IRENA
International Renewable Energy Agency

INTERNET OF THINGS

INNOVATION LANDSCAPE BRIEF

International Renewable Energy Agency

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INTERNET OF THINGS

The Internet of Things (IoT) **enables smart grids.**
As power systems become increasingly complex and decentralised, IoT applications enhance the **visibility and responsiveness** of grid-connected devices.

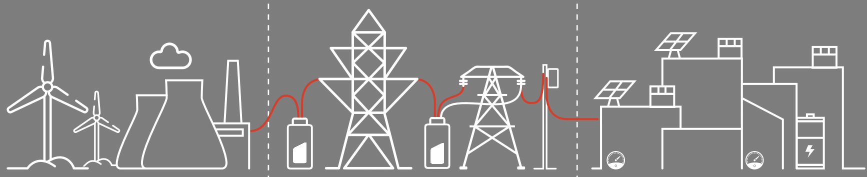
WHAT IS THE INTERNET OF THINGS?

Smart devices monitor, communicate and interpret information from their surroundings in real time. The resulting Internet of Things (IoT) enables meaningful data gathering and system optimisation.

1 BENEFITS

IoT devices enable "smart grids" through the collection, transmission and use of large amounts of data, intelligently integrating grid-connected users, optimising grid operation and increasing system flexibility

IoT benefits for solar and wind integration



Wind and solar generation forecast	Grid stability and reliability	Aggregation and control of DER
Automated control		Automated demand-side management
		Interconnected mini-grid operation
Optimised market operation		

DER = distributed energy resources

2 KEY ENABLING FACTORS

- Reaching technology maturity and reliability
- Ensuring data privacy
- Addressing cybersecurity challenges
- Developing communication procedures and protocols

3 SNAPSHOT

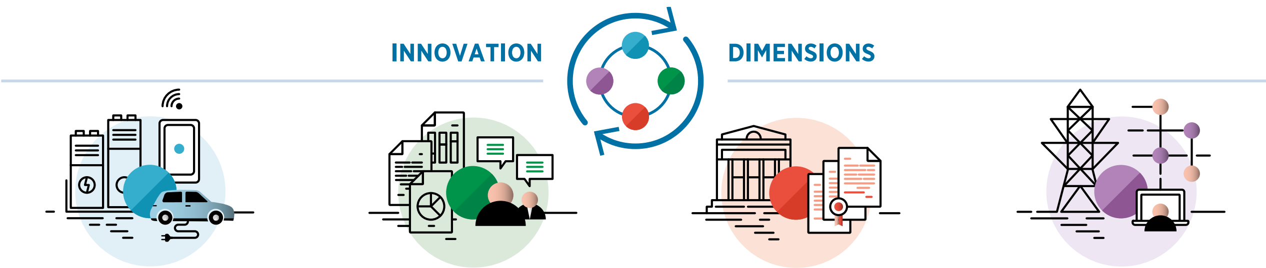
- ➜ 75 billion devices could be connected worldwide by 2025
- ➜ Most IoT projects in the power sector focus on demand-side applications (*e.g.*, smart homes)
- ➜ Digital systems and data analytics can:
  - Reduce O&M costs
  - Boost renewable power generation
  - Reduce renewable power curtailment

ABOUT THIS BRIEF

This brief is part of the IRENA project "Innovation landscape for a renewable-powered future", which maps the relevant innovations, identifies the synergies and formulates solutions for integrating high shares of variable renewable energy (VRE) into power systems.

The synthesis report, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (IRENA, 2019), illustrates the need for synergies among different innovations to create actual solutions. Solutions to drive the uptake of solar and wind power span four broad dimensions of innovation: enabling technologies, business models, market design and system operation.

Along with the synthesis report, the project includes a series of briefs, each covering one of 30 key innovations identified across those four dimensions. The 30 innovations are listed in the figure below.



ENABLING TECHNOLOGIES

1 Utility scale batteries
2 Behind-the-meter batteries

3 Electric-vehicle smart charging
4 Renewable power-to-heat
5 Renewable power-to-hydrogen

6 Internet of Things
7 Artificial intelligence and big data
8 Blockchain

9 Renewable mini-grids
10 Supergrids

11 Flexibility in conventional power plants

BUSINESS MODELS

12 Aggregators
13 Peer-to-peer electricity trading
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MARKET DESIGN

17 Increasing time granularity in electricity markets
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SYSTEM OPERATION

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27 Advanced forecasting of variable renewable power generation
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29 Virtual power lines
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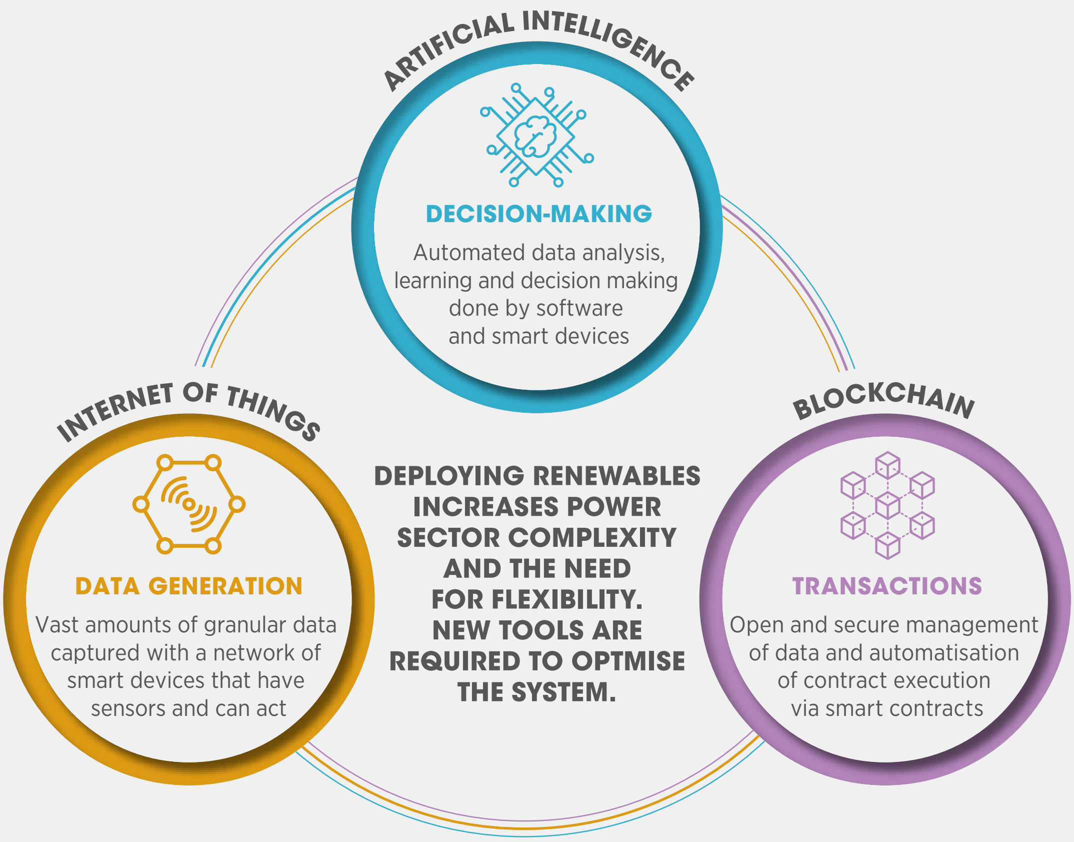
Digitalisation to support VRE integration

Digitalisation is a key amplifier of the power sector transformation, enabling the management of large amounts of data and optimising increasingly complex systems. For the power sector, digitalisation is essentially converting data into value (IRENA, 2019a). The growing importance of digitalisation in the power sector is also a consequence of advances in two other innovation trends: decentralisation and electrification. Decentralisation is led by the increased deployment of small power generators, mainly rooftop solar photovoltaic (PV), connected to the distribution grid. Electrification of transport and buildings (heating and cooling) involves large quantities of new loads, such as electric vehicles, heat pumps and electric boilers. All these new assets on the supply and demand sides are adding complexity to the power sector, making monitoring, management and control crucial for the success of the energy transformation.

