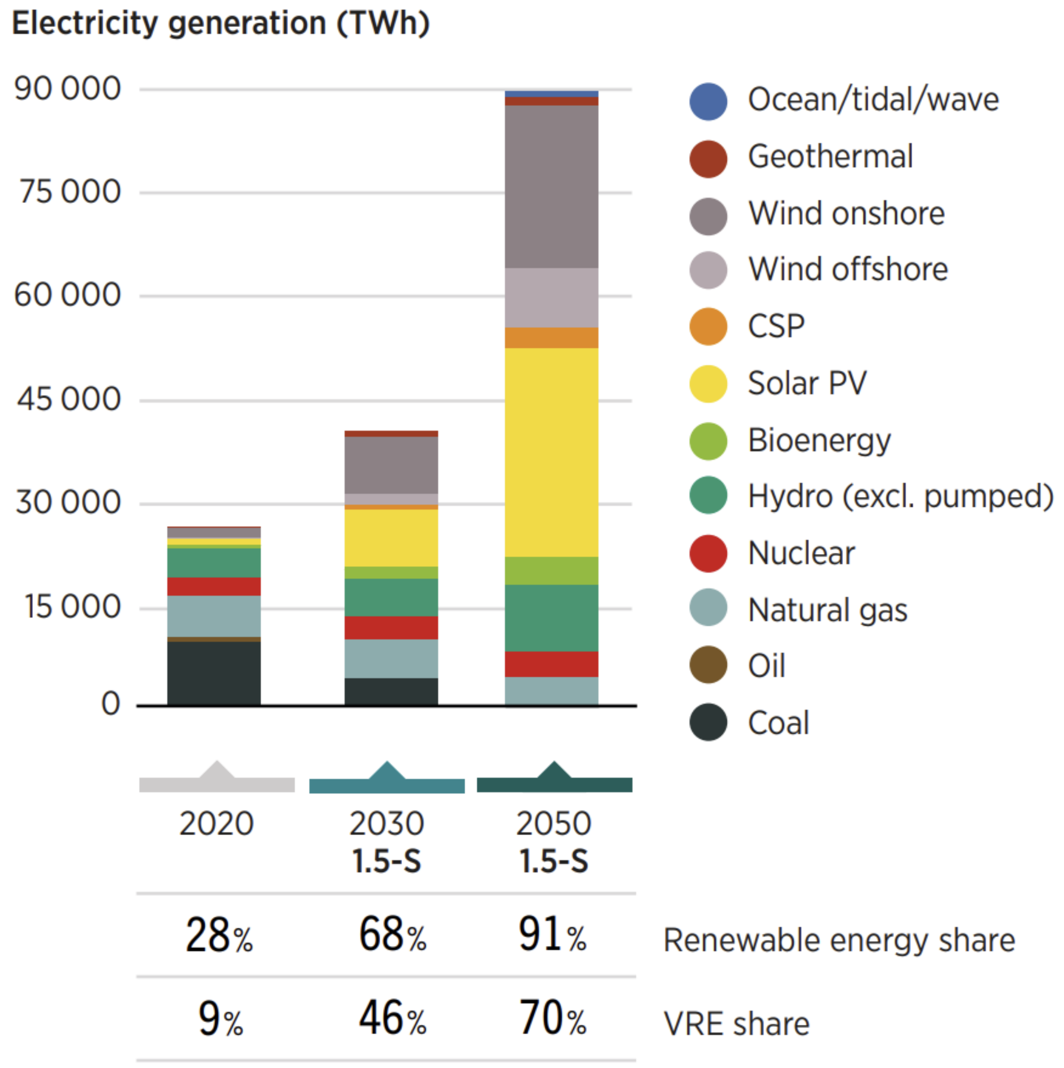
Digitalisation and AI for Power System Transformation

