Capgemini

Shaping Tomorrow's Energy Landscape:

Balancing Sovereignty, Affordability and Climate Responsibility

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05

DIGITAL/ DATA FLOWS

DATA FLOWS AT THE HEART OF THE FUTURE ENERGY SYSTEM

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The electricity system is adding new sources of data at an incredible pace.

Can we manage?

The conventional electricity system already uses lots of data to align the production, distribution, and supply of electricity.

Now we are witnessing a huge increase in data exchange and data applications while moving towards a (renewable) generation driven energy system. The increased unpredictability and volatility both on the production and demand side is creating new demands for data.

New sources of data were added during the introduction of smart meters. The next generation of meters will provide even more insights on both the customer and network end. Edge computing will also be introduced to enable faster decision making.

Where the Transmission System Operators (TSOs) already had insight in energy flows, all primary and secondary substations will be virtualized and further automated. They will produce even more data, providing more operational insights. Also here, edge computing will transform the current centralized network management approach towards a more distributed and local network management.

Data is at the heart of our future energy system and the volume of data is exploding.

All actors in the energy system consume and generate data. Data sets will become available at more a granular level and in real time.

As we become increasingly dependent on the availability of renewable energy, the electricity demand will have to follow the electricity that is generated. This means that appropriate data should be available in real-time for demand response to take place and to secure the system balance at 50 Hz. Power quality management and congestions will further complicate the picture. TSOs and DSOs will need to align their information systems to optimize the energy system at a national level. Also, near and real-time weather and kWh price data will play an ongoing and instrumental role in our energy data system.

To manage this massive amount of data, modelling and AI are necessary to support humans in appropriate decision making. Both financial and operational decisions cannot be made without the support of this new tooling. As more and more computation will need to take place in real time, new technologies such as quantum computing need to be evaluated.

All actors effected ...

To survive, every actor in the energy system will have to master this data challenge. The most successful and profitable players will be those who best master this game.

... and beyond ...

Data management will take place at company level and beyond. The system requires close collaboration and synchronization between all actors. Data will have to flow at a national or even continental level. Data spaces and data hubs are emerging. Standardization is a requirement and regulators will play an increasingly important role to spur action.

We can manage the increasing data volumes.

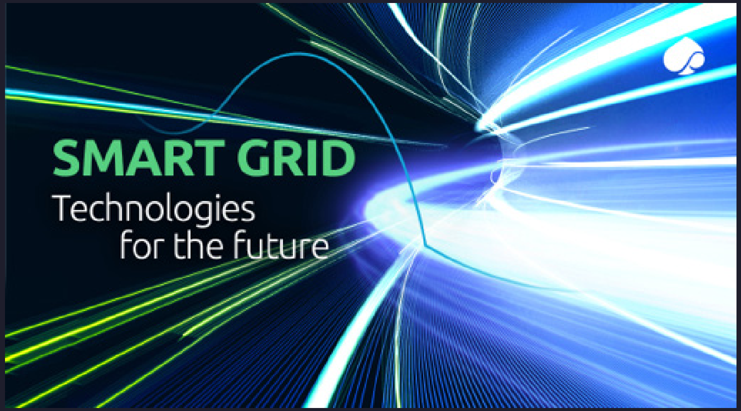
It requires a transformation for many companies to become truly data-driven organizations. Unlocking data, managing data, gaining insights, and making data driven decisions are core competencies everyone in the system needs to develop to survive.

Five relevant articles

In this chapter, I am happy to present five relevant articles that provide insight into how new data sets will be unlocked and managed. In the first and second articles, we will explore industry changes as it relates to the next generation smart meters and new smart substations, respectively, and examine how edge computing will be applied. In the third article, we will offer more insights into the tooling and systems available to gain business insights from the huge stream of data. Article 4 will focus on the possibilities of quantum computing in the energy sector and also provide a concrete example of new tooling applied through digital twin technology.

I wish you an insightful read.

Rene Kerkmeester



05

1. NEXT-GENERATION AMI - BRINGS SIGNIFICANT BENEFITS FOR BOTH CUSTOMERS AND UTILITIES
2. EXPLOITING DATA AT THE SUBSTATION LEVEL. VIRTUALIZATION AND UTILITY EDGE COMPUTING: AN INDUSTRY GAMECHANGER
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NEXT GENERATION AMI BRINGS SIGNIFICANT BENEFITS FOR BOTH CUSTOMERS AND UTILITIES

RUPAK PATRA, SWEDEN

Demand for adoption of next-generation smart meters is growing across Europe, UK and US with market estimations projecting global penetration of smart meters will climb approximately 44% at the end of 2020 to 56% by the end of 2028, resulting in over 1.2 billion devices globally according to Guide house.

Smart meters are a part of the advanced smart grid ecosystem where utilities will be able to monitor their networks in real-time and provide greater and faster benefits to day-to-day operations.

Next-generation smart meter technologies have significant computing power and provide for growing source of customer data including network behavior. Availability of this new data shall enable accelerated development of decentralized energy systems and enable everyday consumers to have more insight and control into their home energy use.

First-generation AMI had limited ability to support real-time customer engagement processes and growing needs of a digitized and smarter grid of the future.

Most of the smart meters installed today are of first generation which do not come with major compute capability nor real time data capture capabilities. Consumers need to wait up to 24 hours before they see their consumption details.

Market evolutions are shaping and enabling new use cases for Next-generation AMI

 # 1 Intelligence is shifting to the edge As new generation smart meters can leverage edge computing technology, more and more use cases can be computed on the smart meters, reducing the need for sending data to the cloud-based applications.

 # 2 New possibilities with digital technologies Real time analysis of consumer behavior and network can be carried out using big data analysis. Artificial intelligence (AI) and machine learning (ML) systems can learn to reduce energy consumption.

 # 3 Emergence of the prosumer Prosumers are a reality and suppliers need to respond to a wide range of additional resources used by them such as rooftop DERs, battery-based energy storage systems including EV charging.

Next-Generation AMI enables consumers with more visibility and control

For consumers this means more control and empowerment. Smart meters will provide real time information on energy consumption and spends, making it easier to manage future energy costs.

Real-time data can be accessed from anywhere making it much easier for consumers to make better decisions about their choice of tariffs or suppliers.

Utilities can provide superior customer experience

It costs many time more to attract a new customer than to retain an existing customer. Utility retailers can provide greater experience to their customers with more personalized tariffs, payment plans, targeted communications.

Similarly, better communications and customer engagement can be managed for maximized debt collection. Increased use of predictive analytics on customer and smart meter usage data can bring in newer insights such as which customers are likely to default on payments.

A major Canadian utility is modernizing their smart metering hardware, network, and systems to keep pace with a rapidly changing energy landscape

Approximately 1.4-million-meters will be replaced to promote timely and accurate billing and enable more granular data for increased grid visibility, improved customer innovation, and consolidation of network, operations, and communication systems to drive cost savings.

The objective of the program is to enable broader grid and utility modernization, with the following target outcomes:

- Full end-to-end installation and integration of next generation AMI 2.0 edge computing smart meters
- Improved grid resiliency, visibility and maturation of OT systems
- Ability to provide customers with energy usage data, and improved customer experience
- Assist in the growing adoption of EVs in Ontario, Canada

Digitized, modern and robust electricity networks are highly reliable and bring greater and faster benefits to day-to-day operations.

With Next-Generation AMI, grid companies can support:

- **Flexibility management:** peak load management, time of use tariffs, demand response management for smart EV charging, battery storage and other residential appliances. .
- **Promote sustainable behavior:** Micro grids for communities that share access to renewables with other users; savings to households in the form of reduced energy bills, reduced energy usage during peak times and balanced demand and supply of energy in the power grid.
- **Grid connection monitoring:** With real-time data and location identification, detection of grid faults becomes faster helping in reducing overall outage restoration time. Additionally, supply limitation at grid connection point supports grid stability.
- **Electrification of transport** is an important factor towards a fossil free future and can be enabled by a smart metering enabled grid which is prepared to support greater demands of fleet charging.