Digital technologies[1] can support the renewable energy sector in several ways, including better monitoring, operation and maintenance of renewable energy assets; more refined system operations and control closer to real time; implementation of new market designs; and the emergence of new business models. Within the context of the *Innovation landscape for a renewable-powered future* report, IRENA's analysis focuses on one concrete application for digital technologies: the integration of VRE technologies into power systems. Accordingly, three specific digital technology groups are studied further: 1) the internet of things (IoT); 2) artificial intelligence (AI) and big data; and 3) blockchain. The analysis indicates that none of these are silver bullets, but rather reinforce each other as part of a toolbox of digital solutions needed to optimise the operations of an increasingly complex power system based on renewable energy.

Figure 1: Increased power sector complexity requires a combination of digital innovations



1 These commonly include: digital twins; chatbots; the IoT; artificial intelligence and big data; distributed ledger technologies (DLT) such as blockchain; and augmented and virtual reality, among others.

This brief provides an overview of the Internet of Things and its applicability in the energy sector, with a focus on how this technology can contribute to increasing shares of VRE in the power system.

The brief is structured as follows:

I. DESCRIPTION

Our increasingly digitalised world is becoming ever more interconnected. The Internet of Things (IoT) will impact nearly every industry, as machines begin to communicate and make decisions autonomously, without human intervention. Innovations range from smart thermostats maximising energy efficiency by adjusting the temperature of consumers' homes depending on whether they are at home; to refrigerators automatically ordering groceries when food is running low; to sensors on machinery parts that enable data gathering, helping to avoid costly failures by pre-emptively notifying that maintenance will soon be needed.

But what is the IoT? The IoT is the inter-networking[1] of physical devices embedded with electronics, software, sensors and exchange data (also referred to as "connected devices" and "smart devices"). Simply put, the IoT transforms physical objects into smart devices to collect communicate, monitor and interpret information from their surroundings in real time (WCO, 2019). The IoT connects devices through the Internet, where each device has a unique IP address, enabling remote monitoring and control through cloud-based control systems. The goal of the IoT is to increasingly automate aspects of our lives while increasing the efficiency of processes.

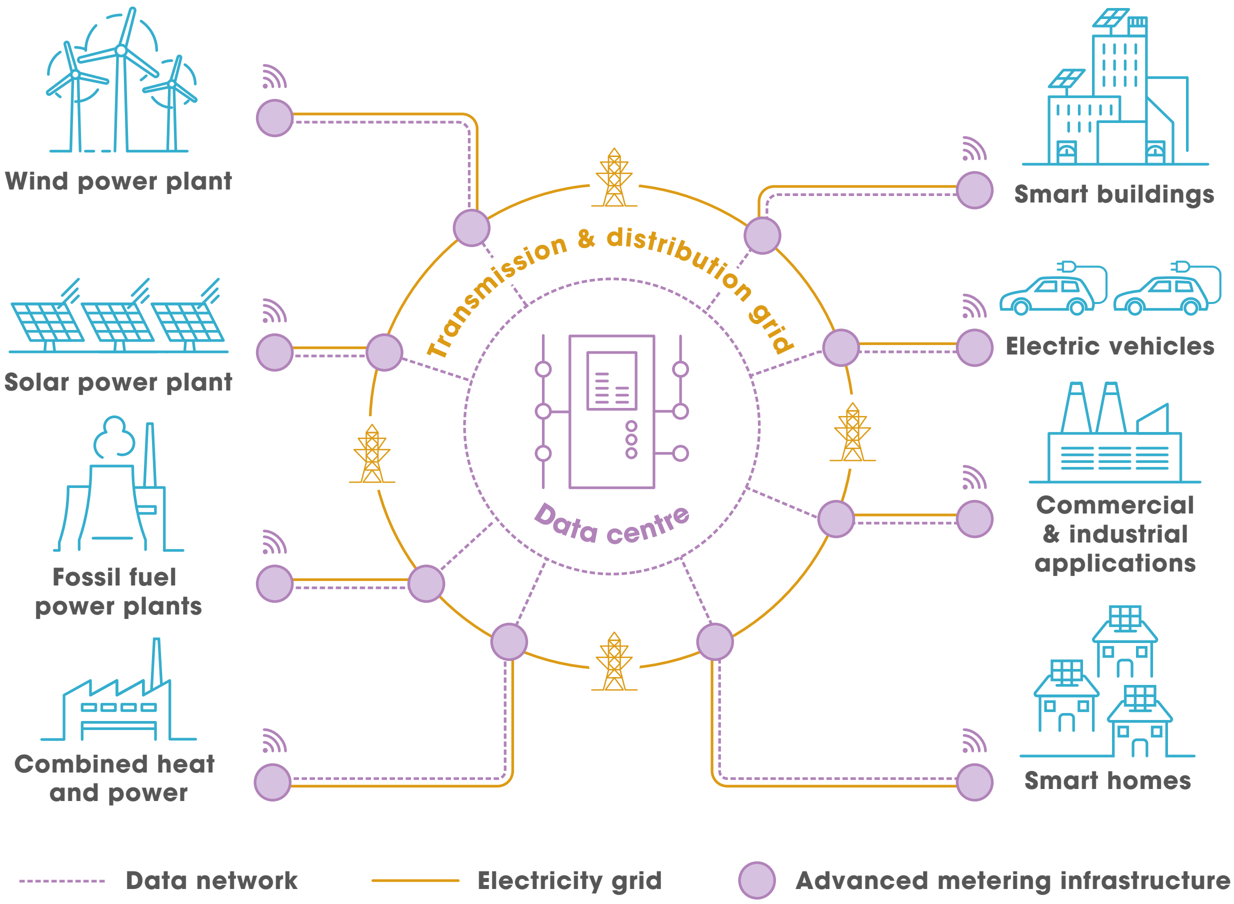
In the power sector, the IoT could play a valuable role in making electricity systems more efficient, or "smart". The IoT is a pillar of "smart grids", which are fundamentally an "electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies" (IEC, 2019). Features of smart grids include the rapidly controllable two-way flow of electrical power, the automated, bidirectional flow of information and even automatic system dispatch on an economic basis.

When the decentralisation of the system is considered, through the deployment of distributed energy generation and battery storage, the IoT holds significant potential for new management and business model options due to its capacity to aggregate data. The deployment of distributed energy resources changes a typical power system from having hundreds of control points to potentially millions. Future decentralised systems require micro-level monitoring and control to reach their potential as providers of services to enhance electricity systems operation.

1 Internetworking is the process or technique of connecting different networks by using intermediary devices such as routers or gateway devices. Internetworking ensures data communication among networks owned and operated by different entities using a common data communication and the Internet Routing Protocol.

IoT technology has the potential to increase the flexibility and responsiveness of the smart assets connected to the grid, as well as the visibility of these assets for the system operator. By connecting energy suppliers, consumers and grid infrastructure, IoT technology aims to facilitate the operation of complex systems and to open new commercial possibilities by enabling clients to further monetise the value created by their assets by providing different services through demand-side management.