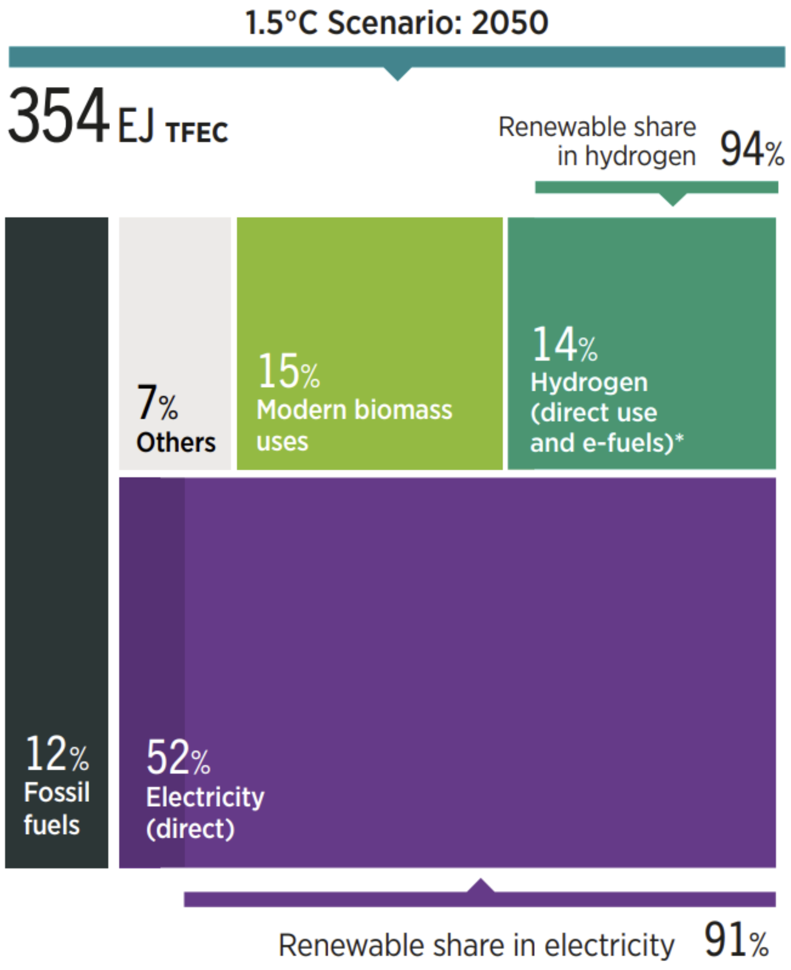
Adrian Gonzalez
IRENA Innovation and Technology Centre