European utility Enedis has set up a new control room service

Enedis is the main operator of the public electricity distribution network in France. ASGARD is their new service leveraging Smart Metering data for Network operation enhancement.

It operates 24 hours a day and monitors their low and medium voltage network aiming to improve the quality of the electricity supply and the responsiveness of interventions. Their key use cases for grid performance include:

- **Data Analytics for Distribution:** Machine learning for network cable renewal allows to prioritize investments on LV/MV networks (both overhead and underground) while predicting the network sections that are most likely to experience incidents.

  Using this, Enedis has already seen significant cost reductions due to avoided repairs and outages.
- **Predictive Maintenance.** Machine Learning for low voltage network assesses events from the AMI communication infrastructure to predict malfunctions that can several days or even weeks in advance. 99% of all suspected incidents raised using this have proven to be justified and allow for actions to be taken before failure.
- **Immediate location and fast repair of electrical faults on LV network.** Control room operator pings the group of meters which have sent electrical surge alarm and pinpoints the precise location of the fault, before the arrival of network crew.
- **Utility call center Instant diagnosis of Customer Outage.** Segregates network faults or customer issues and helps for providing optimized troubleshooting process immediately during the initial call.
- **Renewable asset integration into the grid.** Demand balance and voltage regulation in case of local constraints due to Solar/wind farm Generation

The future is even more demanding

Next-generation AMI-based grid ecosystems will be cornerstone of evolution and emergence of newer possibilities to accelerate energy transformation

Sustainability:

Edge computing for substations plays a significant role in sustainability by enabling efficient and intelligent management of energy infrastructure:

1. **Localized Data Processing:** Edge computing allows data processing and analysis to occur near the source, within the substation itself. This reduces the need to transmit large amounts of raw data to central data centers, minimizing network traffic and energy consumption.
2. **Real-time Monitoring and Control:** By processing data locally, edge computing enables real-time monitoring and control of substation operations. This improves the overall efficiency of the energy grid, optimizing power distribution and reducing waste.
3. **Predictive Maintenance:** Edge computing facilitates the implementation of predictive maintenance strategies by analyzing data in real-time. By detecting potential equipment failures or inefficiencies early on, substations can proactively address issues, preventing downtime, and reducing overall energy consumption.
4. **Enhanced Grid Stability:** With edge computing, substations can quickly respond to changes in energy demand and supply, optimizing grid stability. This leads to more reliable power distribution, minimizing power outages, and improving energy efficiency.
5. **Renewable Energy Integration:** Edge computing enables better integration of renewable energy sources into the grid. By processing and analyzing data at the substation level, energy operators can balance and manage the intermittent nature of renewable energy, maximizing its utilization and reducing reliance on non-renewable sources.

Current Developments

Frontrunners are driving this important new development forward. Grid operators and OEM's are teaming up in global consortia to define global standards and trigger first implementations. The largest European DNO's, as well as some US ones, have started their transformation journey.

It will take a lot of collaboration across the wide spectrum of hardware and software providers to drive this change.

For this reason the Vpac consortium was established in North America whilst the E4s consortim was founded in Europe. The first use cases are being developed and we expect the first demonstrations to the public in H2 2023.

Conclusion:

Virtualisation and edge computing presents tremendous opportunities for substations in the power sector. By enabling real-time data processing, enhancing cybersecurity, and improving situational awareness, it revolutionizes the way we operate and maintain substations. Embracing edge computing technology will undoubtedly contribute to a more resilient, efficient, and secure power grid.

Grid operators will have to define a roadmap to transition the substation to a virtualised, edge computer based solution. Starting with a first implementation, developed on a future proof architecture, they should embark on this journey rather sooner than later.

EXPLOITING DATA AT THE SUBSTATION LEVEL

VIRTUALIZATION AND THE UTILITY EDGE COMPUTING -AN INDUSTRY GAMECHANGER

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RENE KERKMEESTER, NETHERLANDS

Edge computing and virtualisation of substations

30 million electricity substations across the globe will need massive upgrade in the next decade to keep the grid manageable in the future renewable energy system. Substations are at the heart of the system change. Power quality management, fault detection, alarm generation are only some examples of applications that need simultaneous operations in a sub station. Virtualisation and edge computing is the only cost-effective way forward for grid operators to make that change.

Edge computing is revolutionizing how we handle data processing and analysis at the network's edge, bringing numerous benefits to the power industry. Substations serve as vital nodes in the power grid, connecting transmission and distribution networks. With the increasing complexity and volume of data generated by substations, traditional centralized computing models face latency, bandwidth, and security challenges. This is where edge computing comes into play. Edge computing involves deploying computational resources closer to the data source, reducing latency, and enhancing real-time data processing capabilities. By distributing computing power at the edge, substations can perform data analysis and decision-making locally without relying heavily on the centralized cloud infrastructure. This improves operational efficiency and enables rapid response to critical events.

One of the critical advantages of edge computing in substations is its ability to handle massive amounts of data in real-time. By processing data locally, substations can quickly detect anomalies, monitor equipment health, and identify potential failures. This proactive approach facilitates predictive maintenance, reducing downtime and enhancing overall system reliability.

Moreover, edge computing enhances cybersecurity in substations. By minimizing data transfer to the cloud, sensitive information remains within the secure boundaries of the substation. This reduces the attack surface and mitigates the risk of cyber threats. Additionally, edge computing enables localized encryption and authentication protocols, further safeguarding critical infrastructure.

Furthermore, edge computing empowers substations with enhanced situational awareness. Real-time analytics at the edge enable rapid identification and response to abnormal grid conditions, ensuring a stable and secure power supply. This is particularly crucial in scenarios like fault detection, power quality monitoring, and grid restoration after disruptions.

Virtualization in the utility edge brings cost optimization, resource efficiency, scalability, agility, resilience, and security enhancements, making it a valuable technology for optimizing edge computing infrastructure and meeting the demands of modern applications and services.

A solution to address the most relevant of challenges.

Challenge #1
Limited resources: Substations typically have limited computing resources, such as processing power, memory, and storage. Edge computing solutions need to be designed to operate within these constraints.

Challenge #2
Harsh environmental conditions: Substations are often located in harsh environments with high temperatures, humidity, and electrical noise. Edge computing devices must be ruggedized to withstand these conditions and operate reliably.

Challenge #3
Real-time processing requirements: Substations often require real-time processing and analysis of data to detect and respond to events promptly. Edge computing systems must be capable of handling and processing data in real-time to ensure timely decision-making and control.

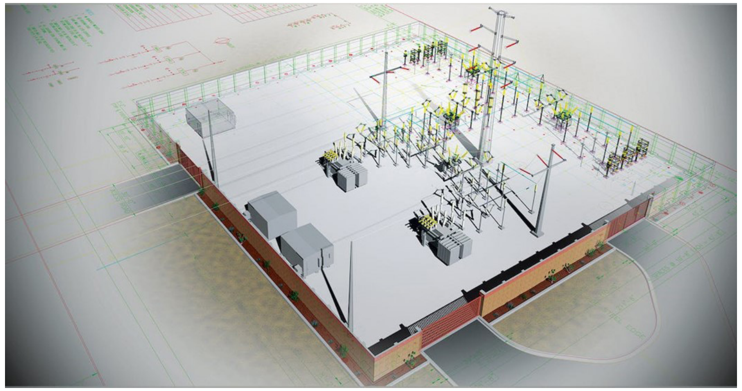
Challenge #4
Network connectivity: Substations may have limited or intermittent network connectivity, especially in remote locations. Edge computing solutions need to account for potential network disruptions and should be able to operate autonomously or with limited connectivity.

Challenge #5
Security concerns: Substations are critical infrastructure components and are potential targets for cyberattacks. Edge computing devices should have robust security measures in place to protect against unauthorized access, data breaches, and tampering.

Challenge #6
Scalability: Substations are part of a more extensive power grid infrastructure, and the number of substations can vary widely depending on the grid size. Edge computing solutions should be scalable to accommodate the increasing number of substations and handle the growing volume of data generated.