Figure 2: IoT in context – Smart grids connecting smart devices, from both the demand and supply sides



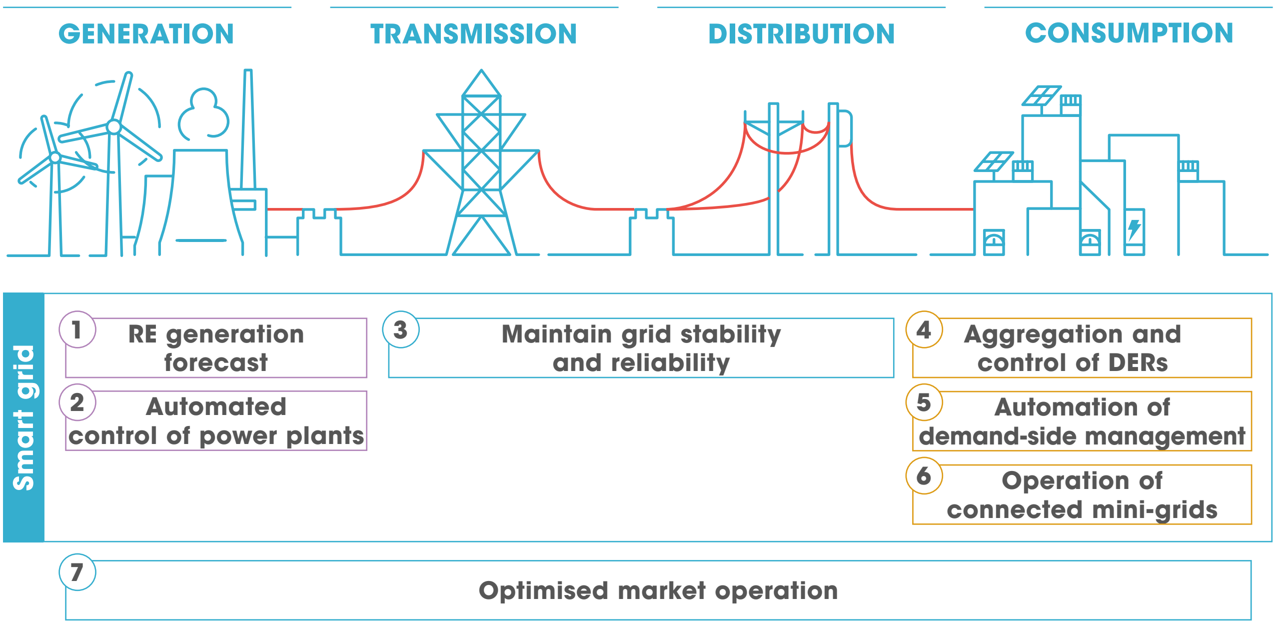
Source: IRENA, adapted from Höfling and Koschel (2019)

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

IoT technologies, namely the data that the devices generate and the automated control they provide, are underpinning a historic transformation that will lead to cleaner, more distributed and increasingly intelligent grids. Improved availability of information across the whole value chain enables better decision-support tools (such as artificial intelligence) and enables remote control and automated execution of decisions (*e.g.*, control of millions of devices with immediate actions, such as algorithm trading or self-driving cars). The application of digital monitoring and control technologies in the power generation and transmission domains has been an important trend for several decades, and has recently started penetrating deeper into power systems. The IoT can lead to better management of assets and operations, resulting in greater reliability and enhanced security as well as new services and business models.

This brief focuses on IoT applications that support the integration of high shares of VRE. The disruptive implications of tens of billions of connected sensors and devices sending and receiving vast quantities of granular data across networks are still being studied. Great potential exists, particularly for unlocking greater flexibility in power systems through demand-side management. The IoT also brings solutions to optimise systems on both the supply and demand sides, leading to enormous opportunities for the integration of larger shares of variable renewable generation into the system (see Figure 3).

Figure 3: Current state of digitalisation of the energy value chain



DER = distributed energy resources

Source: IRENA, IRENA, adapted from BNEF, 2017

1. Renewable energy generation forecast

The IoT enables the distribution of computing intelligence throughout the entire power system infrastructure and enables accessing data from remote wind farms, solar farms or hydro stations in real time. Past generation and weather patterns, together with real-time data collected and communicated through digital systems, can help improve the accuracy of renewable generation forecasts. This would enable renewables participation in electricity markets and help operate the system.

Forecast errors in wind generation increase as wind output levels rise, making it more difficult to manage transmission networks. General Electric estimates that by implementing digital systems and data analytics, forecast accuracy can increase up to 94% from around 88% today (for more details see IRENA's brief, *Advanced forecasting of variable renewable power generation* [IRENA, forthcoming]) (GE, 2016). Furthermore, IBM announced at the CES 2019 conference that it aims to use crowdsourced sensor data to improve local weather forecasting globally. By using a Global High-Resolution Atmospheric Forecasting System (GRAF), IBM said it could offer day-ahead forecasts updated hourly on average, with a 3-kilometre resolution. GRAF incorporates IoT data into its weather models via crowdsourcing (Dignan, 2019).

2. Automated control of power plants

The availability of data surrounding all aspects of the electricity supply chain enables system operators to create more precise predictions about a wide variety of factors. Real-time data could complement the current practice of managing energy supply based on historical data. This transition from reactive to proactive operations is one of the defining and most important features of a smart grid and IoT technology, offering better control over operations.

Applications range from embedded sensors in wind turbine vanes that sense changing wind conditions and prompt real-time adjustments of pitch and rotation to maximise efficiency, to substation control systems that can respond rapidly to network disruptions, thus minimising downtime without human intervention. Similarly, light sensors installed in solar panels can indicate the points where the sunlight energy is the highest, while microcontrollers can activate one motor that tilts the panel through an angle of 45° on the vertical axis and a second motor that can rotate the panel through a 360° angle at a point on the horizontal axis.

3. Maintain grid stability and reliability

Digital technologies can assist in maintaining grid stability and reliability, improving system operation. Using the IoT to connect, aggregate and control industrial and residential loads can allow them to participate in frequency regulation markets and provide balancing services to the grid. An intelligent communications network is the foundation of building a smart grid. Also, substation automation can further improve operations, leading the way to entirely autonomous energy grids. This way, the system can respond more effectively to intermittency from industrial-scale renewable plants as well as smaller distributed generation, by using existing resources.

However, the grid must be observable and measurable before it can be controlled and automated. Substation automation helps utilities add protection and control functions while also providing greater visibility into the performance and health of grid infrastructure. System operators are investing in communications networks to improve their situational awareness of grid assets in order to control, automate and integrate systems. Value is created when the peak load demand is "smoothened out", decreasing the use of costly spinning reserves and alleviating the need for long-term investments in new generation plants and other capital investments. Cisco is working on substation automation (Cisco, 2018).

Also, Cisco is working to modernise the power grid with Field Area Network (FAN). FAN aims to help enable pervasive monitoring and control of energy distribution networks to enhance energy delivery. The Cisco multi-service FAN solution is based on a flexible two-tier architecture that generates IP network services such as security, quality of service, resilience and management, supporting use cases such as Advanced Meter Infrastructure (AMI), distribution automation and work force automation (Cisco, *n.d.*).

4. Aggregation and control of distributed energy resources*

Decentralisation of energy systems must be done in co-ordination with their digitalisation. The grid is becoming more complex due to increasing deployment of distributed energy resources, with system operators requiring greater visibility of changing conditions of electricity networks. The transition from one-way power flows to two-way power flows – with intermittent distributed resources such as wind or solar, and behind-the-meter processes such as on-site energy storage or electric vehicle charging to the main grid – requires digital technologies to adapt. Additionally, the electrification of end-use sectors will mean an expected growth in demand arising from the electrification of heat and transport which, without digital demand management technologies, would require large increases in grid capacity.

