GSMA

IoT Guide: Connected Energy

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Introduction

Introduction

Use of the Internet of Things for remote monitoring and management in the energy sector is increasingly critical. Driven by increasing energy prices, the growing requirement for energy security, the growing electrification of the vehicle fleet, and a concerted push for hitting net zero targets for sustainability, there is a huge need for all aspects of electricity (and gas) production, distribution and consumption to be connected in order to ensure that maximum efficiency. The main manifestation of the adoption of IoT in energy is in extensive global smart metering deployments, which are helping to increase awareness amongst users of their domestic and commercial consumption, helping to reduce demand, as well as integrating that end usage with wider management of production and distribution. At the same time, the growing proliferation of power generation and storage infrastructure, is changing the architecture of power networks.

This report draws heavily on research undertaken by Transforma Insights relating to the adoption of IoT across hundreds of different use cases, and the sustainability impact of IoT. In this report we examine the increasingly diverse connected energy use cases for which IoT will be beneficial, and in many cases essential, to their functioning.

We start by looking at each of the major energy IoT categories. The first relate to the applications most commonly thought of as the critical energy utility use cases: power generation, distribution networks (and the application of Smart Grid), and smart metering. We then move on to discussing some use cases that stem from newer architectures for energy consumption, starting with batteries and microgrids, and moving on to a wider concept of management of energy consumption devices for the purposes of load balancing, of which electric vehicle charging is prime example (as well as being a major growing energy consumption use case in its own right). Finally we look at other ways in which IoT is being used to enable energy saving that reduces demand for power.

The report continues to examine the connectivity requirements of all of the major categories of energy use cases that will have implications for which connectivity technologies might be the most appropriate, and identifying which technologies will be most appropriate for use to support IoT in the energy sector.

Matt Hatton - Transforma Insights

02

IoT use in the Energy sector

IoT use in the Energy sector

There are a wide and diverse range of ways in which IoT is deployed in order to manage and control the generation, distribution and consumption of electricity and gas. This ranges from greater efficiency in electricity generating facilities, local microgeneration, monitoring of the distribution grid, smart metering, batteries, campus microgrids, and EV charging infrastructure. It also increasingly extends beyond dedicated energy infrastructure into the management of power use by connected devices in homes and commercial premises for the purposes of load balancing. In this section we examine each of the key ways in which IoT is used across all of these applications.

2.1

Power Generation: remote monitoring of critical and distributed systems

The starting point for discussion on the energy sector is generation. Here there is a two-way split between traditional centralised electricity generation and new distributed microgeneration. The former involves power plants and using alternative sources such as solar arrays, wind turbines, barrages and hydro-electric plants. The latter includes energy generation devices used generally on a small scale such as directly at people's homes or business premises, such as solar panels, small scale wind turbines, ground source generation, and cogeneration.

For electricity generators, the use of IoT provides valuable insights within traditional power plants. Remote diagnostics can provide significant financial savings to the operators as repairs will need to be conducted only when required, rather than based on regular scheduled inspections. Predictive maintenance further allows operators to reduce costs. There has been a pronounced shift towards sustainable energy generation in the last decade, driving additional IoT requirements. 30% of global energy came from renewable energy in 2022 up from 20% in 2010. In Europe the renewable figure is 43%, up from 25%. This trend is set to continue. In large part the move to renewables is driven by the aim of reducing CO2 emissions. The CO2 impact of wind, solar, geothermal and hydro-electric power are typically between 2% and 20% of that of burning natural gas, the cleanest form of hydrocarbon fuel.

Global energy from renewable energy

2010 — 2022

20% 30%

European energy from renewable energy

2010 — 2022

25% 43%

Coal is around twice as polluting as gas. There are numerous other benefits, including energy security.

Demand for IoT solutions associated with these more remote and unattended pieces of infrastructure is significantly higher than for more traditional gas, oil and coal power plants. Sensors are used in solar panels to enable preventive maintenance alarming, thus minimising operational costs, maximising efficiency, and reducing downtime. Vibration sensors are deployed on wind turbines to collect data regarding the wind speed of the area and vibrations of the equipment in real-time, allowing for early diagnosis of a problem, reducing downtime. The fluctuating supply coming from solar, wind and other forms of renewable energy also necessitate a more active management of the various pieces of energy infrastructure to match supply and demand, compared to simply turning up or down production in central power plants.

Another key trend in electricity generation has been the increasing prevalence of small-scale microgeneration, particularly solar panels, in homes and commercial premises. With a typical cost now of just a few thousand dollars, and a 30-year lifespan, payback has improved significantly, particularly in light of rising energy costs. Financing plans and government incentives have helped to accelerate the trend. The majority of microgeneration solar arrays are connected in some way, in order to track energy production and monitor for faults.

Microgeneration is not limited to solar. Ground source heat pumps, for instance are increasing deployed; during 2022 sales grew 40% in Europe. Cogeneration, combining heat and electricity production in a single more efficient process is also becoming more widely adopted. Small scale wind turbines are also deployed in some cases, but up-front costs are around ten times that of solar. Each of these use cases benefits from remote monitoring and optimisation.

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2.2

Smart Grid: driving greater efficiency in distribution networks

Smart Grid is defined as all aspects of grid operations, in some cases including smart metering – although we consider that application separately, below – but more specifically management of the transmission and distribution (T&D) networks. In many countries, there are significant losses in the distribution network. For example, India loses around 30% of its power generated due to transmission, distribution, billing generation and collection inefficiencies, whereas in South Korea the figure is 4%.

The use of IoT in Smart Grid involves the monitoring of voltage, current, frequency, and electrical lines at various locations across the grid, to improve grids efficiency and minimise the T&D losses. The use of IoT contributes towards peak load management, smooth integration of renewables, and concepts such as self-healing grids. The irregular output of renewable energy sources greatly benefits from real time monitoring and analysis, reducing their unpredictability, and providing energy providers with the means to operate a greater proportion of their power generation capacity as renewables.