Challenge #7
Integration with existing systems: Substations often have legacy systems and equipment in place. Edge computing solutions should be designed to integrate with these systems seamlessly, ensuring compatibility and interoperability.

Challenge #8
Maintenance and management: Deploying and managing edge computing devices in multiple substations can be complex. Remote monitoring, centralized management, and efficient maintenance processes are necessary to ensure the smooth operation of the edge computing infrastructure.



ENERGY OF DATA AND AI

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Data is all you need

In the energy and utilities sector, vast amount of data generated from power generation, transmission, and distribution systems can be leveraged, using enabling technologies, especially AI, to reduce the cost of operations, improve work and asset efficiency, and enhance customer services.

Examples of realized business value from Data & AI in energy market are so inspiring that many utilities rushed to build AI applications overlooking data challenges they may face. Building strong Data foundations is one of the core pre-requisites for successful Digital Transformation in the energy sector.

As utilities become increasingly data-driven, relying on real-time information, extracting actionable insights from data remains one of the major challenges in the energy and utilities sector. Most of the unexplored historical, legacy, and operational data from operational execution systems, resource planning and other systems contain a wealth of information with unexplored potential, that we cannot afford to miss. Only 20-30% of the value from such available data-at-rest is currently accrued. The main challenges of leveraging Data & AI in the energy and utilities domain are manifold. First, a robust IT/OT infrastructure must be created to collect, process, transform and visualize data. Second, we need trained personnel specialized in managing data e.g., data modellers, data architects, and data scientists. Third, we need standardization of data flows and data formats that can ensure data interoperability, be shared with ecosystem players, and be seamlessly integrated with legacy applications. Fourth, we would need a strong and secure communication network to manage huge volumes of data accurately, faster, and without data breach or loss. Fifth, the absence of a data and AI strategy and implementation roadmap for value-driven use cases is hindering the growth of data and AI in the energy and utilities sectors.

Benefits of Data & AI for Smart Grids

IoT data can be used to optimize CAPEX and investments for intelligent grid modernization; artificial intelligence helps to derive value from existing grid data and reduce OPEX; and data and AI together fuel new data-driven business models to enable the transition from consumer to prosumer. Data sharing supports collaboration in the ecosystem and adds transparency with regulators to ensure compliance.

FIGURE 1

Solve Smart Grid Challenges with Fit-For-Purpose custom AI solutions in all four areas of Data-Driven Grid

Custom AI Solution development with RAPIDE framework	Custom AI solution development based on local environmental conditions or other unique factors , e.g. proximity to shoreline, etc. RAPIDE framework to improve analytics quality and fast-track time-to-value.

RAPIDE	Readiness Assessment	Advance data screening	Pinpoint driving factors	Identify candidate algorithms	Develop powerful models	Evolve and embed solution
Industry-proven governance for data science professionals	Clear objectives and sufficient initial data	Demonstrate the predictive or diagnostic potential in the data	Isolate key features driving the behaviour of interest	Down-select most promising techniques to meet objectives	Determine the best hybrid data-driven and principles-based model	Refine the solution using evidence gained from in-service use

Data & AI use cases within above mentioned four categories are driving major business benefits – from better network availability to reducing maintenance costs, optimizing grid upgrades, and generating new revenue streams from software-based business models.

Energy market leaders invest efforts into aligning their Data & AI Strategy to Business & Sustainability Goals, they then roadmap use cases and understand what data will be required to implement them, and they take care of scalability & security of the deployed solutions. For this, they architect future-proof Data Platform Architectures, data interoperability layers, and adjust organizational models and ways of working to ensure agility in solution development with a relentless focus on business value realization, ensuring collaboration among IT, data and AI, operations, and business stakeholders.

FIGURE 2

Data is an impactful lever to modernize grid design operations and enable new services

Data-Driven Grid suite of solutions covers all aspects of Smart Grid: from Advanced asset management, Grid Operations, to Network Instrumentation, Customer Services, and Regulatory Compliance

DATA-DRIVEN GRID SOLUTIONS

Improve grid design and evolution (capex)	Improve grid operations performance (opex)	Bring new services to customers	Enable regulatory compliance
Leverage IoT Data to optimize CAPEX & investments for Intelligent Grid Modernization	Artificial Intelligence to derive value from existing Grid Data and reduce OPEX	Introduce New Data-Driven Business Models to enable transition from consumer to prosumer	Transparency with regulators through data sharing

SMART GRID DATA FOUNDATIONS

Ensure high quality of data, scalability of AI solutions, self-service and value realization from Grid Data

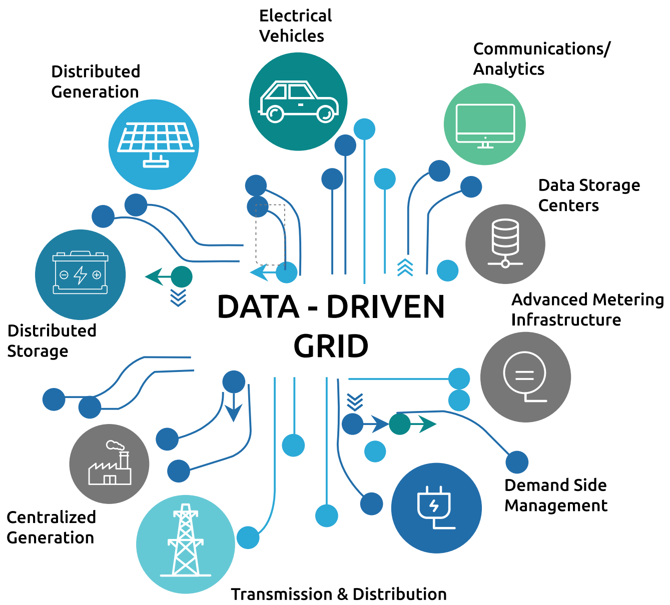


FIGURE 3

Data fuels the evolution of smart grid at scale

OPEN DATA

Energy related data from third parties

1. Consumption evolution assumptions
2. Edge of the grid assets evolution
3. Capacity markets (from capacities to prices)
4. Weather conditions

NETWORK DEVELOPMENT

1. Asset Lifecycle planning data (tech & finance)
2. Network Engineering data, PLM

ASSET GRID MANAGEMENT

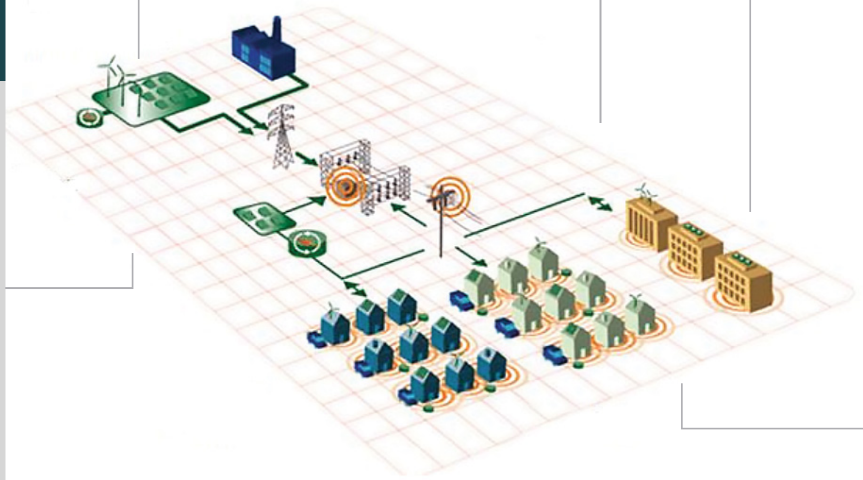
1. GIS network data
2. Asset characteristics
3. Asset history
4. Real-time Asset Health

NETWORK OPERATIONAL MANAGEMENT

1. Maintenance and Field services data (incl. subcontractors' work orders)
2. Spare parts stocks data
3. Inspection data (incl. drone and satellite images)
4. Vegetation data
5. Flexibility data (Connected and realized capacities & Curtailment curves)
6. Network operations data
7. Energy balance and losses data (technical and non-technical)

STAKEHOLDERS & ECOSYSTEM

1. Storage data (utility scale storage)
2. Producers and retailers' data exchanges
3. Carbon emissions footprint data
4. Market and societal development information (scenario planning of capacity needs etc.)
5. HR and Financials including asset values
6. Aggregated data for stakeholders communications
7. Quality and continuity of supply data – network balance and other regulation data



BILLING/ CUSTOMER MANAGEMENT

1. Metering data
2. Contractual data
3. Consumers contracts (direct or through suppliers – third parties)
4. Connected consumer capacities to the network data
5. Load curves valorization & Billing data
6. Customer interactions data (complaints, new connections, work orders, security inspections, etc)

Have you caught the Data wave?