APEC Workshop on AI-Powered Renewable Energy Innovation

17 November 2025

Future energy systems will be dominated by renewables

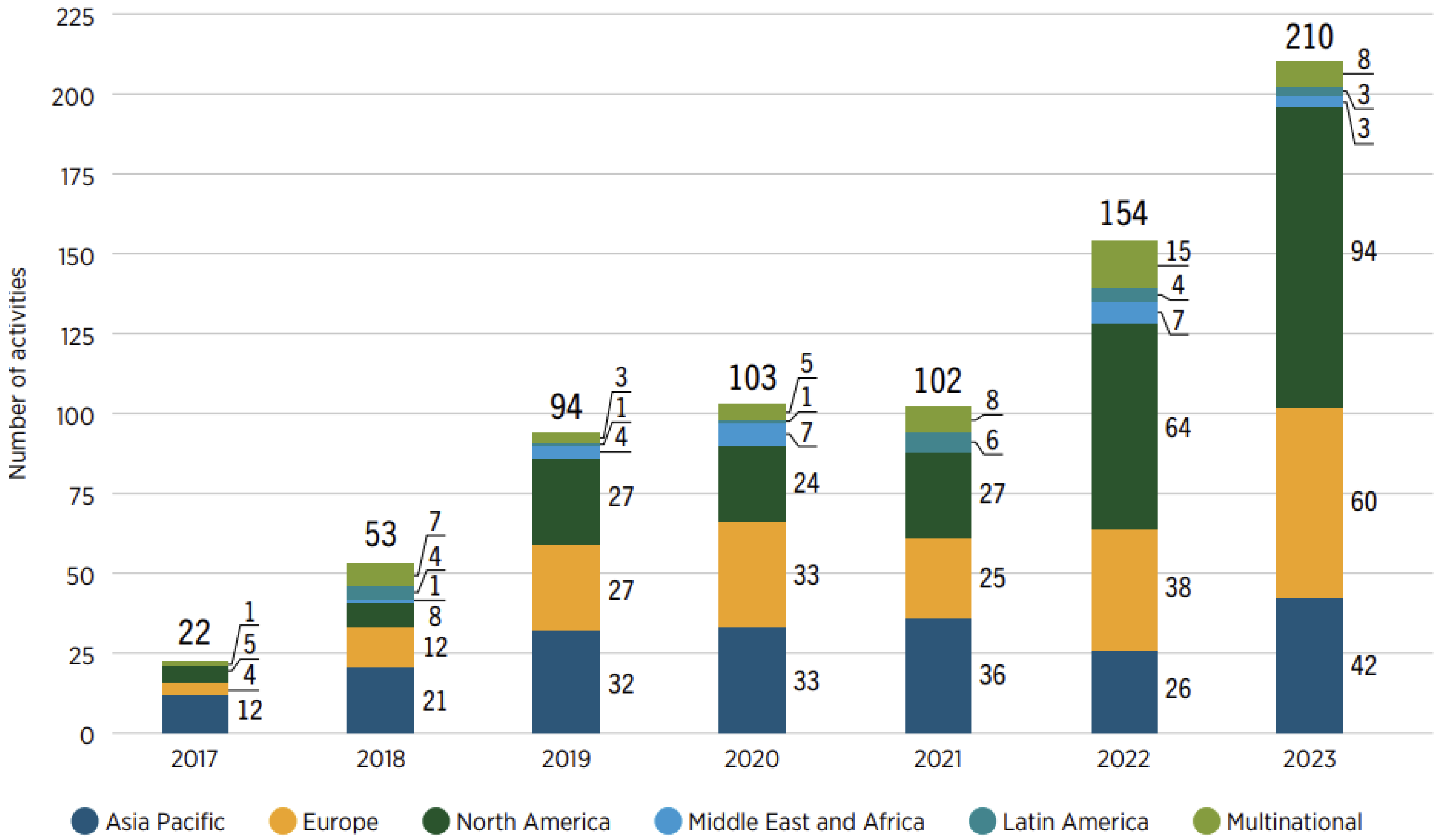




Source: IRENA (2025). CSP = concentrated solar power; EJ = exajoule; PV = photovoltaic; TFEC = total final energy consumption; TWh = terawatt hour; VRE = variable renewable energy

Growing digitalization yet geographical divide

Number of digital projects and partnerships tracked by BNEF in the power sector, 2017-2023



Source: (BNEF, 2024).

Creating value through digitalisation and AI

IRENA
International Renewable Energy Agency

MONITORING

Smart sensors, DLR, digital twins, SCADA, thermal imaging, WAMPAC, asset-health diagnosis, PMU, satellite imagery, etc.

FORECASTING

Demand prediction, renewable energy production forecast, long-term capacity projections, predictive maintenance, etc.

OPERATIONAL OPTIMISATION

FACTS, dynamic voltage control, optimal power flows, grid forming, probabilistic risk assessment, automated power reduction, etc.

END-USER AUTOMATION

Smart appliances, vehicle-to-grid, industry 4.0, demand response, micro-grids trading, HEMS, smart thermostats, etc.

TRANSPARENCY

Data exchange, carbon credits, interoperability, digital permitting, guarantees of origin, stakeholder dashboard, etc.

Source: IRENA (2025). Digitalisation and Artificial Intelligence for Power System Transformation. Perspectives for the G7.