As an example, Dakota Valley Electric Cooperative implemented a smart grid solution supported by Verizon. It faced issues related to resource efficiency with its evolving business needs, large geographic footprint and small staff, meaning that efficiently handling maintenance was a major issue. With the deployment of the PaaS solution, using LTE, the firm improved its power quality and customer service, reduced truck rolls, enhanced ease of decision making and reduced IT overhead with simplified deployment, and lower equipment costs.

Another example from the US is DTE Energy, an electricity and gas utility company in South-eastern Michigan. As part of modernising its power grid, the company installed a grid monitoring platform from Aclara in 2016. The smart grid sensors improved restoration times and introduced cost savings through more efficient maintenance planning and more informed decision making. Grid sensors deployed across its electricity distribution network and substations transmit data over an ABB Tropos wireless network architecture on, for example, real-time loading information, power status and fault data.

A smarter grid, with more balanced demand and supply constitutes the main mechanism to deliver low carbon electricity more efficiently and thereby reducing environmental impact. According to research from Transforma Insights, the use of IoT to monitor and manage grid operations can reduce electricity lost in transmission and distribution by 7-8%.

The concept of Smart Grid also applies for gas distribution networks. More efficient monitoring and management of the distribution infrastructure can provide 0.25%-1% savings across the whole network.

2.3

Smart Metering: removing manual processes and influencing behaviour

Electricity Smart Meters are increasingly being deployed to record and manage the consumption and, where relevant, generation of electricity. In some instances, these devices will transmit usage data to users to encourage more energy efficient behaviour. The UK government estimates smart meters can reduce countrywide carbon emissions by 45 million tonnes which is equivalent to taking 26 million cars off the road in a year.

Smart Meters can be equipped with a variety of capabilities, but they will generally fall into two categories: Automated Meter Reading (AMR) and Advance Metering Infrastructure (AMI). AMR is a technology that automatically connects consumption, diagnostic, and status data from the metering devices and transmits it to a centralised database for billing, troubleshooting, and analysis purposes. AMI covers all the AMR functionality but also allows two-way communication back to the meter from the utility, particularly for purposes of load balancing (see ‘Load Balancing’ section, below).

Traditional meters have significant challenges such as the requirement for manual field reading and billing (i.e. the requirement of a field worker or customer to produce a meter reading and a bill to be generated based on the per unit cost), lack of data storage, lack of outage detection, and requirement for manual disconnection from the electricity grid. These meters also result in significant non-technical losses such as energy theft, errors in unmetered supplies, and conveyance errors that have resulted in increasing demand for smart meters from utility providers. For these reasons, and to encourage changing user behaviour, governments around the world have put in place mandates for the deployment of metering infrastructure.

Automation of metering service tasks results in reduction in operation and maintenance expenses, for which the following items are most notable: reduction in labour hours required for meter maintenance activities (including meter readings, fixing faults), reduction in fuel cost associated with truck rolls, savings in call centre costs (because of reduced outages and other problems), and avoided site visits to pre-payment meter customers.

The most significant benefit of smart meters is in the savings in electricity and gas bills driven by less consumption of resources and reduced number of errors in the meter readings. Smart meters, in addition to changing consumer behaviour, provide details about pricing rates at different times of the day. This gives consumers the opportunity to consume more energy during off-peak hours and save significantly on electricity bills. It is also an opportunity for distribution companies to manage power consumption peaks, thus preventing grid overloads and enabling a lower capacity grid overall. Electric Power Research Institute (EPRI) estimates that by 2050 Smart Meters and Smart Grids can reduce an average electricity bill by 50%.

In large part, smart meter deployments have been driven by government regulation. For instance, new EU regulation required the upgrade or replacement of 5.4 million smart meters, both domestic and enterprise, across Sweden by 1st January 2025. In 2019, Telia won the tenders from several utility companies to upgrade almost half of those meters, and today a major part has already been completed. NB-IoT is the chosen technology which help the energy company provide deep indoor coverage, ideal for connecting utility meters underground or inside buildings and delivering economies of scale. The deployment commenced in 2020 with the overall deal to continue over the next ten years.

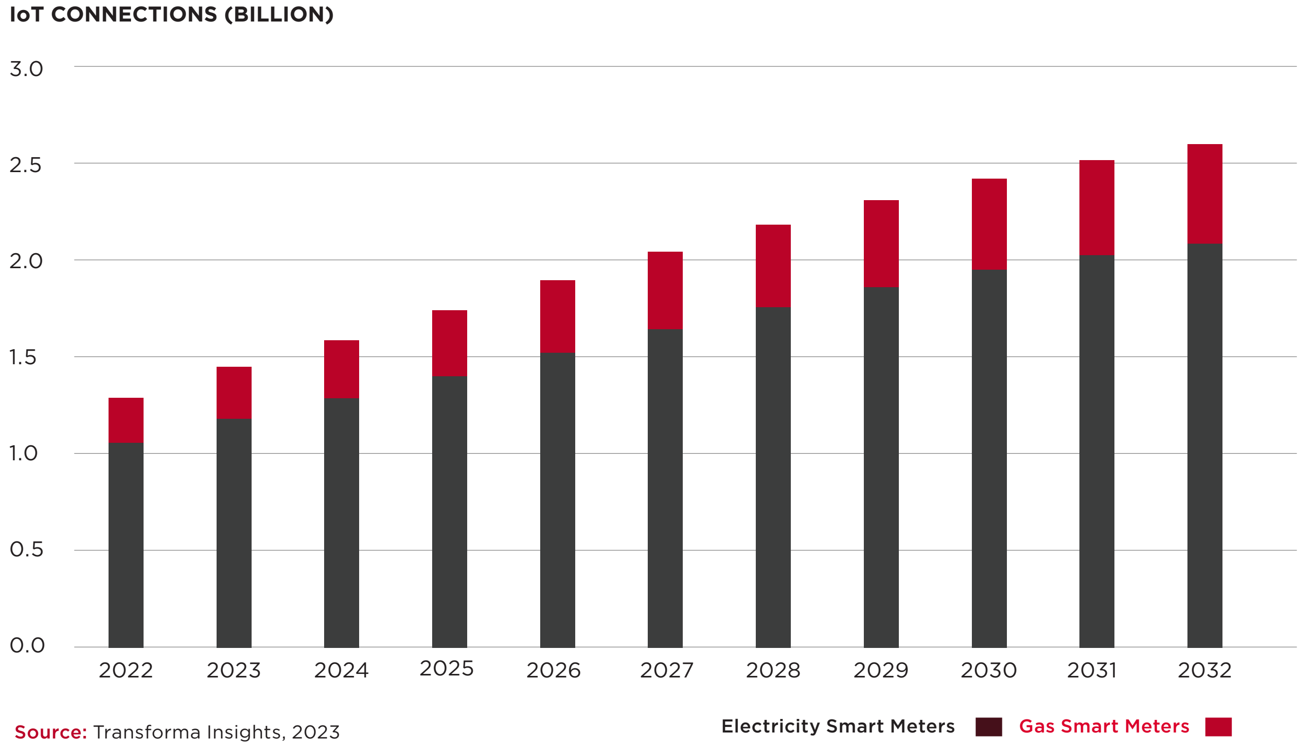
While Europe has seen a big drive to adopt smart metering, it is common around the world to see large scale smart metering projects. For instance, Vodafone in collaboration with Qatar General Electricity & Water (Kahramaa) will equip IoT SIM cards in 600,000 smart meters across homes and offices in Qatar. The Vodafone managed IoT connectivity platform will remotely transmit real-time metering data to KAHRAMAA's systems, and the data collected from the smart meters will drive operational efficiencies, enhance the customer experience, help in overall network planning and infrastructure, and help meet environmental and sustainability targets.