Considering AI's value in Energy market, 92% of Energy & Utilities companies are either already invested in AI or will do so in the next two years, obtaining competitive edge. Two-thirds (67%) of energy executives are realizing AI benefits in creating better customer experiences, and more than a half (55% and 53%) in improved decisions making and innovating products and services.

Proven Data & AI use cases in Energy

Data & AI enables multiple use cases across the value chain of the energy market. For example, in 2023, we observed a spike in interest to Grid Digital Twin. Companies develop and deploy Grid Digital Twins in production, at scale. Data & insights from Grid Digital Twin help to forecast peak consumption, predict outages, future demands, and organize system modeling with specific solutions, e.g., EV Charge Hub, Lighting as a Service, to integrate into a comprehensive model of the energy system. What are the categories of proven use cases that generate business value in energy sector?

1. Reduce the number of breakdown & outages

One of the challenges in the energy & utilities industries are detecting defects in the processes. Outages are costly for utilities in both financial and brand value. Hence, it is no surprise that 35% of energy executives are realizing AI's benefits in performing predictive maintenance and automating routine tasks (33%), as per the PWC report. AI image recognition and computer vision systems are cost-effective and process photos and videos of the assets to identify anomalies and sound an alarm if any anomaly is detected.

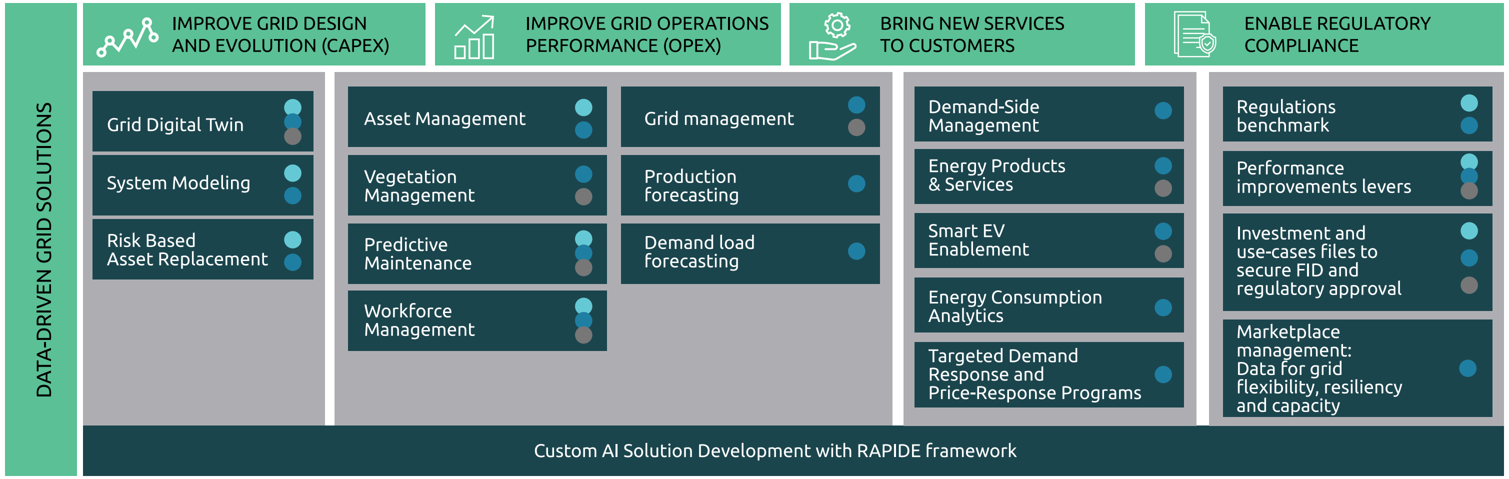
For example, Offshore wind plays a key role in our efforts to decarbonize and reach net zero. Capgemini utilized predictive maintenance to effectively extend the lifecycle of turbines' gearbox oil, increasing the maintenance interval by 40%, leading to substantial cost savings for the operator while also reducing its carbon footprint.

For another client, Capgemini explored and developed AI solutions running neural network models to forecast ice-sleeve formation and vegetation intrusion across the client's transmission lines. The solution enabled the TSO to accurately forecast and categorize risks and adapt its maintenance programs accordingly. This helps to address the reality of climate change as transmission operators are challenged by extreme weather conditions that add additional strain to their network.

One more case was about a huge amount of the inspection data from drones is analysed by ML models, which produces a birds-eye view of the grid, and its most critical parts. AI-generated detailed report for work crews highlight defects for human supervision, which allows to expedite the processing of up to 15%.

FIGURE 4

Data fuels the evolution of smart grid at scale



2. Ensure safety of operations

Pattern recognition algorithms, processing video streams, or AI image recognition can be used in terms of safety, flagging violations of adequate dressing for dangerous operations.

3. Address Prosumers challenges: Reduce Grid Congestion, and optimize pricing

With the growth of renewables and regulations favouring electricity consumers to become generators (Rooftop Solar, Wind, Biomass, etc.) not only for captive consumption, but also to export surplus energy to the grid. There are software applications available that track real-time data on energy availability and demand, time-of-use consumption, and factors affecting energy prices. Considering the intricacies of real-time electricity markets, AI/ ML tools can be applied for scenario modelling based on energy demand, load forecasting, pricing factors, etc. For Instance, Capgemini developed a machine learning model that offered a large windfarm operator, the ability to generate more accurate wind speed readings while reducing costs associated with maintaining offshore measuring towers. Accurate wind speed readings enabled the operator to generate more accurate and reliable power-curve models used for generation forecasting.

Also, the utility suppliers can predict with the help of AI consumption of energy and thus come up with dynamic pricing to offer super-low variants when there is excess capacity. Customer, concerned with the bill size, could adjust and regulate their utility consumption in the most rational way.

4. Stabilize Grid

The electricity grid is transforming rapidly to accommodate more renewable energies. The complexities of RE connections from various locations, and maintaining grid stability, security, and compliance must be tackled.

According to OFGEM, "the data landscape is evolving across the energy sector, and its effective use can provide valuable insight for grid operators, consumers and marketplace intermediaries." Ofgem is encouraging more effective use of data, to improve efficiency in grid operations and customer services, while adhering to regulatory compliance and data privacy norms.

31% of energy executives are realizing AI's benefits by analysing production scheduling scenarios using simulation modelling. The latest trend in energy efficiency suggests the usage of decentralized microgrids, combining several renewable and non-renewable sources of power, whereas traditionally energy supply chains are centralized and formed around the power plant providing the electricity to the end-users. Thus, AI technologies can predict the times when energy is effectively produced while the sun is shining or the wind is blowing. Then store the excess of it in their batteries at home because energy is cheap and selling it makes little sense for the supplier. AI can forecast the times of high energy usage and then sell accumulated energy as prices rise. The main idea of this AI enhancement is to maximize micro producers' profit as well as reduce the expense for end-users.

5. Improve Sustainability

A key to reducing greenhouse gas emissions is through decarbonising of power, heat, and transportation which account for approximately 75% of global emissions. Decarbonising heat and transportation can be achieved through electrification and introducing cleaner sources like hydrogen into the gas blend. In parallel, replacing conventional power generation sources with renewable energy sources will decarbonise power. To accommodate these low-carbon technologies (LCT), significant network modifications are required.