Automated control over distributed energy sources and their aggregation into virtual power plants will support grid operation, by balancing intermittency in the grid and regulating power flows. Digitalisation would enable system operators to alert distributed energy resources to the current needs of the grid, so that consumers, retailers or other service providers could react and benefit accordingly. The IoT can support this process by improving the monitoring of end-devices and data integration into the system. Distribution automation and the IoT are already being introduced into the grid, with aggregators as key emerging players that facilitate distributed energy sources to participate in electricity and ancillary service markets (for more details see the Innovation Landscape brief *Aggregators* [IRENA, 2019c]).

In Belgium, the electricity transmission system operator Elia accepts distributed energy resource capacity to compensate for the mismatches between production and peak power demand. Aggregators, such as REstore and Next Pool, provide the required capacities to Elia from distributed energy resources. With IoT technology, REstore aggregates flexible industrial capacities – 1.7 gigawatts in total – and constantly monitors the grid load. At peak demand moments, companies in REstore's portfolio help to maintain grid balance by load shifting, enabled by automated control. Through digitalisation, Next Kraftwerke is aggregating 5 000 energy-producing and energy-consuming units in the virtual power plant (VPP) Next Pool. With a total capacity of over 4 100 megawatts (not only in Belgium) the VPP trades the aggregated power on different energy spot markets. The VPP contributes substantially to stabilising the grid by smartly distributing the power generated and consumed by the individual units during times of peak load.

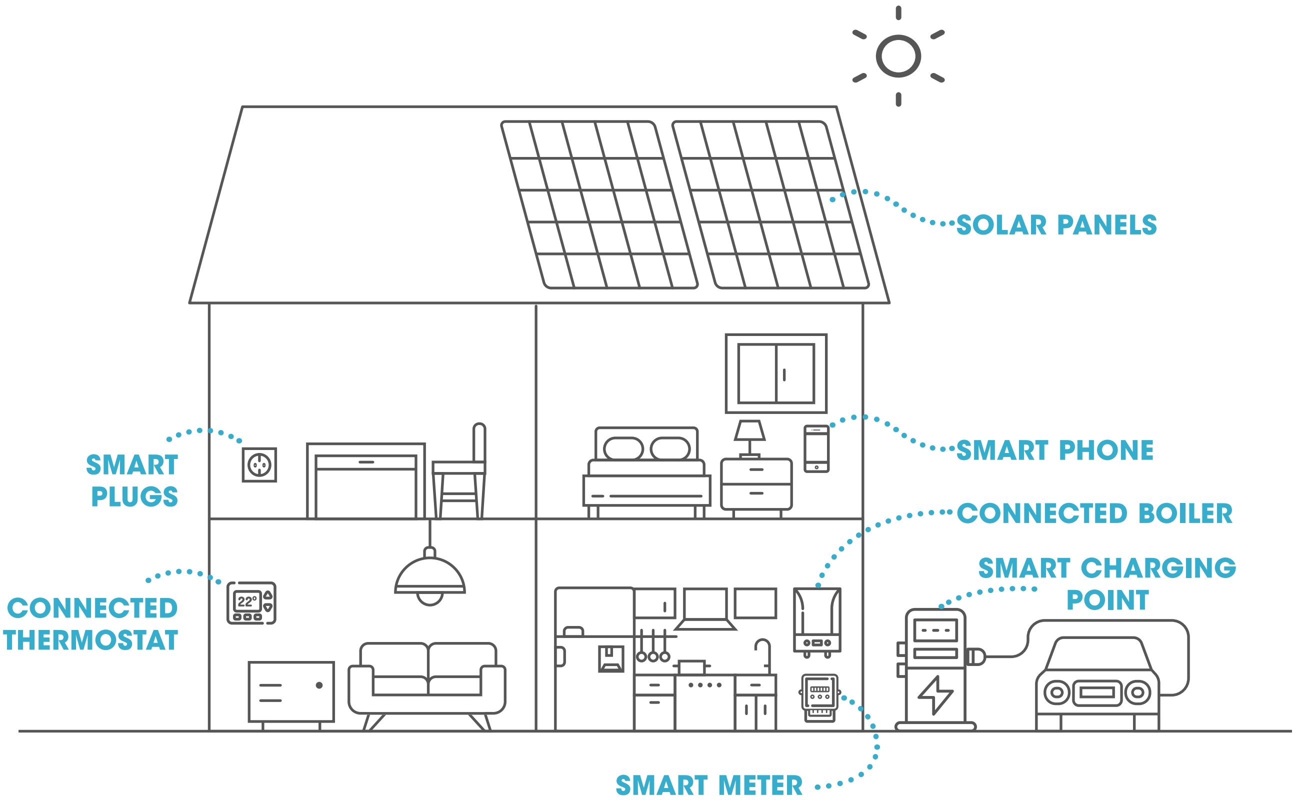
* Distributed energy resources are small or medium-sized resources that are directly connected to the distribution network. They include distributed generation, energy storage (small-scale batteries) and controllable loads, such as electric vehicles, heat pumps and demand response (see the Innovation Landscape brief *Market integration of distributed energy resources* [IRENA, 2019b]).

5. Automation of demand-side management

The IoT enables demand-side management at a micro scale and offers flexibility to the system, provided that time-of-use electricity tariffs are in place to incentivise the consumption of electricity at times when VRE is available. Automation and digitalisation of home appliances, as well as ready-made services for consumers, are key for demand management and demand response.

Thermostats, lighting, and energy monitoring and controls are increasingly embedded with Internet-connected smart devices that can be controlled remotely by smart phones. "Smart appliances" have been available since the 1980s but were "smart" only in the sense that they had computer chips to monitor operations and inform users about issues. Adding communication capabilities and remote controls to existing sensors and diagnostics creates a functioning energy management system. The IoT can turn houses into smart homes and is expected to drive innovation and create new business models for the consumer, such as new forms of demand management and creative alternatives to traditional energy consumption patterns.