Smart metering is, without doubt, the number one IoT use case in the energy sector. According to Transforma Insights forecasts, at the end of 2022 there were 1.1 billion electricity smart meters, and 226 million smart gas meters deployed around the planet. Those figures will grow to 2.1 billion and 504 million over the next decade. Around 10% of electricity smart meters and 5% of gas smart meters are deployed in enterprises, the remainder being residential.

> The most significant benefit of smart meters is in the savings in electricity and gas bills driven by less consumption of resources and reduced number of errors in the meter readings.

Figure 1

Global electricity and gas smart meter deployments, 2022-32



Source: Transforma Insights, 2023

As well as customer education, smart meters are also a critical part of network load balancing, as discussed in the section below. In such a system, consumers can opt for the likes of electric vehicles, heating systems and smart appliances, such as washing machines and dishwashers, to be programmed to automatically take advantage of cheaper rates, reducing the need for energy companies to fall back on their least efficient generation capacity (often diesel generators) during times of peak demand. Smart meters provide the conduit over which this happens.

Transforma Insights' research indicates that residential smart meters decrease electricity consumption of consumers by 3-5%, enabled by changed consumer behaviour emerging from frequent energy monitoring and awareness. Businesses can reduce their electricity consumption by 10-12%.

The use of IoT in the energy sector, and the use of smart metering, is not limited to electricity. While the impact of gas smart metering consumption is not as pronounced as it is for electricity, the impact can be significant. Transforma Insights estimates that the use of gas smart meters typically results in a reduction of 2-2.5% in household gas consumption. And, as with electricity meters, we should not ignore the energy savings implicit in reducing or removing the need to manually activate, deactivate and read meters. For instance, Georgia Power, an electric utility company in the United States, took 300 vehicles off the road, and eliminated 14 million miles of travel by deploying smart meters for 2.4 million customers.

As an example, the city of Long Beach, USA faced a challenge in transitioning from a mesh network to a secure licensed network for gas meters along with enhanced customer data protection. California utility 'SoCalGas' in collaboration with Sensus deployed a smart gas meter AMI solution using the FlexNet communication network across eight neighbourhood districts with more than 156,000 meters using the publicly available spectrum. The benefits drawn after installation include increased read rate success, consistent data accuracy, data privacy and elimination of 80 truck rolls per day (local staff control meters remotely as residents transition between properties, saving two trips to manually shut down and re-start the meter) . The city has also planned to install the technology across 90,000 water meters endpoints similar to that of gas.

2.4

Batteries: grid-scale and distributed energy storage

The increasing use of renewable energy sources, both directly by power generating companies and by households and businesses, as well as advances in battery technology due to the growth of electric vehicles, has led to a significant growth in demand for energy storage in the form of batteries. This ranges from batteries contained in household devices to grid-scale energy storage. The use of IoT connectivity allows for the remote monitoring of remaining capacity, temperature, and performance. Furthermore, portable batteries may make use of location tracking. In some cases, the onboard connection can be used to communicate with smart meters and other grid infrastructure to enable features such as load balancing.

Grid Scale Batteries allow utilities and power system operators to store energy for later use. These high-capacity batteries are connected to power grids for energy storage and support, including grid stabilisation and outage prevention. Batteries are also a critical part of Microgrid implementations (as discussed in the following section). They integrate distributed generation and energy storage units to meet localised energy demand with uninterrupted continuity and flexibility in supply.

At a smaller scale, in-building connected batteries are connected to microgeneration equipment, such as solar panels, heat pumps, fuel cells, micro wind, and hydro schemes, and store the generated energy to reduce reliance on grid electricity. This includes batteries located inside or outside of a commercial or residential space. For instance, Walmart installed 40 MWh of energy storage in 27 stores across Southern California. The systems help Walmart in reducing peak electricity demand and provide dispatchable grid support to the utility company Southern California Edison. The solution was adopted as a part of its plan to increase reliance on renewable energy and reduce capacity required from the grid.

Homeowners that allow grid operators to access local batteries can receive a payment from the grid operator, administered via smart meters. For example, OhmConnect paid USD1 million to its customers in 2020 when it accessed home batteries for balancing energy supply.