Electric vehicles (EV) will need a network of charging infrastructure; analytics and AI are currently used by industry to identify optimal charging locations based on transportation patterns and consumer behaviour. To enable network accommodations for EVs, it is important to identify locations of the network that will observe a higher rate of EV uptake by analysing consumer demographics.

To accommodate these advancements, grid operators need to decentralize their networks and utilize analytics and AI for intelligent decision-making when making network modifications. Capgemini helped National Grid address this issue with the use of machine learning and spatial graph technologies to clean network data. The solution addresses the vast network uncertainties by offering enhanced network oversight to deliver data-driven infrastructure investment. Capgemini did a study that looked at comparing affluence with EV uptake and how this can be useful for the network.

6. Provide Flexibility Management

As grid operators transition to a decentralised network, data plays a key role in facilitating grid flexibility. Technology integration is part of the roadmap to flexibility, introducing smart meters, advanced sensors and monitoring systems that form the crucial foundations for data science and AI. AI enables grid flexibility by optimising grid response. AI analyses energy patterns and consumer behaviour, feeding into the concept of Smart Grids Optimisation, which coordinates the utilization of distributed energy resources, storage systems, and EVs.

Capgemini delivered a consulting project for the development of a home demand-response system that reduced peak network usage while reducing consumer energy spend and providing appropriate heating provision. The solution generated home usage profiles by monitoring 1000 electric boilers to determine which boilers could be switched off during peak hours while minimising disruption.

7. Address Regulatory Challenges & Data Privacy

Data democratisation is a growing topic within the utilities, concepts like Open Data in the UK and the Green Button Initiative in the US introduce the use of data by third parties to service the utilities and drive innovation. With these advancements, concerns regarding privacy and security arise among regulators and consumers who seek clarity on data storage and handling practices.

Despite the concerns, data democratisation is an enabler in the utilities' drive to modernise and decentralise. Privacy-enhancing data management methods have been gathering interest across the industry to protect sensitive data benefiting from the valuable insights generated by AI and data science applications. Federated learning enables the deployment of ML models across devices while protecting sensitive data. This technique is useful for developing predictive maintenance models and load forecasting algorithms. While edge AI enhances privacy, it provides additional benefits to grid companies like real-time insights and local decision-making, while also boosting sustainability by reducing energy-intensive data transfers.

Capgemini played a role in a UK-based grid operator fulfilling its regulatory requirements with the Office of Gas and Electricity Markets (OFGEM). As part of the client's ED2 business plan, Capgemini delivered the client's data strategy and the roadmap to its digital transformation journey.

Pre-requisites and recommendations for value realization from Data & AI

Whole-systems management is becoming increasingly relevant for data-driven operators across their utilities. The concept of whole systems thinking focuses on integrating and coordinating interconnected systems across the entire value chain of utilities, including generation, transmission, distribution, customer services, and information systems. It takes a comprehensive approach to optimize the performance and efficiency of the utility infrastructure.

Data enables Digital Continuity across all these systems, and AI allows for automated response and optimization.

What are the prerequisites for efficient use of Data & AI in the energy transition?

Challenge	Description	How to Solve?
Insufficient or poor-quality data and difficulties in exchanging data with other players in the value chain	Utilities face challenges in augmenting and correcting legacy data for assets, often installed decades ago. Data quality improvement initiatives are often complicated by the fact that utilities are often located underground.	Assess the **Utility's current maturity in Data & AI** within the dimensions of Organizational setup, Competencies, Technology landscape, Data and Leadership. **Gap analysis** becomes the basis for improvements. To enable connected systems to leverage data from multiple sources and facilitate advanced analytics and AI for real-time decision-making, **Data Strategy** should be developed with an implementation roadmap, followed by setting up a robust data governance and management practice. Evaluate Utility's **maturity of Data Governance and blueprint Data Trust Foundations:** Data ownership, Data Quality, Master Data Management, Meta Data Management, Privacy & Security. **Formulate Data Ecosystem strategy** and define **Data Sharing mechanisms** to enable stakeholders and 3rd parties' access to data to fast-track value realization and Energy Transition CALLOUT1
Data is locked in silos	Data is generated and stored in multiple IT and OT systems, which makes it difficult to extract, govern, and use for AI.	Integrate information and communications technology (ICT) with operations technology. **IT-OT integration** improves real-time situational awareness of the grid and the customers, accounting for the energy flow at a more granular level, to take informed decisions on resource and cost optimization, manage operational constraints and promote sustainability. IT-OT integration benefits the following applications: Fault and Outage Management Network Quality and Efficiency improvement Asset Management – Network Planning DER management and Integration
Hard to find data	Myriads of legacy data exist in hand-drawn blueprints, pdfs, maps and handwritten notes that need to be found/located, digitized and interpreted by data and engineering experts.	**Knowledge Graphs & Ontologies** can be leveraged to create **Data Catalogues** alongside **Generative AI models** (LLMs) to extract data from digitized documents and organize company-specific, proprietary knowledge retrieval systems. For example, Generative AI can be used for corporate information retrieval for R&D or for marketing content generation. Invest in the necessary IT infrastructure, such as Data Platforms and Generative AI portals which may involve upgrading hardware, utilizing new cloud services, and in Generative AI solutions by cloud leaders Microsoft, Open AI, Google, AWS, and Adobe, as well as challengers like Cohere, Anthropic, Stability AI, and Hugging Face.

Disparate legacy data landscapes and a lack of modern data platforms	Legacy data is collected in multiple legacy systems that are loosely integrated but are often completely disparate. This creates challenges in determining systems of records and drives data discrepancies.	Innovative Data & AI solutions require modern and **scalable Data Platforms for data ingestion, processing, cataloging, and AI deployment.**
Data Interoperability	Data formats, types, and naming conventions vary across multiple IT/OT systems and across value chain players.	Detail interoperability layers of the Utility organization **CALLOUT2 and leverage Utility-specific information models, data models, and ontologies** such as IEC CIM (incl. CIM-Market), Flexoffer, IEC 61850, USEF, OpenADR, DLMS/COSEM, SAREF4ENER, CGMES, IEC-62559
Challenges in use-case prioritization	With a broad selection of use cases available, utilities are tasked with balancing regulatory requirements with business benefits but lack a repeatable, data-backed process	Define a value-driven Utility's **strategic vision for Data & AI and identify prioritized Smart Grid use cases** with high potential. Develop a **Data & AI roadmap** on strategic, operational, tactical levels, and a common way to execute.
Difficulties to transition from POC to AI in production at scale	To derive tangible benefits from data, Utilities need to progress from Proof of Concepts to deployment of AI/ML application in production at scale.	This requires a change in Data Management, Processing, choice of Platforms, and MLOps. A fully integrated, secure, and scalable Smart Grid Data & AI platform in a hybrid cloud context able to deliver trusted data and analytics solutions at scale into production. Accelerated Deployment of Data & AI Platform, Data Mesh, and Data Products - seamless integration, sharing, and processing of heterogeneous data and industrialized deployment of Data-driven Grid solutions

QUANTUM TECHNOLOGY ITS ESSENTIAL ROLE IN SMART GRID 2040

JULIAN VAN VELZEN, NETHERLANDS

In the ever-changing world of energy, quantum computing offers exciting prospects for tackling key issues in energy grids.

Alain Aspect, a distinguished Nobel laureate of 2022, suggests that using quantum simulators to balance energy grids could be one of the earliest applications of quantum computers. As the energy sector adjusts to fluctuating energy supply and a surge in connected smart devices, the immense computational power of quantum computers becomes highly desirable.

The shift towards sustainable energy sources presents significant challenges for energy grids. These grids increasingly rely on variable energy sources and must accommodate a growing number of connected devices. Such changes create computational obstacles that impact the stability and reliability of the grids.