Figure 4: IoT and smart homes

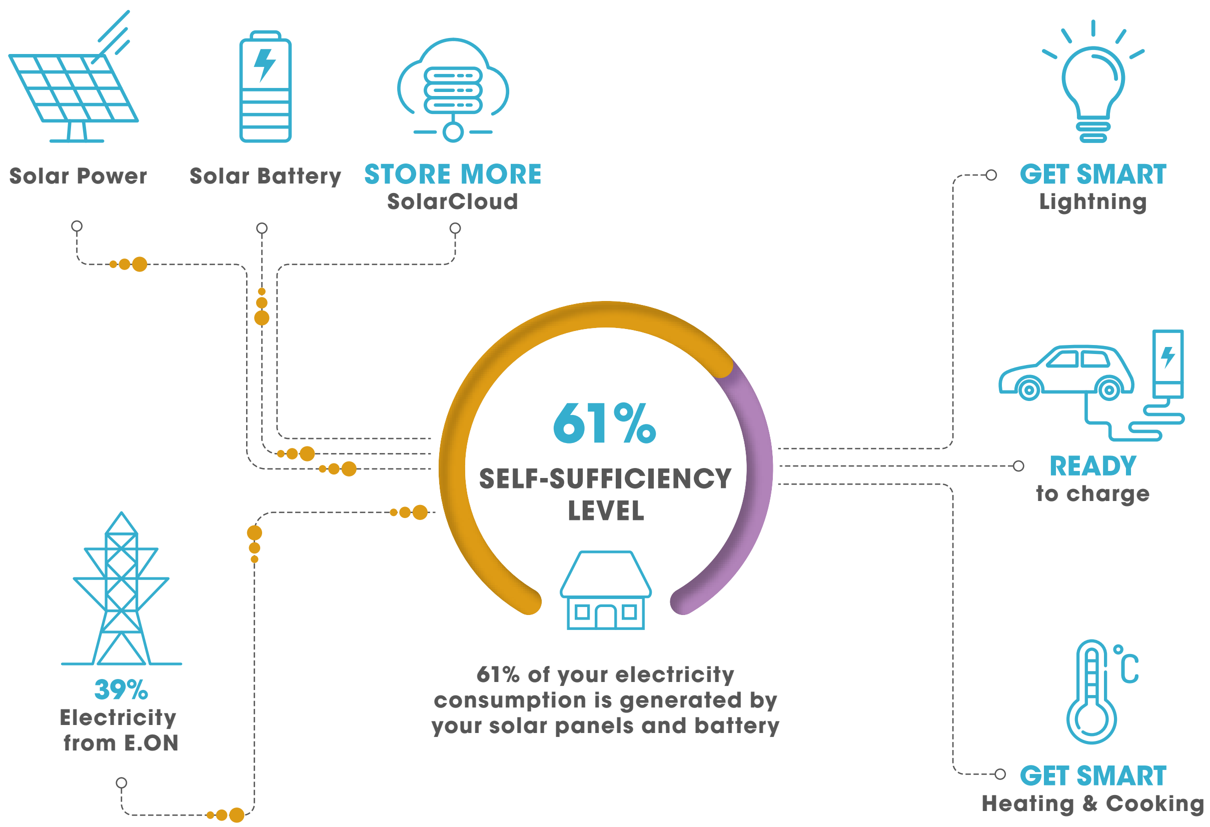


The impacts of digitalised systems in the energy efficiency of buildings are clear. From sensors designed to monitor room temperature to complex applications controlling the energy use of entire buildings, IoT technology is cutting costs and creating more productive, connected buildings. In commercial buildings, connected devices and integrated energy management systems generate data that can be used to reduce heating or cooling in underutilised zones and to adjust lighting when offices or spaces are empty.

Adding artificial intelligence algorithms can increase the energy efficiency even further (see the Innovation Landscape brief *Artificial intelligence and big data* [IRENA, 2019d]). In the United States alone, 30% of the energy used in an average commercial building is wasted, according to the Department of Energy (US DOE, 2019). In Europe, the Stockholm-based telecom company Telia has signed a deal with ONE Nordic AB to connect nearly 1 million electricity meters for Swedish electricity distributor Ellevio. The partnership will rely on Telia's recently launched Narrowband Internet of Things (NB-IoT) network, a low-power, wide-area technology designed to deliver small amounts of IoT data on a massive scale (Telia, 2019).

E.ON, one of Europe's largest energy companies, has partnered with Microsoft to integrate Azure Sphere (an IoT solution that combines secured chips, a unique operating system and cloud services to ensure software updates) into the company's "E.ON Home" solution, to secure the management of demand-side resources (Microsoft, 2018). These devices aim to provide consumers with increased security, visibility and control over their assets, as illustrated in Figure 5.

Figure 5: E.ON Home, secured by Microsoft Azure Sphere technology



Source: Microsoft, 2018

Another example is the Flex PowerPlay, a smart home energy platform launched in 2017 in Australia that consists of three elements: solar panels, a home battery and an IoT monitoring system. The Energy App allows users to simply switch between appliances and automatically control power loads, helping to control energy consumption and related costs. Similar optimisation solutions will be essential for users to reap the benefits of their solar systems and reduce electricity bills. Users can monitor their power generation and manage it in real time via an application on a smart phone. PowerPlay, working with smart technology appliances, can be programmed to turn the lights on in the night and off again during daytime. Users can also remotely control their air conditioners, televisions and sound systems. The platform not only shows the exact amount of real-time energy generation, but also allows consumers to automatically optimise their consumption.

In 2017, SP Group launched the "SP Utilities App", which aims to empower consumers with knowledge and tools so that they can optimise their electricity consumption and decrease costs. Around 25% of households in Singapore have used the app, which allows consumers to monitor their electricity consumption data on a 30-minute interval for those with Advanced Metering Infrastructure (AMI) or smart meters. SP Group also introduced a new feature to help simplify the decision-making processes for consumers faced with myriad choices of retailers and retail plans. The engine matches the consumer's current utility consumption with the retail plans available and recommends plans that result in the best savings for the consumer (Singapore Power, *n.d.*).

6. Operation of connected mini-grids

Micrograds combine power demand with distributed energy resources into a single controllable entity that can be operated separately from the grid. Mini-grids enable renewable energy deployment in grid-connected areas, allowing local generation to provide independence from the main grid at times, and in areas that are not connected to the grid, powering remote communities with distributed generation.

Digital tools allow a mini-grid to automatically deal with the multitude of individual devices, forecast demand and generation, operate the system, optimise reserves, control voltage and frequency, and connect or disconnect from the main grid, when possible. The more effectively these sources are balanced, the lower the generation costs for the mini-grid and the higher the revenue from additional services provided to the main grid. For example, the research institutes CSIRO and the National Renewable Energy Laboratory, from Australia and the US respectively, are working together to simplify the integration of renewable energy mini-grid systems by creating a plug-and-play controller that can maximise the use of solar energy (NREL, 2016; Ritchie, 2013).

New tools, including blockchain paired with smart devices, can facilitate decentralised, peer-to-peer trading in mini-grid systems. These tools can consequently increase transparency, and have the potential to minimise operation costs while offering new revenue streams for prosumers (see the Innovation Landscape brief *Renewable mini-grids* [IRENA, 2019e] and the Innovation Landscape brief *Blockchain* [IRENA, 2019f]).

7. Optimised market operation

A system where energy is traded in shorter increments is more difficult to manage and requires a greater degree of automation. Digital systems can monitor remote generators and automatically send simple instructions, operational data and corrections to operators.

Algorithmic trading, or algo-trading, is an emerging method of electricity trading. Algo-trading is a method of executing a large order (too large to fill all at once) using automated pre-programmed trading instructions, accounting for variables such as time, price and volume to send small slices of the order out to the market over time. These methods have been developed in the financial sector so that traders would not need to constantly watch a stock and execute trades by hand. Currently, more than 50% of the trades conducted on the German intraday market are algo-trades (EPEX Spot, 2018). Enabled by data collection and a communication system with IoT, algorithms are able to fine-tune positions in response to movements in market prices and changing forecasts, at lower cost than employing teams of human traders to operate 24/7.

Other IoT applications in the power sector

Another key benefit of IoT data is in preventive maintenance. Proactive tests and repairs can reduce machine downtime and maintenance costs. This can be applied to generation, transmission and distribution systems, all of which are asset intensive. Smart devices and sensors, for example, can send information from remote equipment indicating an imminent failure, thus avoiding costly downtime or damage. GE's Predix Platform was designed to simplify data collection and forwarding for industrial applications, in order to enable companies to engage in smart predictive maintenance (GE, 2019).

Digital systems are expected to deliver significant operations and maintenance (O&M) savings through practices and systems such as: condition-based maintenance from data and trends gathered; reduction in manpower; minimisation of impact of human errors; improved asset-life management; and optimisation in utilisation of assets. Globally, the International Energy Agency estimates that O&M costs in power generation and electricity networks were just over USD 300 billion in 2016. Through 2040, a 5% reduction in O&M costs achieved through digitalisation could save companies, and ultimately consumers, close to USD 20 billion per year on average (IEA, 2017).

Furthermore, power production can be increased by identifying and addressing causes of inefficiencies, as well as better capturing renewable energy resources, and through significant improvements in long-, mid- and short-term weather prediction (thus minimising the need for operational reserves).

III. KEY FACTORS TO ENABLE DEPLOYMENT

IoT technology still faces several serious challenges that need to be overcome before widespread implementation is possible. The biggest factors include reliability, security and communication.