A benefits-oriented approach

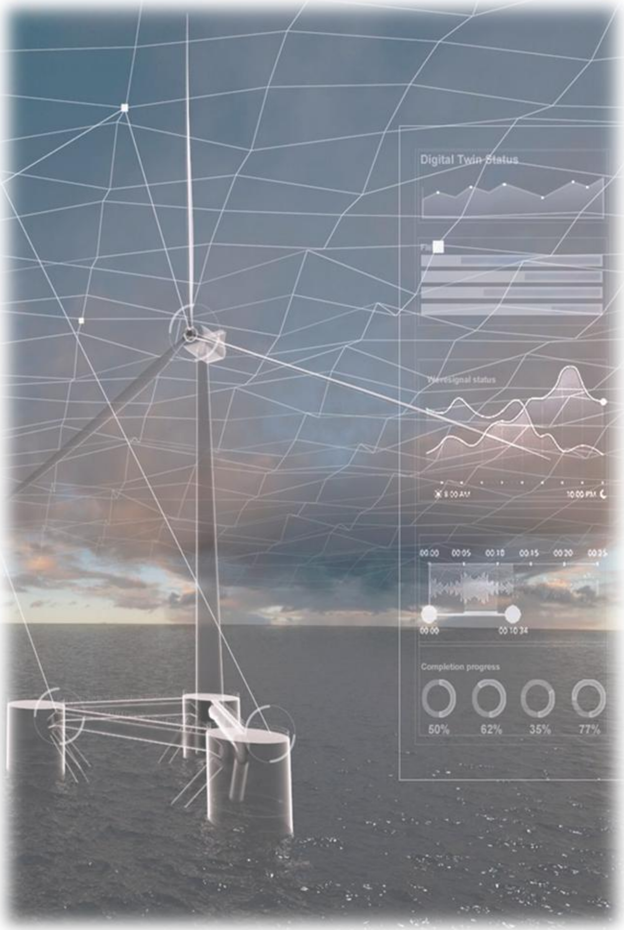
Reduction of electricity costs for end users: Decreasing the final cost of electricity for consumers and businesses through improved operational efficiency, optimised market participation of distributed resources and integration of low-cost generation based on renewables.

Greater security of supply: Ensuring continuous, reliable electricity delivery even under stress conditions, during outages or during extreme events, with faster recovery from disruptions.

Greater integration of renewables: Increasing the share of renewable energy in the generation mix by enabling flexible integration and managing variability effectively.

Added value for customers: Providing end users with greater control of their consumption, greater comfort, and greater awareness and knowledge of the opportunities they have for optimising costs and cutting emissions.

Improved business performance: Improving the operational and economic efficiency of companies in the energy sector or directly linked to it, increasing asset utilisation and strengthening competitiveness.



Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: Monitoring

IRENA
International Renewable Energy Agency

Note:
● Excels at delivering that benefit directly.
◒ Relevant in achieving this benefit.
○ Its contribution to it is a side effect.

Value Clusters	Use case/digitalisation benefit	Reduction of electricity costs for end users	Greater security of supply	Higher renewables penetration	Added value for customers (e.g. comfort, control)	Improved business performance
MONITORING	Highly granular monitoring of system parameters	○	●	○	◒	●
	Real-time asset health monitoring	○	●	○	○	●
	Wide-area situational awareness (WAMPACS/PMUs)	○	●	◒	○	○
	System communications and cyber security anomaly detection	○	●	○	○	○
	Monitoring of environment and weather conditions	◒	◒	●	○	○

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: Forecasting

IRENA International Renewable Energy Agency

Note:
- ● Excels at delivering that benefit directly.
- ◒ Relevant in achieving this benefit.
- ○ Its contribution to it is a side effect.