Portable Batteries are small batteries which serve a variety of use cases. They can be used for charging or powering small electrical household equipment such as bulbs, TVs, radio and sound systems, fans, smoke alarms, and phones. Portable batteries have gained significant prominence in African and Asian countries that lack reliable electricity as a household electricity supply.

2.5

Microgrids: localised production, storage and distribution systems

A microgrid is a group of low-voltage distribution systems and distributed energy resources, that can operate either connected to or disconnected from the main grid. These grids can be used for energy generation and storage for a defined area such as a building, industrial site, campus, military base or community. Microgrids provide access to electricity in areas beyond national grids (such as rural areas and islands). Microgrids can also be more easily modified and deployed without re-designing the national distribution system. Altering microgrid components to add renewable energy sources is far easier than redesigning the national distribution system. These grids will also continue to work even during the failure of a national grid or natural disasters such as cyclones due to the use of localised assets. Growth in microgrid use is predominantly occurring in rapidly developing nations with an unreliable or underdeveloped national grid, areas that frequently suffer from extreme weather events, or particularly remote communities.

2.6

Load Balancing: integrating connected devices into the energy ecosystem

Using renewable energy sources for electricity has been a major factor influencing the need for load balancing as the supply is often highly variable. Electricity providers that are heavily reliant on renewable electricity generation may look to invest in projects that allow them to influence demand in response to changes in supply. Smart meters will be a potential solution, allowing electricity providers to either implement dynamic pricing or to use smart meters to communicate with devices to reduce their consumption and balance the load.

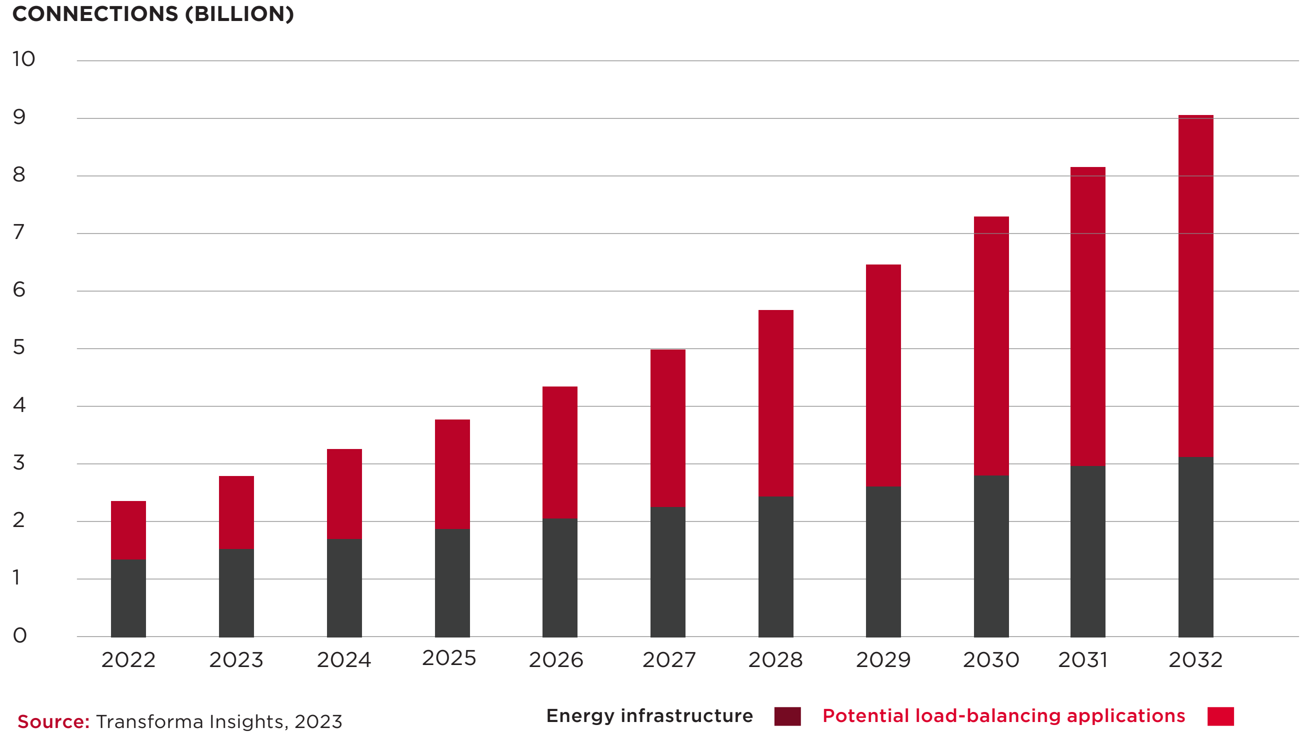
There is also, increasingly, a push to integrate devices that are consuming energy, such as white goods, HVAC, and lighting. By IoT-enabling these devices and connecting them with a centralised system for energy management, via the smart meter, the hope is to allow greater control over when certain devices are operating, in order to smooth out peaks and troughs in demand. For instance, freeze cycles of a home freezer could be undertaken at times of lower demand. The main focus of such load balancing would be on power consumption within buildings. Buildings account for nearly one-third of global energy consumption and 55% of global electricity demand.

For businesses that have high consumption of electricity, demand-response services give additional revenue opportunity by trading and by compensation they receive for use in non-peak hours. For example, Börje Ivars Greenhouses added revenue equivalent to EUR90,000 by grid balancing services, which resulted in 8% increase in its profit.

In Figure 2 we illustrate the scale of IoT connected devices that could be used for the purposes of load balancing, relative to those deployed to support the other use cases related to specifically energy infrastructure, i.e. smart meters, smart grid, batteries, EV charging, and power generation. By 2032, the IoT connections to these potential load balancing use cases outnumber those for energy infrastructure by two to one.

