i>End-user power supply interruption indicators by country, 2016-2020 average</i> .

GDP Uplift

As this report explores, AI-enabled power systems have the potential to make electricity more accessible, affordable and reliable; and in doing so, can increase economic growth.

We focused this analysis on middle- and low-income countries, where the biggest impacts on GDP are expected, and modelled the impact of three levers between now and 2050:

- Increase in the share of the population with access to electricity
- A reduction in grid outages
- An increase in renewables investment



These levers were then used to estimate the additional percentage points to annual GDP growth.

Modelled levers	Assumption	Source
Increase in electricity access		
Increase in share of middle- and low-income countries population with electricity access	Increase in 2050 access rate from 92% (IEA STEPS scenario) to 94% (low) and 95% (high)	Systemiq assumption based on expert interviews.
GDP multiplier	A percentage point increase in electricity access is associated with an average 0.056 percentage points of additional economic growth per annum over the subsequent decade	Best, R., & Burke, P. J. (2018). <i>Electricity availability: A precondition for faster economic growth?</i> Energy Economics, 74, 321–329. Opoku, E. E. O., Acheampong, A. O., & Salim, R. (2025). <i>Does energy access matter for achieving inclusive growth? Insight from a global perspective.</i> Applied Economics, 1–18.
Reduction in grid outages		
Reduction in SAIDI [note – this is not modelled for high-income countries as grid outages are already very low]	Reduction from an average of ~20 hours/year today, to 10 (low scenario) and 5 (high scenario)	We assume that middle- and low-income countries are able to realise grid outages seen in high-income countries (~5 hours/year) – see IEA, <i>End-user power supply interruption indicators by country, 2016-2020 average</i> .
GDP multiplier	A 1% decrease in outages increases GDP by 0.11% a year.	Andersen, T. B., & Dalgaard, C.-J. (2013). <i>Power outages and economic growth in Africa.</i> Energy Economics, 38, 19–23. Chen et al. (2023), <i>How will power outages affect the national economic growth: Evidence from 152 countries.</i> Energy Economics 126.
Increase in renewables investment		
Increase in economic activity from renewables	Green investment has a GDP multiplier of \$1.1 for every \$ of investment; fossil investment generates \$0.5. We take the difference (\$0.6 / \$ of investment) and apply to our assumptions of accelerated renewable deployment / investment.	Batini, N., Di Serio, M., Fragetta, M., Melina, G., & Waldron, A. (2021). <i>Building back better: How big are green spending multipliers?</i> (IMF Working Paper No. 2021/087). International Monetary Fund.



Endnote

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