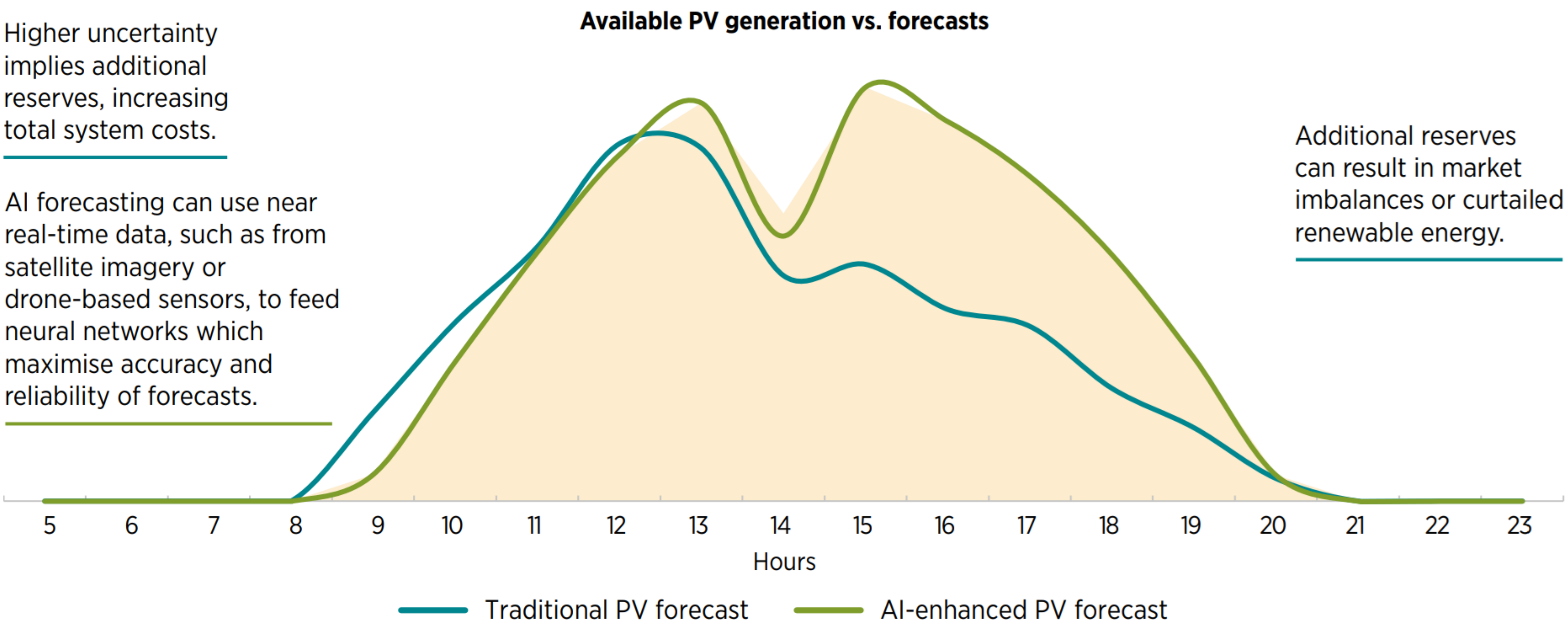
FORECASTING	Reduction of electricity costs for end users	Greater security of supply	Higher renewables penetration	Added value for customers (e.g. comfort, control)	Improved business performance
AI-enhanced demand forecasting	◒	◒	○	◒	◒
AI-enhanced forecasting of variable renewable generation	◒	○	●	○	◒
Predictive maintenance	◒	●	○	○	◒
Short-term market price forecasting	●	○	◒	◒	◒
Early awareness of grid constraints	○	●	○	○	◒

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: Forecasting

Higher uncertainty implies additional reserves, increasing total system costs.

AI forecasting can use near real-time data, such as from satellite imagery or drone-based sensors, to feed neural networks which maximise accuracy and reliability of forecasts.



Additional reserves can result in market imbalances or curtailed renewable energy.

Source: IRENA (2025). Digitalisation and Artificial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: Operational Optimisation

Note:
- ● Excels at delivering that benefit directly.
- ◒ Relevant in achieving this benefit.
- ○ Its contribution to it is a side effect.

OPERATIONAL OPTIMISATION	Reduction of electricity costs for end users	Greater security of supply	Higher renewables penetration	Added value for customers (e.g. comfort, control)	Improved business performance
Power flow optimisation	◒	◒	◒	○	◒
Probabilistic risk assessment	◒	○	●	○	●
Virtual power plants	◒	◒	◒	○	○
Control centre of the future and automated FLISR	○	●	○	○	●
Dynamic line rating	●	○	●	○	○