Figure 2

Combined energy infrastructure and potential load-balancing IoT applications growth, 2022-28



Source: Transforma Insights, 2023

2.7

Electric Vehicle Charging: hugely growing demand due to rocketing EV adoption

The transportation sector is expected to account for 10% of all electricity consumption by 2050 due to increasing adoption of electric vehicles. Governments around the globe are playing a key role in aiding this switch by providing incentives to drivers for switching to EVs. Additionally, many countries have announced plans to halt the sale of new fossil fuel powered vehicles in the near future. The growing demand for EVs has led to the need for sufficient charging infrastructure to be in place to charge these EVs. As a result there is huge demand for the installation of IoT-enabled charging points, both public and private.

Public EV charging comprises charging stations at workplaces, malls, hotels, retail outlets, and public stations that drivers can access at any time to charge their vehicles. These stations may be operated by governments, OEMs (e.g., Tata, Tesla, Mahindra, BMW), power companies (e.g. Tata Power, NDMC), and dedicated providers (e.g. ChargePoint, EVGo, G2 Mobility).

Private EV charging consists of charging stations at homes (including multi-family properties and multi-unit dwellings) and the stations operated by the government or private companies for their own fleets, such as bus stations of public transport operators or fleet depots of logistic companies. These include stations that are exclusively used for private purposes and cannot be accessed by the public, as well as domestic chargers that may be rented to other individuals through various schemes and Apps such as Co Charger or EVmatch.

Almost all of this additional charging infrastructure require IoT connectivity. Typically, this is to provide drivers with remote functionality to decide the time and charge amount of their vehicles in the case of private chargers and allowing for remote monitoring and maintenance or dynamic charging for public chargers. For instance, Siretta, a UK based designer, integrator, and manufacturer of IoT solutions provides its linkCONNECT modems with integrated software to UK charging station provider Elecktromotive. The modems offer a secure connection with 2G/3G connectivity. This reduces redundancy and maintains the required connections with remote equipment. The system is also capable of monitoring system performance, check charger usage patterns, check operating status, initiate maintenance, take payments securely, and update charging rates.

Over time, home charging stations have evolved from simple chargers to bidirectional charging that includes vehicle-to-grid (V2G) and vehicle-to-home (V2H) charging. These features allow charged vehicles to also be used to provide electricity for homes or to the grid depending upon the need and requirement. If charging of EVs isn't managed in a coordinated way, it could lead to an increase in peak loads and require major infrastructure investment to avoid supply failure. As a result, EV charging needs to be managed carefully to when demand is low or when production from renewable energy is high. As such, EV charging, and specifically the EVs themselves, are likely to become the number one candidate for the load balancing through management of end devices as outlined in the previous section. Similarly they represent a huge battery resource, to be used in much the same way as other forms of distributed storage.

> Integrated building systems with HVAC and Lighting control can save up to 10-15% of total building electricity consumption.

2.8

Wider energy saving

The final category of relevant IoT use cases involve the use of IoT to optimise processes and minimise the consumption of electricity or hydrocarbon fuels, independent of the electricity network and the load balancing examples stated above. Adopting the widest definition possible of 'energy' related applications, we could include a diverse set of applications aimed at efficient asset utilisation. For instance, there are applications in Precision Agriculture which focus on targeting resources only where they are needed, for instance in weeding, or managing livestock. Industrial applications will often focus on remote diagnostics or process streamlining, ensuring that equipment is working in the most effective way possible. Another prime example is supply chain efficiency using applications such as stock level monitoring. And by further extension, the increasingly electrification of fleets means that the 10-15% savings in fuel from fleet management use can also be extended to electricity consumption.

As noted in the section on load balancing, above, the most prominent energy-consuming use case, and therefore the prime candidate for making energy savings is buildings. For instance, heating, ventilation and air conditioning (HVAC) accounts for 30-40% of energy use, especially in a commercial building. Optimising the usage of these systems can help buildings save a significant amount of electricity. Smart HVAC systems interpret information from a variety of HVAC sensor points, which can be used to build algorithms that optimise the monitoring and control of HVAC systems such as minimising energy consumption in unoccupied building zones, reducing HVAC usage during peak times of energy demand, and optimising the flow of conditioned air. According to the International Energy Agency (IEA), digitalisation of buildings (including smart thermostats, controllers, smart lighting) could cut total energy use in residential and commercial buildings between 2017 and 2040 by as much as 10%. Integrated building systems with HVAC and Lighting control can save up to 10-15% of total building electricity consumption.

03

Connectivity requirements

Connectivity requirements

Decisions over which technology to use to connect IoT devices will be first and foremost dictated by the demands of the application. There are nine key sensitivities identified by Transforma Insights which will vary greatly, depending on the nature of the IoT deployment and will dictate connectivity/networking choices.

- **Cost -** This is always going to be consideration and a limitation. There are almost no applications that are completely price insensitive, meaning there is always an incentive to keep prices low. It's important to distinguish between the cost of the device and the cost of the connectivity.
- **Power** – Access – or lack of it – to mains power, is a key determinant of how an IoT application is architected. The use of battery power necessitates numerous compromises in terms of connectivity technology used, communications protocols, processing, and more. All those choices have implications for the power usage and require some sort of trade off. While many energy sector use cases have access to mains power, there are some that do not, e.g. smart gas meters, and others where minimising power consumption is itself a great asset.
- **Speed -** The requirement for high-speed connectivity will be largely determined by the type of use case. Smart meters might report only very small amounts of data, while smart grid infrastructure may be reporting large volumes. Performing some processing on the device can reduce the demand for high bandwidth connectivity.
- **Latency -** For some use cases, the key thing will not necessarily be the volume of data to be sent, but the round-trip time of the interaction between the IoT device and the server. Smart grid management, for instance, may require a very low latency, whereas basic meter reading is fine with long delays on delivery. Some communications protocols are better for reducing latency, for instance those that do not require complex handshakes between client and server.
- **Availability** – Many energy use cases will demand high availability, whereby access to the devices is provided with very reliable, robust connectivity technologies. Device location is a constraint when it limits access to specific networks (and power) and/or the ability of people to access the device. Geographically remote devices may have very limited options of how to be connected, often being limited to technologies that are low bandwidth or costly, or both. Also being located inside buildings, often in basements, will create challenges for some connectivity technologies. Many use cases demand high availability, necessitating the use of particular types of technology.
- **Mobility -** Some IoT use cases are mobile, whereas others are static. This has implications for the choice of technology. For instance, a connected vehicle requires a cellular technology capable of handing over between cells at high speed. Static devices, in contrast, may need a technology with superior propagation characteristics to ensure coverage within a building or in a remote location. In the energy sector almost all are static.
- **Durability -** Turning predominantly to the hardware aspect, some IoT deployments will require ruggedised devices, potentially able to withstand extremes of temperature and vibration. This will have some implications for other connectivity-related choices. For instance, more ruggedised devices will often favour MFF2 soldered SIMs, or iSIMs, rather than removable SIM cards, with potential implications for how connectivity is delivered.