Technology maturity and reliability

The IoT essentially means letting machines communicate. The fundamentals should be solid and proven before removing human interference, hence high-quality standards for each single implementation are required. This implies a multi-stage approach for implementation: from setting up sensors, data collection, data pre-processing, processing, testing and cyber security risk management, to coping with (new) regulatory policies.

While some consumers already use smart devices such as activity trackers, smart thermostats and drones, industrial IoT requires additional conditions to be met before it becomes widely used. Reliability is one of them. A connectivity failure between a smart thermostat and a boiler at home or between process control sensors in the steel industry have vastly different consequences.

Industrial adoption of IoT technology, including industrial machines, factories and buildings, offers vast opportunities. To increase the use of IoT technology while ensuring reliability, highly qualified software engineers and extensive testing of IoT devices are needed before deployment. Also, a local interface should be available to allow consumers to override systems in case of failure.

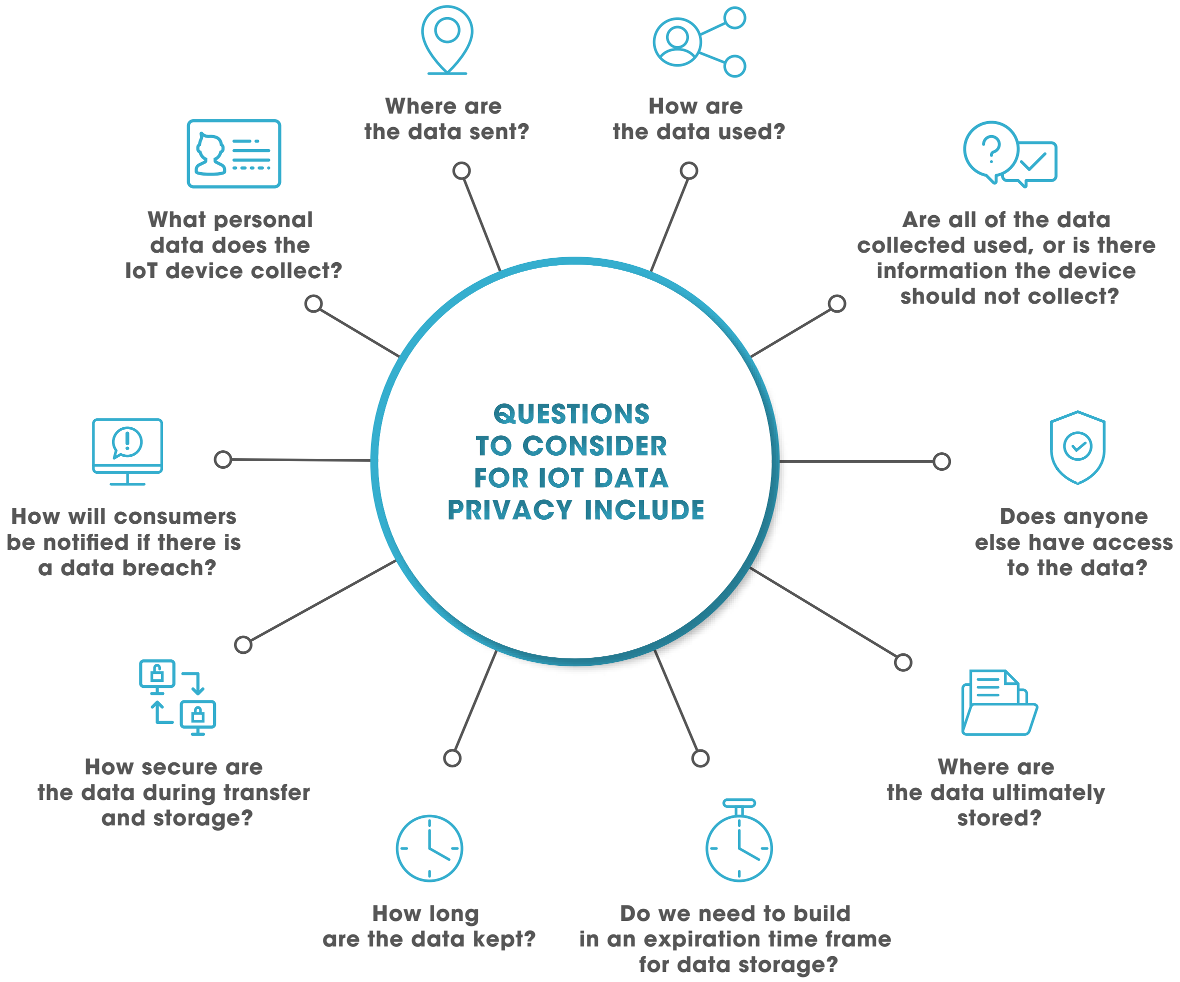
A study from IDC projects that "smart manufacturing" will be the largest potential application for the IoT in the energy sector moving forward (IDC, 2017).

Data privacy

As we progress into an ever more connected, digitalised world, data rights and privacy become increasingly important. Electric vehicles, for instance, could exchange information that might be considered personal, such as detailed information about their location or times of day when they are using energy or being charged. Smart home appliances could collect data on personal habits such as when you are home and when you go to sleep. Privacy has two issues: on the one hand, data might be exploited commercially (legally), and on the other, data might be stolen and exploited illegally. Issues such as secure authentication, standardisation, interoperability and liability need to be properly addressed.

Data ownership, data location and data protection will also require action at the national and international levels. For example, in the European Union (EU), Regulation 2016/679 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data sets strict rules (EC, 2016). When considering data privacy regulations around the world, particularly those required by the EU's General Data Protection Regulations (GDPR), in effect since May 2018, the amount of data generated by the growing IoT is a pressing concern. Both developers and consumers of IoT devices should be aware of the data privacy and security implications (IEEE, 2019).

Figure 6: Questions to consider for IoT data privacy



Adapted from (IEEE, 2019)

Cybersecurity

Security is an important issue that needs to be solved for IoT technologies to be widely deployed. The digitalisation of energy raises several risks and challenges, not the least of which are guaranteeing network neutrality[2], ensuring fair competition, protecting personal privacy, ensuring data security, and thwarting cyber-crime and cyber-terrorism.

As we automate controls and remove humans from the decision-making process, we may introduce the possibility of systemic failure or systemic cybersabotage. The challenge is not only to make systems more secure to prevent unwanted intrusion, but also to make systems more resilient against the inevitable attempts at intrusion that are difficult to prevent. Super systems will be required to monitor and contain the effect of attacks, as well as systems that can be isolated and where no single point of failure (error or sabotage) can bring down the entire energy system.

The increasing number of connected devices (Figure 6) has provided a vast surface area for attacks, as shown recently with the Mirai IoT botnet[3], and others, which exploit IoT devices with weak security. The Mirai botnet, for instance, scanned the Internet for IoT devices with a certain type of processor running a stripped-down version of the Linux operating system. Many of these devices were using their default username-and-password combination, which enabled Mirai to log in and infect it (Cloudflare, 2019). In an effort to combat these types of attacks and ensure the validity of information recorded and transmitted by IoT devices (by making the devices much more

2 Network neutrality is the principle that Internet service providers treat all data on the Internet equally, and not discriminate or charge differently by user, content, website, platform, application, type of attached equipment or method of communication.

3 A botnet is a number of Internet-connected devices, each of which is running one or more bots.

tamper-resistant), Microsoft has introduced the Azure Sphere, a secured microcontroller unit running its own operating system and supported by Microsoft cloud services for periodic updates. The aim is to deliver end-to-end IoT security that responds to emerging threats (Microsoft, 2019).

Communications procedures, standards and protocols

Benefiting from this increase in decentralisation requires the ability of all parties to share data about their consumption/production state and to respond (automatically or not) to price signals. Because these benefits are spread across so many actors, the viability of such a system depends on participants keeping to agreements with each other and being appropriately compensated.