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: End-use automation

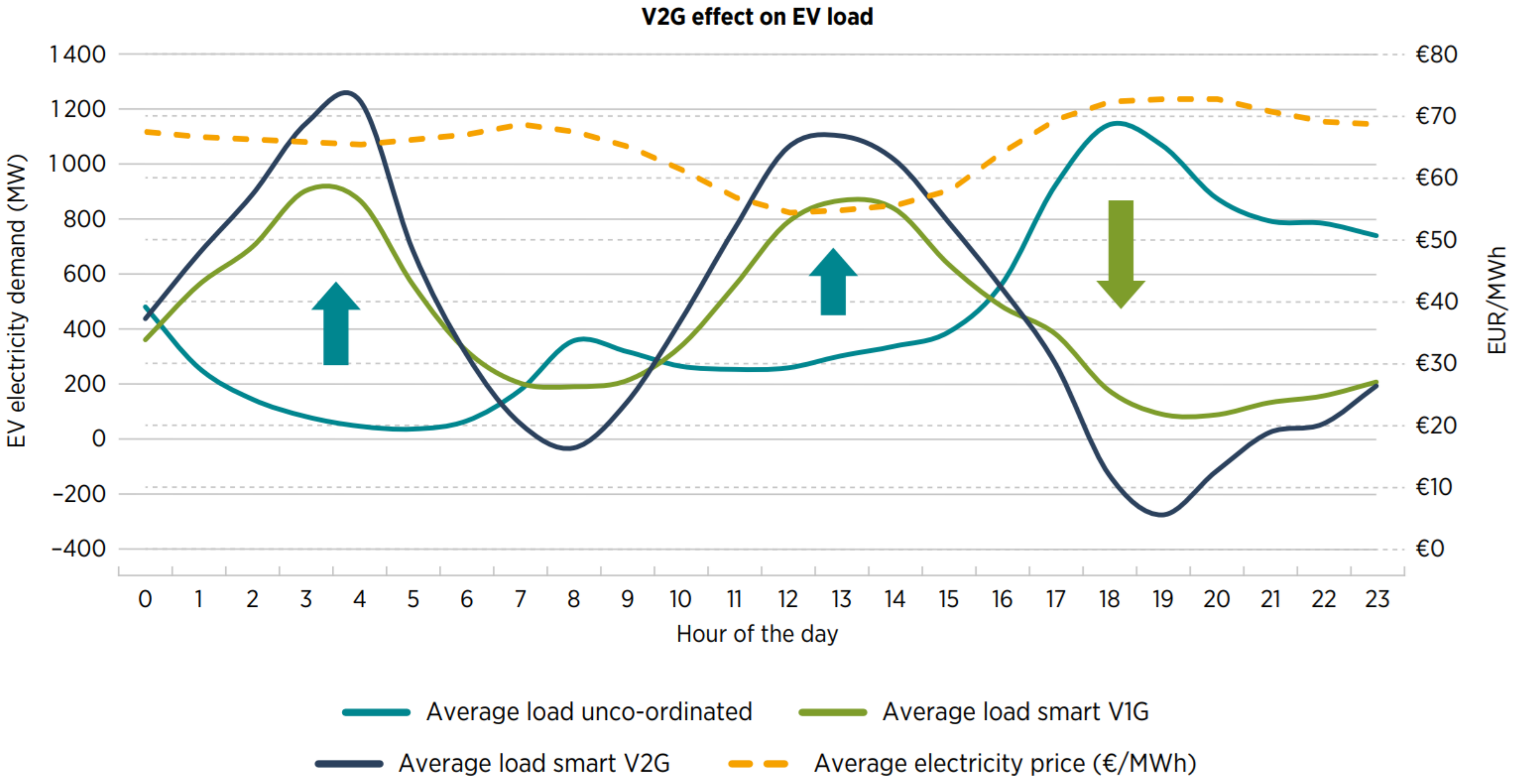
Note:
- ● Excels at delivering that benefit directly.
- ◒ Relevant in achieving this benefit.
- ○ Its contribution to it is a side effect.

END USER AUTOMATION

	Reduction of electricity costs for end users	Greater security of supply	Higher renewables penetration	Added value for customers (e.g. comfort, control)	Improved business performance
Adaptative demand patterns from appliances/devices	●	○	◒	●	○
Adaptative behaviour from BESSs and EVs	●	○	●	○	○
Adaptative demand from industries	◒	◒	●	○	◒
Energy management systems for end users (HEMS/BEMS/FEMS)	◒	○	○	●	○

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: End-use automation



Source: (ENTSO-E)

G7 2025 KANANASKIS

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

Use cases delivering benefits: Transparency

IRENA
International Renewable Energy Agency

Note:
- ● Excels at delivering that benefit directly.
- ◒ Relevant in achieving this benefit.
- ○ Its contribution to it is a side effect.