- **Space -** This relates to the dimensions of the device and the inherent limitations that come from that. A monitoring device attached to a piece of smart grid infrastructure can probably be of any size, within reason (although will probably need some consideration of ruggedisation to cope with vibrations, dust, heat and cold). The energy sector applications are not particularly limited by such a requirement.
- **Security -** Some use cases have a greater inherent requirement for security than others, for instance those involving the taking of payments (e.g. payment terminals or ticket machines), those that handle potentially personal or household data (e.g. smart metering), those where there is a risk to life (e.g. connected heart rate monitors) or those relating to critical national infrastructure (e.g. smart grid). Energy applications, because of the criticality of energy provision, tend to have the greatest requirements for security.

In the chart below we map the requirements of each of the major energy use cases onto the characteristics listed above.

Figure 3

Energy IoT application sensitivities

The first and probably most critical consideration for most of these applications is security. Smart grid and metering deployments are all part of a country's critical national infrastructure and will be a target for hacking, either for ransom or as offensive campaigns by foreign powers. As such, guaranteeing the security of those use cases should be the first consideration for any deployment. But this is not just limited to the utility infrastructure. Even the likes of HVAC systems will have fairly significant requirements; being able to hack an HVAC system, or more relevantly large numbers of HVAC systems, can allow a bad actor to initiate grid surges through artificially creating energy demands by turning on heating or AC systems. Security across almost all these systems is very important.

In many ways the deployment characteristics of energy applications are quite similar. They are almost universally static (i.e. low 'Mobility') devices, being fixed infrastructure. Because of this, they will demand networks with good coverage, and particularly inside buildings, most obviously smart metering where devices are often located in basements and other less accessible locations. Similarly, they mostly have only moderate sensitivity to the size of the connectivity unit. Being fixed in place, usually in a space with plenty of room, means that size considerations are not too significant. However, they do mostly need to be durable. A large proportion are installed in harsh environments and sometimes very harsh, in the case of, for instance, wind turbines. And most will need to remain in place and working for decades, such as smart meters.

Almost all energy applications have limited requirements for connectivity technologies to rely on battery power. Most have direct access to mains power. The main exception is gas meters and infrastructure, where that is not the case. Some energy applications, such as connected batteries and microgeneration, will want to minimise power consumption so as not to reduce their own operational effectiveness.

The communications requirements are also quite similar. Few energy applications require very fast data speeds. There is no requirement for video streaming, for instance. Smart Grid applications are the most demanding because they may need to deliver quite large volumes of data, in near-real-time, but even there, the needs are comparatively moderate compared to many other IoT applications. Where most energy applications are more demanding is in availability, i.e. having access to a reliable connection. The requirement for low latency, i.e. the round-trip-time of sending and receiving data, however, is highly variable. Electricity Smart Grids will typically want response times measured in milliseconds in order to effectively manage load balancing and faults, while use cases handling payments, such as EV charging, will also want relatively low latency. In comparison, some applications in the sector will be almost ambivalent to latency. Automated meter reading, for instance, will often be perfectly happy with messages delivered with seconds (or perhaps even days) delay.

Price sensitivity is also a significant consideration for some energy applications. When deploying millions of smart meters, for instance, just a few dollars difference in hardware costs can make a significant impact. Similarly, small differences in the cost of connectivity over the decades-long lifespan of a device will also be meaningful. In comparison, the potential efficiency savings of Smart Grid use cases, or the relative cost of the connectivity element of a multi-million-dollar wind turbine, will make connectivity cost a modest consideration compared to other aspects of the deployment.

Decisions around how IoT is deployed will involve consideration of each of these constraints, and more importantly the inter-relationship and trade-offs between them. For instance, devices that need to rely on low bandwidth networks may need additional capabilities for pre-processing the data on-device. Similarly, with unlimited funds most of the other challenges can be resolved, for instance through very small components or the use of expensive network technologies. Some of these may need to be compromised when deciding on the best combination of technologies and device specifications to use.

When deploying millions of smart meters, for instance, just a few dollars difference in hardware costs can make a significant impact.

04

Key technologies

Key technologies

Having established the diversity of characteristics that any particular application might have, it's now worth considering the diverse set of connectivity technologies that might be considered for an IoT deployment, their strengths and their weaknesses. There is a dizzying array of potential technologies that might be appropriate for connecting different use case.

Figure 4
IoT connectivity technologies for Energy use cases

TECHNOLOGY	WHAT IS IT?	STRENGTHS	WEAKNESSES	OPTIMUM FOR
2G/3G	A public network cellular standard.	Cheap (2G) and mature network technology.	In many parts of the world these networks have been switched off or will be shortly. Low bandwidth.	Inadvisable to use for any energy use cases due to the shut-down or imminent shut down of networks around the world.
LTE Cat 1	A public network cellular standard. IoT-oriented LTE technology, available on all LTE networks.	Very widely deployed, giving the most universal coverage of LTE globally. Moderately high data rates and good latency.	Power consumption is comparatively high. Performance not as strong as 5G. Higher cost than LTE-M/ NB-IoT. Will only be supported for as long as there are LTE networks.	Smart Grid, Power Generation (particularly when deployed as private networks), Batteries and Microgrids where 5G is not available. Less appropriate for Smart Metering due to higher cost.
LTE Cat 1 bis	A public network cellular standard. Has capabilities very similar to LTE Cat 1, but using only a single antenna.	Mid-range data speeds and latency at low cost and decent power consumption. Supported everywhere with LTE networks.	Not good for in-building coverage, or areas of marginal cellular coverage. Will only be supported for as long as there are LTE networks.	All use cases where LTE Cat 1 is appropriate but not in hard-to-reach locations such as deep in-building or very remote.
LTE-M (LTE Cat M or Cat M1)	A public network cellular standard aimed at low power IoT applications.	Cheap devices, relatively good battery life. Will be supported for lifetime of 5G.	Only moderate data speeds and latency. LTE-M support is not universal by all operators globally.	All use cases except where low latency is required (i.e. Smart Grid).