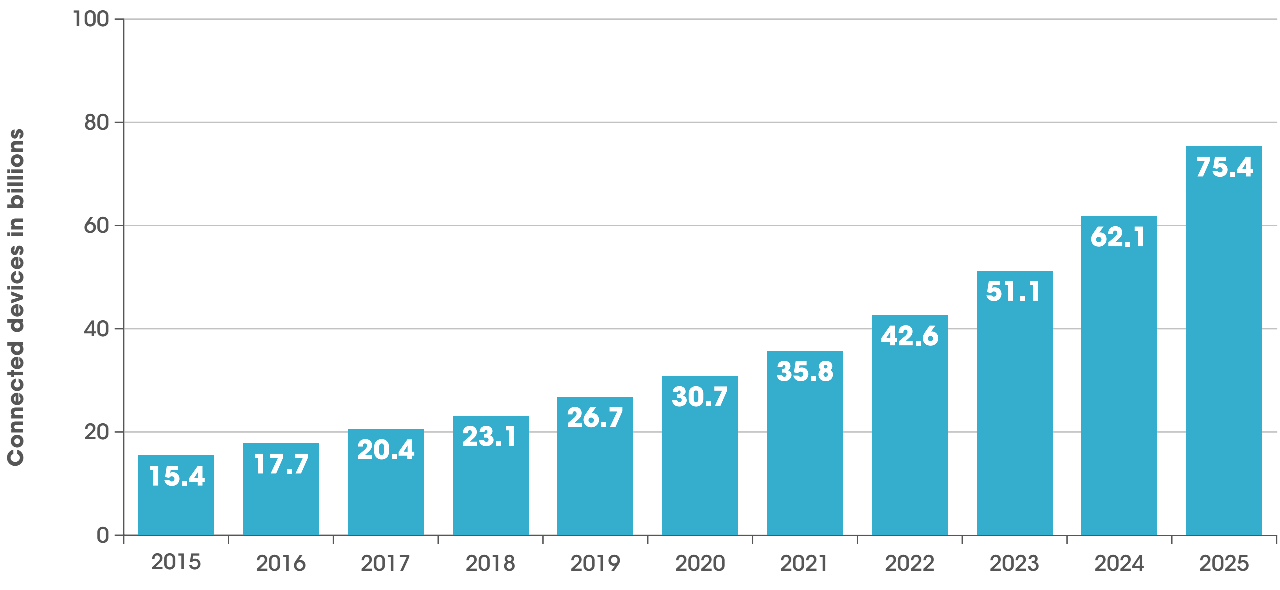
Various means of enabling improved communication between numerous devices and establishing transparent, enforceable contracts exist. Solutions based on blockchain are one example. With their ability to support payments and smart contracts, blockchain applications can accelerate the development of IoT use cases in the energy sector (see the Innovation Landscape brief *Blockchain* [IRENA, 2019f]).

Communications protocols and standards need to be developed to ensure smooth communication between disparate devices. As an example, devices today rely on NFC, Wi-Fi, Zigbee, Bluetooth, DigiMesh and Thread, among many others, but clear means of continuously linking data from various devices are lacking (Postscapes, 2019). Alliances and organisations are working to address the issue of communication through the establishment of IoT protocols.

IV. CURRENT STATUS AND EXAMPLES OF ONGOING INITIATIVES

By 2025, 75 billion devices worldwide are expected to be Internet connected, providing a wealth of information to consumers, manufacturers and utility providers (Statista, 2018). The rise of the IoT goes hand in hand with the rise of artificial intelligence, powered by big data, as it provides the granular information needed to feed machine learning algorithms (see the Innovation Landscape brief *Artificial intelligence and big data* [IRENA, 2019d]). The explosion of data generated, due in part to the proliferation of IoT devices, will power new technologies and unlock new industries in the coming years and decades.

Figure 7: IoT installed base of connected devices worldwide from 2015 to 2025 (in billions)



Source: Statista, 2018

General Electric estimates that by implementing digital systems and data analytics, renewable energy O&M costs can be reduced by 10%, generation increased by 8% and curtailment cut by 25%. Machine learning algorithms applied to weather and power plant output data can increase the accuracy of forecasts to up to 94%, from around 88% across the industry (GE, 2016; GE, 2017).

Most importantly, complex systems have the most to gain from IoT integration, where many actors and devices are participating in the power system by injecting or withdrawing power from the grid. To address the full potential of the IoT for smart energy, the ultimate goal is to transform the system into a customer-centric system that can offer more value-added services to the end-consumers. A large number of companies, consortiums, foundations and groups are working on IoT technologies at different levels: the app layer, data layer, connectivity layer and device layer. Table 1 presents a non-exhaustive sampling of major players in the IoT value chain.

Table 1 Major players in the IoT value chain

App layer	**Technology leaders:** Amazon, Apple, Cisco, GE, Google, IBM, Microsoft
	New entrants: Alibaba, Huawei, Samsung, Schneider, Siemens, Tencent
Data layer	**Technology leaders:** AWS, Google Cloud Services, Infosys, Fortinet, IBM, Microsoft, Oracle, SAS, Tableau
	New entrants: Alteryx, Cloudera, Hortonworks, Dataiku, RapidMiner
Connectivity layer	**Technology leaders:** Nokia, Arista Networks, AT&T, Cisco, Dell, NTT, Ericsson, Orange
	New entrants: Citrix, Coriant, Equinix, Bharti Airtel, China Telecom, Tata Comms
Device layer	**Technology leaders:** AMD, Intel, Nvidia, Apple, Fitbit, Honeywell, Sony
	New entrants: AAC Tech, Garmin, GoPro, LinkLabs, Ambarella, Goertek, HTC

Table 2 provides a non-exhaustive sampling of companies, consortiums and foundations working at the intersection of IoT and the power sector, particularly related to VRE integration. A large share of the use cases noted in the table fall within *automation of demand-side management* due to the increasing decentralisation, leading to self-consumption and opportunities for increased energy efficiency on the consumer side.

Table 2 Companies, consortiums and foundations working on IoT in the power sector

Project (company)	Service provided	Description
AMD IoT Gateway (AMD)	• Automation of demand-side management	Provides processors for various applications such as industrial automation.
AMMP	• Operation of connected mini-grids	Enables the monitoring of data of mini-grids on the production side, as well as on the battery and PV inverters using local communication gateways to operate off-grid networks in remote areas.
Analytics for IoT (SAS)	• Maintain grid stability and reliability • Aggregation and control of distributed energy resource assets	Data analytics solution that provides artificial intelligence, machine learning and streaming capabilities to organise and analyse large amounts of data for grid operation and energy systems.