TRANSPARENCY

	Reduction of electricity costs for end users	Greater security of supply	Higher renewables penetration	Added value for customers (e.g. comfort, control)	Improved business performance
Improved information flow among energy stakeholders	◒	○	◒	◒	●
Granular renewable energy certificates	○	○	◒	●	○
Digital permitting	○	○	●	○	●
Customer-friendly dashboards	○	○	○	●	○
Open data platforms	○	○	○	◒	●

Source: IRENA (2025). Digitalisation and Artifficial Intelligence for Power System Transformation. Perspectives for the G7.

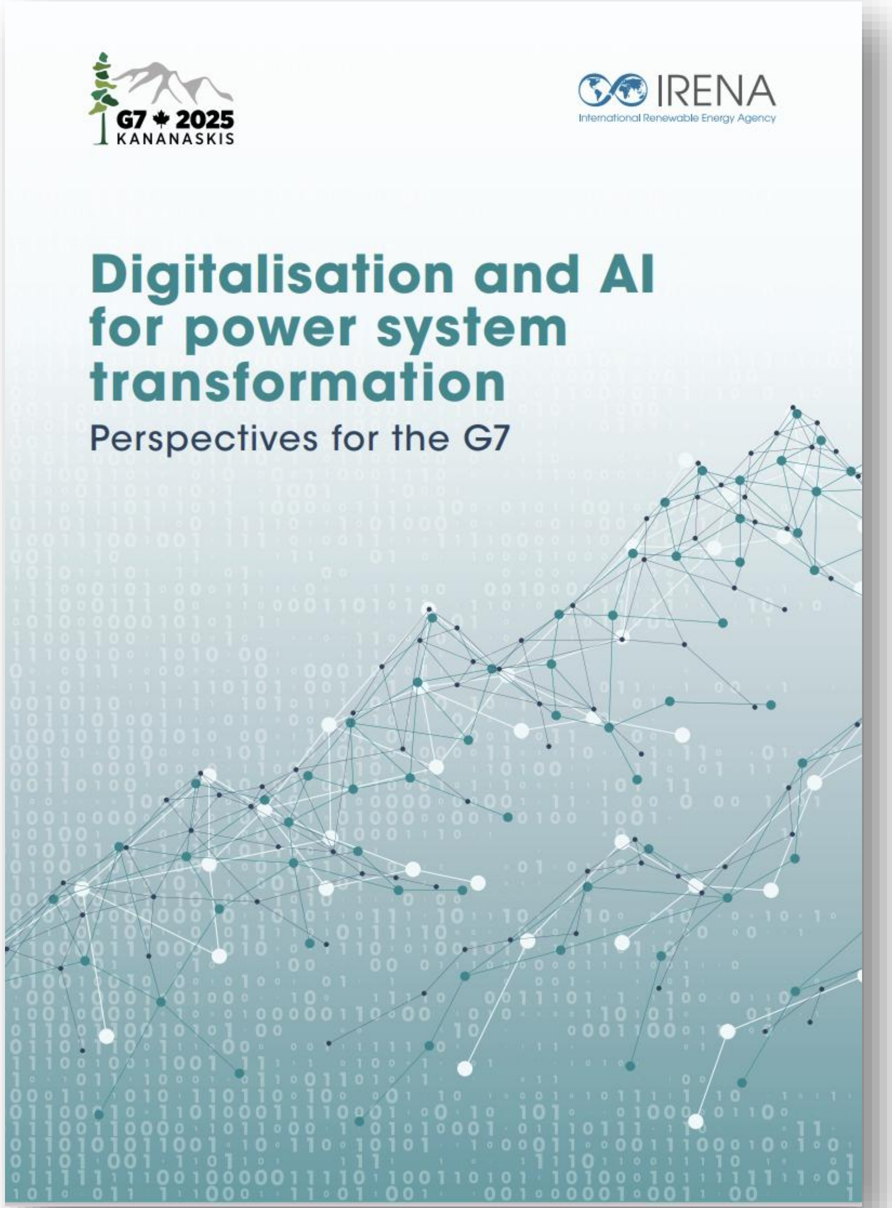
Essential takeaways on AI for renewables