Amidst the hype surrounding quantum computing, it is essential to examine its true potential. By investigating how quantum computers can be applied in energy grids, we aim to understand the advantages, limitations, and feasibility of leveraging this transformative technology. Through this exploration, we hope to uncover the possibilities that quantum computing holds for shaping the future of energy grids and their crucial role in an interconnected and sustainable world.

Key trends and challenges of smart grids

A changing world is driving change in energy grids, with challenges in development and operation as a result. Firstly, there is a growing investment in the energy transition and green energy, resulting in an increasing share of renewable energy sources on the grid. While this shift is crucial for sustainable energy generation, it presents challenges in maintaining grid stability and balance due to the intermittent nature of renewable sources. Managing peak loads becomes more complex as the two-way energy flow requires sophisticated grid management systems. Secondly, grid operators are actively working to reduce transmission and distribution losses, improving overall efficiency. However, these efforts often require higher capital investments per kilowatt-hour to deploy more efficient energy generation technologies. Thirdly, the decentralisation of the grid, driven in part by prosumers who both consume and produce energy, introduces complexities in grid management and makes it challenging to detect and accurately predict faults and outages accurately.

Additionally, the increasing adoption of electric mobility, such as electric vehicles, adds to the demand for energy and highlights the need for increased storage technologies like batteries to accommodate fluctuations in supply and demand. Lastly, the energy market itself is becoming increasingly volatile, necessitating adaptive pricing mechanisms and strategies.

Addressing these challenges will be essential for the successful implementation and modernisation of smart electric grids in order to unlock their full potential in supporting a sustainable and resilient energy future.

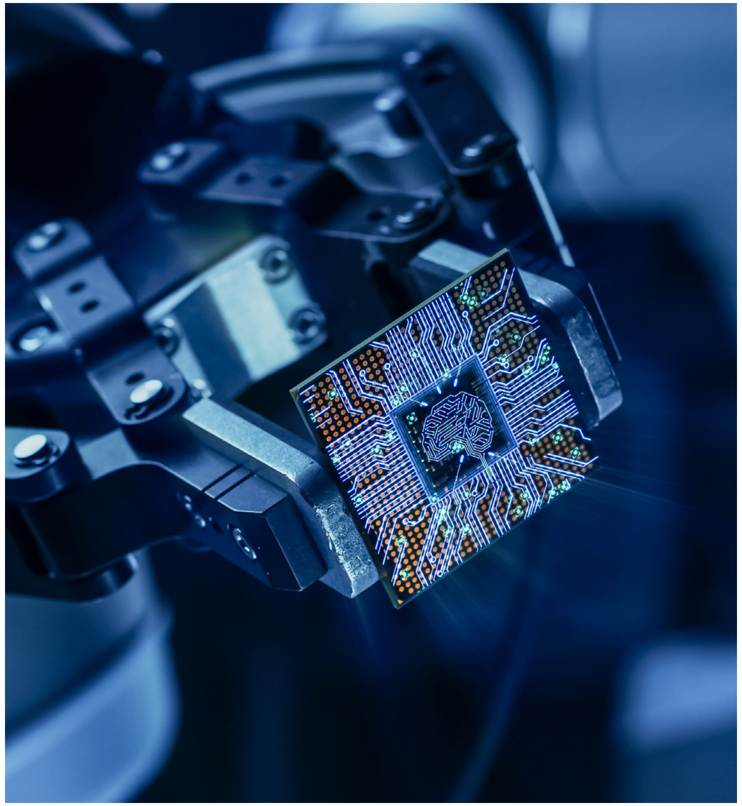
Exploring the impact of quantum computing

Quantum computing, deeply rooted in the intricate principles of quantum mechanics, presents unparalleled computational advantages, particularly in domains demanding high-performance computing and those that align with the subtleties of quantum mechanical systems. While the precise applications of this technology continue to evolve, the energy sector is increasingly recognizing its potential impact across the spectrum of compute-intensive activities, including in generation, transmission, distribution, and consumption of energy.

In the realm of energy generation, renewable sources such as solar and wind, while promising, come with inherent limitations. To overcome these constraints, advanced energy generation systems are imperative. However, the development of such systems often hinges on complex material modeling at the nano and micro scales. Classical computers, though powerful, frequently struggle with these intricacies, resorting to approximations that fall short of capturing the full spectrum of quantum behaviors in molecules and materials. Quantum computers, on the other hand, exhibit a unique prowess in simulating the exact quantum behavior of molecules and materials. This transformative capability has the potential to revolutionize technologies like solar cells, hydrogen production methods, and the quest for nuclear fusion as a clean energy source. For instance, a noteworthy collaboration in 2022 saw EDF partnering with Quandela to employ photonic quantum computing for simulating the structures of hydroelectric dams, showcasing the tangible application of quantum computing in the energy generation sector.

In the context of energy transmission and distribution, the integration of unpredictable renewable sources into the energy grid introduces significant challenges related to grid stability and efficient energy distribution. Quantum computing holds the promise of optimizing complex processes such as transmission and distribution, fault assessment, and overall grid management. Industry leaders, including E.ON, Eni, and EDF, have embarked on the journey of harnessing quantum computing's capabilities to bolster energy delivery efficiency and ensure grid stability, heralding a potential transformation in how energy grids are managed and operated.

Turning our attention to energy consumption, quantum computing emerges as a pivotal tool for addressing key challenges. It offers the potential for more precise demand and load forecasting, enabling efficient resource allocation and utilization. Moreover, quantum computing's role in the development of advanced energy storage solutions, such as next-generation batteries, is of paramount importance. In 2022, IonQ, a prominent player in the quantum computing industry, forged a partnership with GE Research to explore the advantages of quantum computing in modeling multi-variable distributions for risk management. This collaboration exemplifies the expanding horizons of quantum computing, particularly in enhancing energy consumption modeling and addressing the intricacies of risk management in a dynamically evolving energy landscape.



Significant challenges remain before the full potential of quantum computing is realised.

The Energy Quantum story just begins.

While the energy sector offers numerous potential use cases for quantum computing, the reality is that current-day quantum computers are not yet capable of performing useful computations. Present quantum computers face several limitations, making them comparable to computer mainframes from the 1960s rather than mature commercial machines.

One notable constraint is the slow operational speed of quantum computers. Their gate speeds are thousands of times slower than classical computers, significantly impeding their computational efficiency. Moreover, fault-tolerant operations involving additional overhead for error detection and correction would make quantum computers millions of times slower, nullifying any potential speedup. Additionally, quantum computers have limited number of qubits, typically a few hundred on current-day machines. Although this size is approaching the level required to address real-world problems, achieving fault-tolerant qubits would necessitate thousands of physical qubits through error correction techniques. However, the most significant limitation lies in the quality of quantum computers, specifically the fidelity of two-qubit gates. Presently, state of the art exhibits error rates of approximately one percent for such gates. As a result, use cases of a few hundred gates produce unreliable results, rendering them impractical.

As near term quantum computers are severly limited, the full potential remains decades away. Nonetheless, first applications that cleverly deal with the limitation of available hardware are on the horizon. Academic institutions, innovative startups, and end-users are actively engaged in pioneering ways to extract the maximum benefit from the existing quantum hardware, inching us closer to harnessing the quantum advantage.

One key strategy involves a clever approach to managing the inherent errors and noise that plague current quantum systems. Researchers are developing techniques to mitigate these issues, improving the reliability and stability of quantum computations. Additionally, a selective approach is emerging, focusing on high-value applications that align seamlessly with quantum computing's strengths. Furthermore, efforts are underway to optimize quantum algorithms and software for specific applications, enhancing their efficiency and practicality. These collective endeavors mark the initial steps toward unlocking the immense potential of quantum computing, even in its nascent form.

A quantum simulator for near-term quantum advantage?

One avenue that shows promise for a potential quantum advantage in the near future is the optimization of graph-related problems using quantum simulators. Quantum simulators are specialized machines designed to focus on specific applications, prioritizing simplicity over universality. These systems appear to be particularly well-suited for addressing graph-related problems, such as those encountered in energy grid optimization.