TECHNOLOGY	WHAT IS IT?	STRENGTHS	WEAKNESSES	OPTIMUM FOR
NB-IoT (aka Narrowband IoT, Cat NB1/2)	A public network cellular standard aimed at low power IoT applications.	Very cheap devices, good in-building coverage, long battery life. Will be supported for lifetime of 5G.	Low data speeds and high latency. Network deployments are country specific.	Smart Metering and Load Balancing, where networks are available. Potentially viable for other use cases such as Batteries and elements of Microgrids where there is no requirement for low latency.
5G RedCap (Reduced Capability)	A public network cellular standard aimed at low power IoT applications. Variant of 5G offering a cheaper and more power efficient (but more limited) version of 5G.	Good data rates, decent battery life.	Limited deployments of 5G and support for RedCap. Power consumption significantly higher than NB-IoT. Still high costs.	None currently due to limited network a vailability and minimal benefit versus existing LTE technologies. Future iterations will make this a key technology for all use cases.
5G New Radio (NR)	A public network cellular standard. Full capability cellular 5G, providing very high bandwidth and low latency connectivity.	Very high data speeds and very low latency.	Not universal coverage of 5G (and/or upgrades to 5G Stand Alone), very high costs.	Smart Grid, EV charging. Power Generation where deployed as private networks. Not suited to Smart Metering.
NR+	Mesh network technology using licence-exempt spec-trum. Part of the 5G standard. Deployed as field area networks e.g. for smart meter-ing.	Decent battery life. Good (3Mbit/s) data speeds and low latency. Good in-building cover-age.	Requirement to build dedicated network.	Smart Metering
Wi-Fi HaLow	IEEE standard 802.11ah. Network technology closely related to Wi-Fi using licence-exempt spectrum. Can be deployed as mesh. typically deployed in campus environ-ments. Range of 1-3km.	Good battery life. Can provide high bandwidth (up to 15Mbit/s). Moderate latency. Good in-building coverage due to use of sub-GHz frequency bands.	Requirement to build dedicated network. No ecosystem of device makers today.	None, currently.
Wi-SUN	Mesh network technology with range of 700-800 metres. Uses license-exempt spectrum. Typically deployed as field area network.	Very long battery life. Good in-build-ing coverage.	Requirement to build dedicated network. Very high latency and low data rates. Unable to support mobile devices.	Campus Microgrids.

GSMA

TECHNOLOGY	WHAT IS IT?	STRENGTHS	WEAKNESSES	OPTIMUM FOR
Wireless M-Bus	A European standard for smart metering. Network technology using license-exempt spectrum, deployed as private network, typically for smart metering. Range of up to 5km.	Very long battery life. Good range (for a Good in-building coverage.	Requirement to build dedicated network. Very high latency.	Smart Metering (in Europe)
mioty	License-exempt network technology, supporting up to 15km range.	Very long battery life. Good in-building coverage. Good range.	Requirement to build dedicated network. High latency.	Smart Metering
Powerline Communica-tions (PLC)	Uses the power line between the electricity sub-station and the smart meter to communicate. Widely used in smart metering.	Uses existing electricity grid infrastructure.	Requirement to implement infra-structure to support. Requires backhaul from concentrator at the substation.	Smart Metering
LoRaWAN	Network technology using license exempt spectrum, typically deployed as a private network, but there are public networks available in some geographies.	Cheap devices. Useful for managing campus/ building deployments of multiple devices without need to manage via the owner's network.	Requirement to implement dedicat-ed network in most countries.	White Goods and other Load Balancing.
Wi-Fi 802.11	Short range technology typically using 2.4GHz and 5GHz bands for in-building private networks.	Widely deployed in homes and offices. High bandwidth.	Security is not as strong as most other technologies. Hard to rely on self-de-ployed (e.g. by the home-owner) infrastructure to manage IoT devices.	Domestic and commercial Microgeneration.

Note: the above is not an exhaustive list and particularly does not include consideration of the wide range of technologies that might be used to connect in-building applications aimed at energy saving, such as connected HVAC, lighting or other building automation. For these, technologies such as LonWorks, BACnet and Zigbee will likely be very appropriate.

4.1

Public vs private networks

The first thing to note is that there are two main categories of network technologies: public and private. Public networks, such as 2G, LTE, 5G and numerous variants of those technologies as outlined in table above, are deployed and operated by mobile network operators (MNOs). Private networks, such as Wi-Fi and various mesh networks used in smart metering, are rolled out by the user themselves, or by a third party on their behalf.

Public networks have the obvious advantage that they do not require the user, for instance an electricity utility, to be involved in the deployment, operation and management of the network. In the case of the cellular networks operated by MNOs there are typically multiple options within any give territory, with good availability, high performance, and high levels of security.

Private networks, in comparison, may benefit from similar performance and security (e.g. for private 4G/LTE and 5G networks) but in other cases will not. However, in most cases energy devices are either located in remote areas (e.g. smart grid monitoring or wind turbines) or are deployed in scenarios where it is inadvisable to make use of a private network such as Wi-Fi. For instance, smart metering deployments will need to work regardless of whether a Wi-Fi network is available.