IRENA
International Renewable Energy Agency

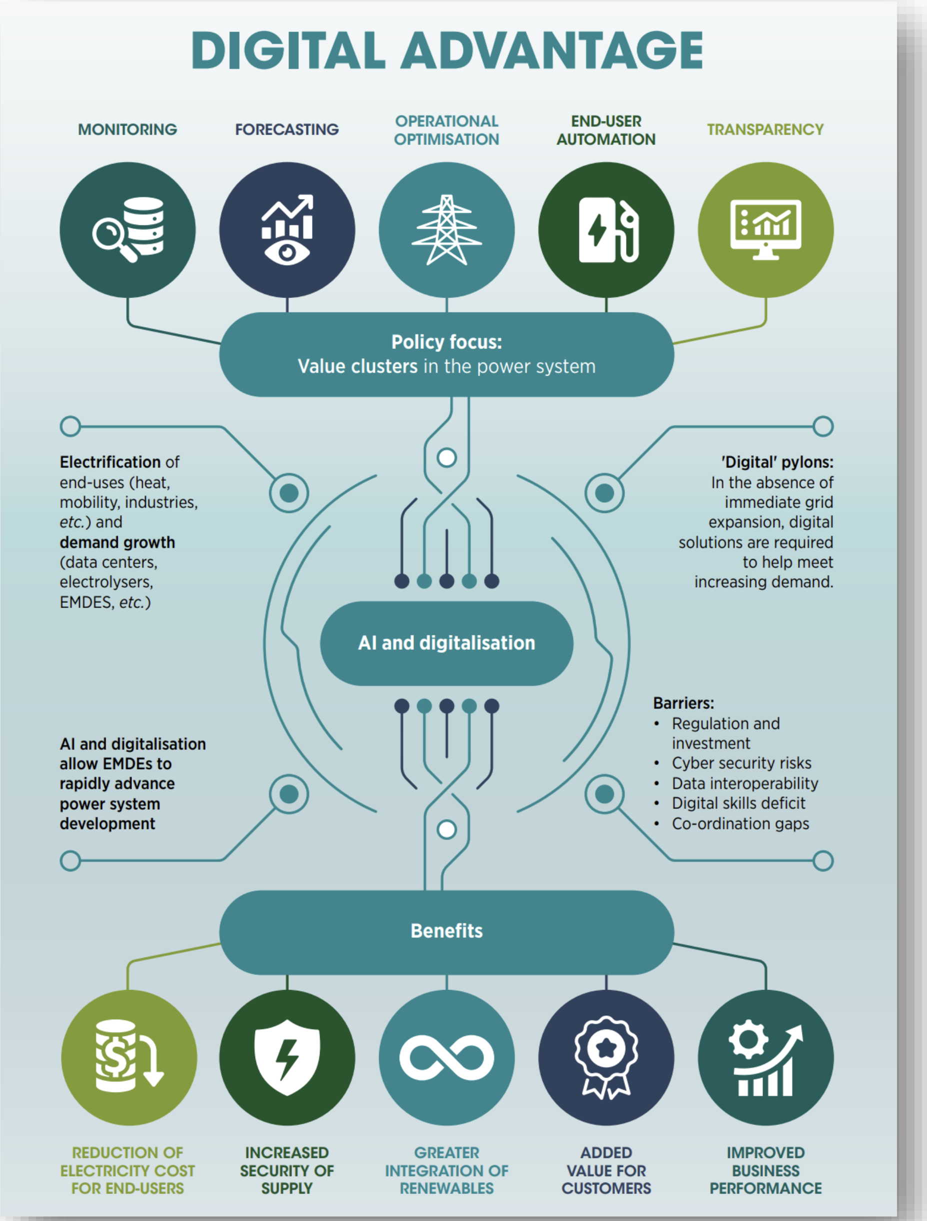
Digitalization is a high-return investment that maximizes the socioeconomic welfare provided by renewables, and raising awareness is an essential pilar to accelerate their synergetic deployment.

Smartness in the electricity value chain has quantifiable benefits as reduction of final prices and emissions, and qualitative benefits as enhanced security of supply and added transparency.

Artificial Intelligence is a component of the evolving digitalization of power systems that allows revolutionary optimizations for integrating high shares of renewables with surging electrification.



Download the report



International Renewable Energy Agency

Thank you for your attention

AGonzalez@IRENA.org
LinkedIn