Several companies, including Parisian Pasqal and QuEra from Boston, are actively working on developing this technology and express optimism about discovering commercial applications within the next few years. However, as these systems operate on heuristic principles, the actual advantage they offer can only be determined through empirical observation. Additionally, the viability of commercial interest in the problem class that can be effectively addressed by these systems is a crucial factor to consider.

The energy sector is facing evolving challenges that require enhanced computational capabilities. Quantum computers offer the potential to exponentially speedup specific tasks and provide valuable contributions to use cases in energy production, distribution, and consumption. Many utilities players have started the thinking and some experimentations.

By carefully selecting applications, optimising quantum hardware, algorithms and software, startups, academics, and companies are bringing a quantum advantage closer. Additionally, specialized quantum hardware emerges as a promising solution for niche applications within the energy sector in the coming years.

Ultimately, quantum computing will be a vital role in the smart grids of 2024. To make that happen, continued research and development efforts are crucial to unlock the full potential of quantum computing.

WHAT IS A DIGITAL TWIN IN THE CONTEXT OF LINEAR ASSETS: HOW DOES A UTILITY BENEFIT?

VINNIE NAIR, AUSTRALIA

GAUTAM GANDHA, AUSTRALIA

How do you define a digital twin?

In the electricity industry, and when applied to linear assets, the term "digital twin" represents an accurate model of linear assets, zone substations, vegetation management, and other electrical assets.

Most recently, the application of this concept in the linear asset management space has gained significant traction and has consequently yielded significant benefits to utilities.

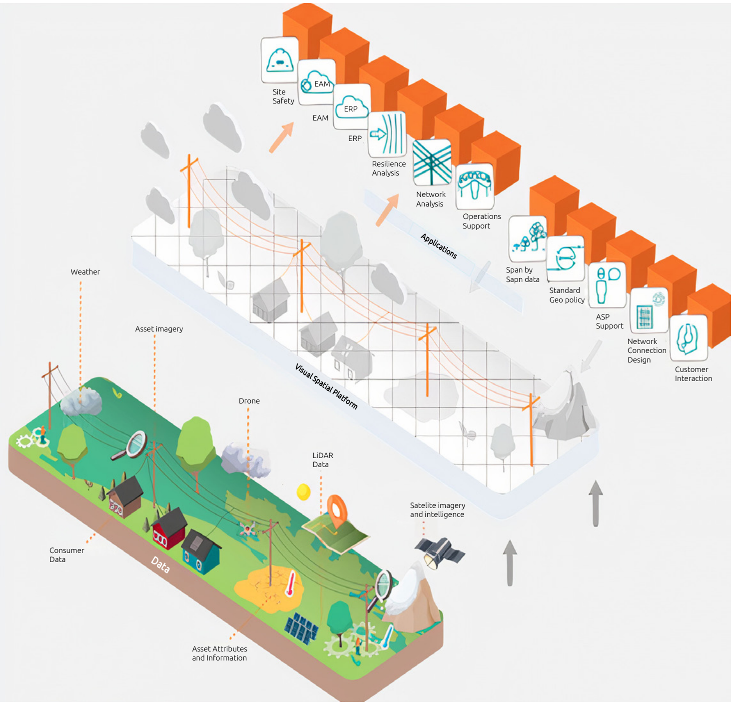
Why linear assets?

For some utilities in Australia, linear assets form a significant proportion of the Regulatory Asset Base (RAB). For example, certain Distribution Network Service Providers (DNSPs) in rural Australia have a significantly high ratio of poles per customer, and therefore very few customers are serviced per kilometer of powerline.

Due to their rural and sparse geography, these utilities are also under pressure from customers, regulators and climate-related events such as bushfires and floods. Creating a digital twin from these assets can help these businesses shift from reactive asset management to an insight-led and data-driven approach.

FIGURE 1

Digital Twin in Action



COMBATING CLIMATE CHANGE: FLOODS AND FIRES

The Endeavour Energy story

Endeavour Energy is an electricity distributor serving Greater Western Sydney, the Blue Mountains, the Southern Highlands and the Illawarra region. With more than one million customers, enough length of underground cables to travel from Sydney to London and back, and an area served of over 25,000 square kilometers, Endeavour Energy is a significant player in the New South Wales Economy.

Endeavour Energy has been using Neara's digital twin software to accelerate its design process and fast-track ratings studies. However, in March 2021 Sydney experienced severe flooding, which is typically considered a 1-in-50-year event. Given the significant impact these floods were having on customer outages and the damage caused to power infrastructure, Endeavour Energy approached Neara for an urgent solution.

The Neara team was able to implement a floodwater simulator which used open-source government data. This development helped Endeavour Energy effectively pinpoint areas with electricity supply vulnerabilities, particularly in cases of flooding or when flooding posed a safety risk to communities by encroaching on live power lines.

Incredibly, within 48 hours of the emergency commencing, the Neara solution was able to provide visibility across the network and produce reports on flood activity. This was significant given that floodwaters were still in the process of rising at the time.

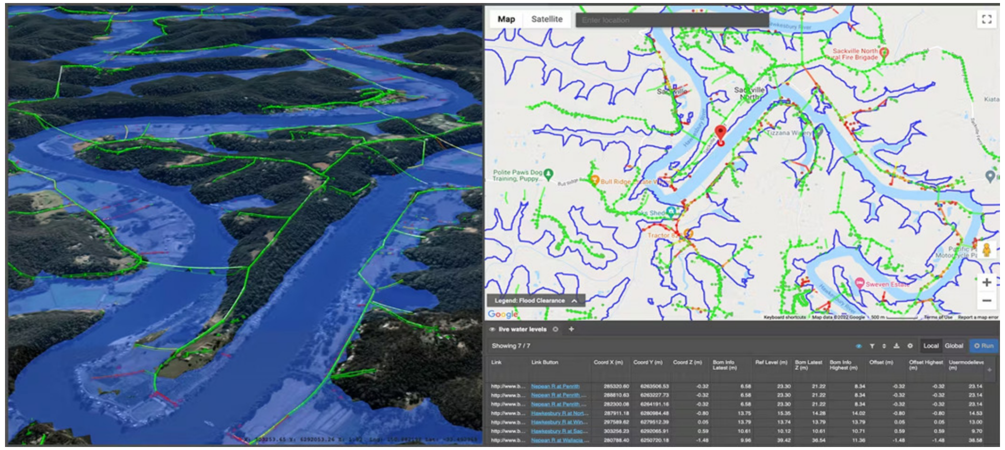
As the floodwater gradually subsided and the worst of the storm was over, Endeavour Energy was able to use the "flood mapping" feature to prioritize inspections to restore customer supply, as well as understand where potential hazards existed to increase safety for the crews dispatched.

The bushfire story

Vegetation management typically is the highest-cost item for utilities. This is because vegetation requires continual cyclic treatment and can present one of the greatest wildfire risks.

Neara can quickly help detect vegetation encroachment within conventional clearance zones and highlight those violations across the network. Users have the power to redefine and iterate on the dimensions of these zones, and compare the resulting violation count, risk, and cost. At-risk locations can be detected and highlighted across the network, so the utility can identify and prioritize their at-risk assets and proactively address those issues.

They can also model the heightened probability of vegetation falling into the network using modeled vegetation fall-in arcs and terrain models. These models help identify areas that are more susceptible to wildfires that may spiral out of control. Currently Neara has been working with several utilities on bushfire mitigation strategies and implementation.



A Neara dashboard used by Endeavour Energy to prioritize their emergency response and recovery efforts. The dashboard integrates live river depth readings, historic flood maps, and dynamically calculated flood polygons to identify assets at risk of water contact.

UNLOCKING GRID CAPACITY: INCREASING THE CAPACITY OF RENEWABLES ON THE GRID

Essential Energy and additional capacity

Essential Energy is an energy distributor that supplies electricity to a remarkable 95% of the geographic area of New South Wales, despite having the smallest customer base among the three major distributors in the state. With up to 200,000 kilometers of power lines, Essential Energy plays a critical role in powering rural New South Wales and supporting the energy transition.