4.2

Licensed vs unlicensed spectrum

One major challenge with many of the private network technologies is that they rely on license-exempt spectrum bands, i.e. spectrum that can be accessed by almost anyone (as long as deployments fulfil certain criteria related to transmit power and frequency of messages). As such it offers fewer guarantees over the availability of network resources, compared with those using licensed bands. For applications that require guarantees over network availability, technologies using licensed bands (e.g. 4G/LTE, LTE-M, NB-IoT, and 5G) will generally be more reliable options.

4.3

Range and in-building penetration

The most critical consideration for anyone considering choices of connectivity technology is whether they meet the performance characteristics required. To be viable, any selected technology choice has to be able to firstly provide coverage for the relevant device. In many cases, devices might be located in basements or remote locations.

Public cellular networks typically have the best country-wide coverage, albeit with some limitations. The first consideration is the availability of a network at all. While almost all countries have 4G networks deployed, the IoT variants available, e.g. LTE Cat 1, may not be the most appropriate for IoT applications, given their higher power consumption. LTE-M and NB-IoT Networks have been deployed in most mature IoT market countries with over 270 networks now available according to the GSMA IoT Community. There are numerous examples where operators have implemented those upgrades, particularly NB-IoT, in order to support smart meter deployments.

The second consideration for public networks is how well the technology provides coverage within the country in which it is deployed. NB-IoT in particular is optimised for superior range and in-building coverage, making it a technology that is particularly appropriate for smart meter deployments.

Turning to non-cellular technologies, range is usually very limited, to just a maximum of a few kilometres. In one or two cases, technologies such as LoRaWAN offer much wider coverage, and are sometimes deployed nationally by network operators, although with inferior in-building coverage and very limited data speeds. Some hybrid deployments involve deployment of a gateway that is cellular connected but which uses an alternative such as LoRaWAN for connected to the devices within a building.

In some cases, relevant technologies can be architected as mesh networks, i.e. connecting from one deployed device to another rather than each connecting to a network transmitter. These types of topologies can work well if there are large numbers of quite densely packed devices. They will be inappropriate for many of the more geographically remote devices such as for smart grid.

4.4 Uplink/downlink/latency

Assuming that it is possible to connect the device using the selected technology, considerations then turn to whether the capabilities match the requirements of the application in terms of uplink/downlink speeds and latency. Very few energy use cases require particularly high data speeds, meaning that almost any technology is appropriate from that standpoint. Smart metering, for instance, requires only very limited amounts of data to be sent and received, although requirements may increase as more load balancing requirements are added. Anyone making technology selections needs to have one eye on future requirements.

Requirements for latency vary tremendously. For smart grid implementations it may be very significant. Managing an electricity grid may require real-time interaction, which would necessitate the use of a technology with very low latency, such as 5G.

4.5 Power consumption

Minimising power consumption is one of the key requirements of many IoT applications, and one for which many new technologies have been optimised. However, in the case of the energy sector, most IoT applications have access to power, being themselves connected to mains electricity. The main exception is gas smart metering, where low power technologies that promise to operate for 5-10 years without replacing the battery are very valuable. In such deployment scenarios, the low power consumption of technologies such as LTE-M and particularly NB-IoT provide a significant benefit.

4.6 Lifespan and support

Most of the use cases considered in the energy sector will have deployment lifespans stretching into decades, such as for smart metering. Those organisations will need to give careful consideration to the likely long-term availability of the network technologies and ongoing support for them.

The most obvious manifestation of this lifespan issue is in the availability of public cellular networks. In many countries around the world 2G and 3G networks have already been switched off, with spectrum refarmed to use to support 4G and 5G. The result is that typically 2G and 3G networks are not appropriate for energy deployments. The most future-proof option, where available, is to opt for either 5G or one of the massive Machine Type Communications (mMTC) technologies that have been developed specifically to support IoT devices. While NB-IoT and LTE-M were initially developed as part of 4G, devices can be supported on 5G networks, giving them the optimum longevity compared to purely LTE technologies such as LTE Cat 1 or LTE Cat 1 bis. Recent developments in 5G have also provided a more IoT-oriented pure 5G technology in the form of 5G RedCap, but as discussed in the Transforma Insights report 'What is 5G RedCap and how does it fit into the portfolio of cellular IoT connectivity technologies?' it is still not yet optimised for requirements of low cost and long battery life relative to NB-IoT and LTE-M; but future iterations promise improvements.

For private networks, the questions are two-fold: firstly, will the technology continue to be widely used, supporting an ecosystem of device developers and service providers, and secondly, will the organisation deploying the technology want to continue to support it itself for the duration of operations. The IoT connectivity landscape is littered with technologies that were too limited in functionality or not sufficiently widely supported, for long-term success.

4.7 Cost

Decisions over each of the requirements listed above will inevitably require a trade-off with each of the other factors, e.g. good in-building coverage will often require sacrifices over latency or bandwidth. In all cases, there are also considerations of cost. Some technologies, such as 5G and to a lesser extent 4G LTE Cat 1, have expensive connectivity modules, ranging from USD20 up to north of USD100. In comparison, LTE Cat 1 bis, LTE-M are priced at around USD10 and NB-IoT closer to USD5 per unit. Unit costs for the unlicensed technologies are typically even cheaper, at USD1-2 per unit.

We should also consider connectivity costs too. The public cellular networks will involve a recurring cost for the connectivity, albeit one which not be explicitly stated and may be bundled into the full price of a solution. Prices here have been dropping substantially over the last decade. For low data IoT use cases such as smart metering, it is not unusual for prices to be below USD1 per annum, a trend highlighted by Transforma Insights as '$1 IoT'. Private network deployments do not have this specifically attributable connectivity cost.

The thing to consider with cost is not the unit cost of the individual items, but the total cost of ownership (TCO) for the whole project over the duration of the deployment, including potential unexpected costs. This includes the price of devices and connectivity, of course, but also includes the cost of rolling out a network (if relevant), the risk of having to rip-and-replace redundant technologies, the impact of any security breaches that might occur, and any future upgrades that need to be supported.

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