Due to Essential's extensive network, they have traditionally employed rudimentary standards to assess the network's capacity. This approach was necessitated by the limitations of older tools, which couldn't facilitate minute-scale analysis. However, recently they have partnered with Neara to digitally model each asset on the network and create a complete replica.

Through this solution, Essential Energy has been able to model each span of cable individually, allowing for detailed analysis. In many cases, engineers realized that the temperature certain lines had been operating at was much higher than previously known. As a result, capacity in some parts of the network was double than what had been applied.

Historically, grid constraints such as those originally understood to exist by Essential Energy have limited the amount of clean energy which can be injected into the grid.

However, with new digital technologies and a greater understanding of the network, requirements for export limits on rooftop solar and other large clean energy systems could be alleviated.

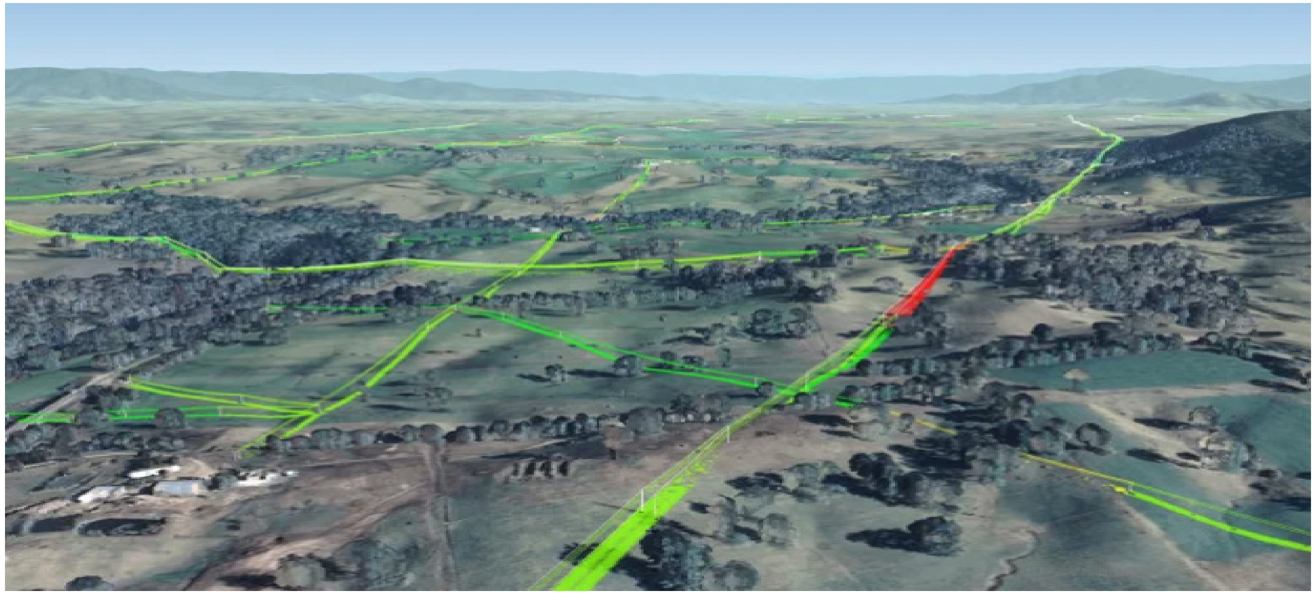
In Australia, the government has set a target of having renewable energy account for 80% of the country's energy mix by 2030. However, there is concern the transition is not occurring fast enough to meet those targets.

To reach this target, it is imperative that urgent investments are made in clean generation, as well as in transmission and distribution infrastructure.

By expanding the Essential Energy Neara use case, there is the potential for a more cost-effective and expedited transition. This is because new transmission and distribution infrastructure may not need to be constructed for the existing clean generation sources.

How does all this help fast track renewables one might ask?

Statistics show that in NSW alone certain large connection application requests have a wait time of up to 60 months. In a high cost of capital environment, this level of efficiency is not palatable to investors and stakeholders associated with the connection applicant.



Neara digitally mapping the Essential Energy's supply locality.

Conclusion and Recommendations:

How can you leverage a digital twin?

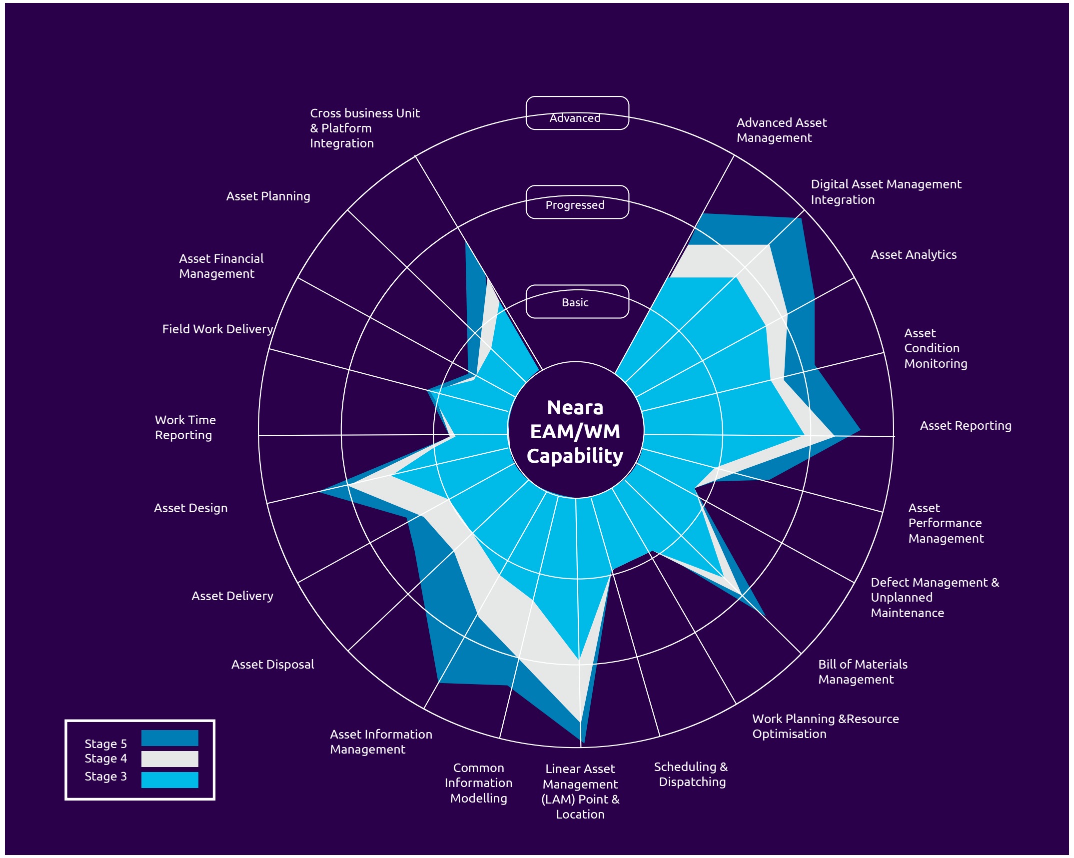
With a bit of creativity and imagination, a digital twin could reform the management of linear assets. The most beneficial use cases can be categorized under two major headings:

1. **Increasing safety:** The ability to simulate the impact of a natural disaster on the grid (such as bushfires or floods) to reduce the amount of time field crews spend in high-risk scenarios. This improves safety outcomes and metrics, such as lost time injury frequency rate (LTIFR). [5]
2. **Reducing operational expenditures (OPEX):** Through intelligent intervention and routing of work orders in the field, schedules per field crew are optimized, which can, in turn, reduce operational expenditure.

How does a utility achieve this?

The key to successfully implementing a digital twin platform is integration. The digital twin platform should not be considered as a separate analytics tool used solely to provide insights and perform complex "what if" analysis. It should be considered a central part of the utility and treated no differently than any other core system within a utility's IT landscape, like GIS, ERP, Asset Management, and the Distribution Management System.

FIGURE 2



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