Project (company)	Service provided	Description
AT&T IoT Platform (AT&T)	• Automation of demand-side management	Customisable platform with extensive solution templates that allows the user to integrate data services, devices and automation along with SIM-card connectivity. It can increase energy efficiency and improve energy management in buildings.
Autonomous Energy Grids (NREL)	• Aggregation and control of distributed energy resource assets • Maintain grid stability and reliability • Automated demand-side management	NREL is working on an autonomous energy grid that can automate most operations of a smart grid, including transmission and distribution control, energy consumption management and aggregation of distributed energy resource assets such as rooftop PV.
AWS (Amazon)	• Renewable energy generation forecast • Maintain grid stability and reliability • Automation of demand-side management • Automated control of power plants	Provides computation and storage cloud-based capacity for intensive workloads such as weather forecasting and demand response, as well as energy consumption analytics in industrial and residential buildings to improve energy efficiency.
Azure (Microsoft)	• Renewable power generation forecast • Aggregation and control of distributed energy resource assets	Cloud computing service that allows connection, monitoring and management of IoT devices. Combined with ADAMA, it can help to predict solar power production and manage distributed energy resource assets.
Cloud IoT (Google)	• Optimised market operation	Software and cloud platform that connects, processes, stores and analyses data with machine learning capabilities. Can be used for smart billing for smart grid operators and end-users for flexible pricing schemes.
Cloud IoT Hub (Tencent)	• Automated control of power plants • Automation of demand-side management	Platform access service for energy equipment monitoring, energy scheduling and big data processing. Can also be used for smart home management to improve domestic energy efficiency.
EcoStruxure Power (Schneider)	• Automation of demand-side management	Provides actionable data to aid decisions regarding low and medium power distribution systems in buildings.
Enerlytics (Uniper)	• Automated control of power plants	Power plant monitoring platform that enables the optimisation of plant assets, maintenance scheduling and increased efficiency through real-time data streaming and analytics.
FAN (Cisco)	• Maintain grid stability and reliability	Automates distribution services for the enabling of monitoring and control of energy networks.
GRAF (IBM)	• Renewable energy generation forecast	Crowd-sources weather forecasting data from millions of sources to create accurate forecasts for weather conditions and renewable energy generation.
HomeKit (Apple)	• Automation of demand-side management	App provides a simple way for users to connect various home accessories, control them and communicate with them. Can be used with energy management devices to improve energy efficiency in homes.
Hortonworks Dataflow (Hortonworks)	• Maintain grid stability and reliability	Manages streaming data from enterprise operations and assets for predictive analytics and data flow streamlining. Can be used in conjunction with other technologies to monitor transmission lines and smart meters to predict and prevent failures.

Project (company)	Service provided	Description
IMPACT (Nokia)	• Automation of demand-side management	Platform to manage data and devices across endpoints and gain insights using data analytics. Can be used with the Smart Building Energy Management application to improve energy efficiency by offering more data insights and control.
IMRS (Intel)	• Automation of demand-side management • Maintain grid stability and reliability	Uses data to deliver insights on various applications. In the case of smart cities, it can facilitate energy efficiency measures and energy data communication with operators.
IoT Smart Lighting (Tata Communications)	• Automation of demand-side management	Utilises LPWA communications to connect sensors to automate lighting in buildings and public areas for improved energy efficiency and to identify electricity theft locations.
NarrowBand-IoT (Telia)	• Automation of demand-side management • Maintain grid stability and reliability	Provides connectivity between LPWA devices to improve energy efficiency and power consumption, as well as share and visualise data.
Nest Learning Thermostat (Google)	• Automation of demand-side management	Uses machine learning and artificial intelligence to optimise cooling and heating of homes and businesses, which can improve energy efficiency.
PLC-IoT AMI Meter Reading (Huawei)	• Automation of demand-side management • Maintain grid stability and reliability	Provides communication channels for smart meters and displays consumption data for household users and operators.
Predix (GE)	• Automation of demand-side management • Automated control of power plants	Platform for industrial applications that can provide asset connectivity, analytics, machine learning and big data processing, for example for wind farm monitoring.
SolarEdge	• Automated demand-side management • Aggregation and control of distributed energy resource assets	Bundled device solution that provides greater control for residential rooftop PV systems by using smart inverters, storage power optimisers, and monitoring platforms to maximise energy self-consumption, production and safety. It can also be connected to home appliances to increase energy efficiency and reduce electricity bills.
Substation Automation (Cisco)	• Maintain grid stability and reliability	Provides a solution for the automation of substations in areas of predictive maintenance, protection and remote diagnostics.
Tableau	• Automation of demand-side management	Uses data analytics and visualisation for energy consumption and weather forecasts to regulate and manage energy use.

Table data sourced from individual websites.

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS

Hardware:

- Smart meters with high-resolution metering data and sensors.
- Sensors installed in different devices.
- Supercomputers or "cloud technology".
- Other digital technologies add automated control to the electricity system to increase flexibility and manage multiple sources of energy flowing to the grid from local energy resources.

Software:

- Data collection, data pre-processing, processing, testing.
- Optimisation tools.
- Software for version control, data storage and data quality assessment.

Communication protocol:

- Common interoperable standards (at both the physical and the information and communication technology (ICT) layers).
- Define cybersecurity protocols

POLICIES NEEDED

- Inform and empower consumers, including prosumers, to participate in demand-side management programmes.
- Encourage data exchange and improved communications on a transparent basis.
- Establishment of regulatory sandboxes to try out new business models.
- Develop data privacy policy and regulation for consumers and define cybersecurity protocols.

REGULATORY REQUIREMENTS

Retail market:

- Customer support and empowerment, through efficient price signals, such as time-of-use tariffs, or other load management schemes.
- A free retail market that enables innovative business models for consumers, such as energy-as-a-service models.

Distribution:

- Incentivise distribution system operators to invest in smart grids.

Wholesale market:

- Appropriate markets and product-service definitions to value flexibility in operation of generation fleet (and demand response, batteries, etc.).

STAKEHOLDER ROLES AND RESPONSIBILITIES

- **System operators:** Adopt an innovative approach to system operation by enhancing co-operation among distribution and transmission system operators, accounting for the evolving role of distribution system operators.
- **Distributed energy resource owners/operators** (*e.g.*, aggregators)**:** Participate in pilot projects as data providers.
- **ICT companies:** Work closely with power sector actors (*e.g.*, system operators) to develop tailored digital solutions for smart homes and the integration of VRE into the power system.

ANNEX

Table A1 Organisations working on IoT standards and protocols

ETSI (European Telecommunications Standards Institute) • Connecting Things Cluster
IETF (Internet Engineering Task Force) • CoRE working group (Constrained RESTful Environments) • 6lowpan working group (Ipv6 over Low power WPAN) • ROLL working group (Routing Over Low power and Lossy networks)
IEEE (Institute of Electrical and Electronics Engineers) • IoT "Innovation Space"
OMG (Object Management Group) • Data Distribution Service Portal
OASIS (Organization for the Advancement of Structured Information Standards) • MQTT Technical Committee
OGC (Open Geospatial Consortium) • Sensor Web for IoT Standards Working Group
IoT-A (Internet of Things Architecture) • European Lighthouse Integrated Project addressing IoT architecture, proposing the creation of an architectural reference model and defining an initial set of key building blocks
oneM2M • Aims to develop technical specifications for a common M2M Service Layer that can be readily embedded within hardware and software, and relied upon to connect devices in the field with M2M application servers worldwide.
OSIoT (Open Source Internet of Things) • Developing and promoting royalty-free, open-source standards for the emerging IoT
IoT-GSI (Global Standards Initiative on Internet of Things) • Aimed to promote a unified approach for development of technical standards
ISA (International Society of Automation) • Develops standards, certifies industry professionals, provides education and training, publishes books and technical articles, and hosts conferences and exhibitions for automation professionals
W3C (World Wide Web Consortium) • Semantic Sensor Net Ontology • Web of Things Community Group
EPC Global • Set up to achieve worldwide adoption and standardisation of Electronic Product Code technology.
JTC (Joint Technical Committee) webpage for the **IEC** (International Electrotechnical Commission) and **ISO** (International Organization for Standardization)

Source: Postscapes, 2019

ACRONYMS AND ABBREVIATIONS

AMI	Advanced metering infrastructure
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed energy resources
DLT	Distributed ledger technologies
EU	European Union
FAN	Field Area Network
GDPR	General Data Protection Regulations
GRAF	Global High-Resolution Atmospheric Forecasting System
ICT	Information and communications technology
IoT	Internet of Things
LPWA	Low-power wide-area
LPWAN	Low-power wide-area network
M2M	Machine to machine
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
PV	Photovoltaic
US	United States
VPP	Virtual power plant
VRE	Variable renewable energy
WPAN	Wireless personal area network

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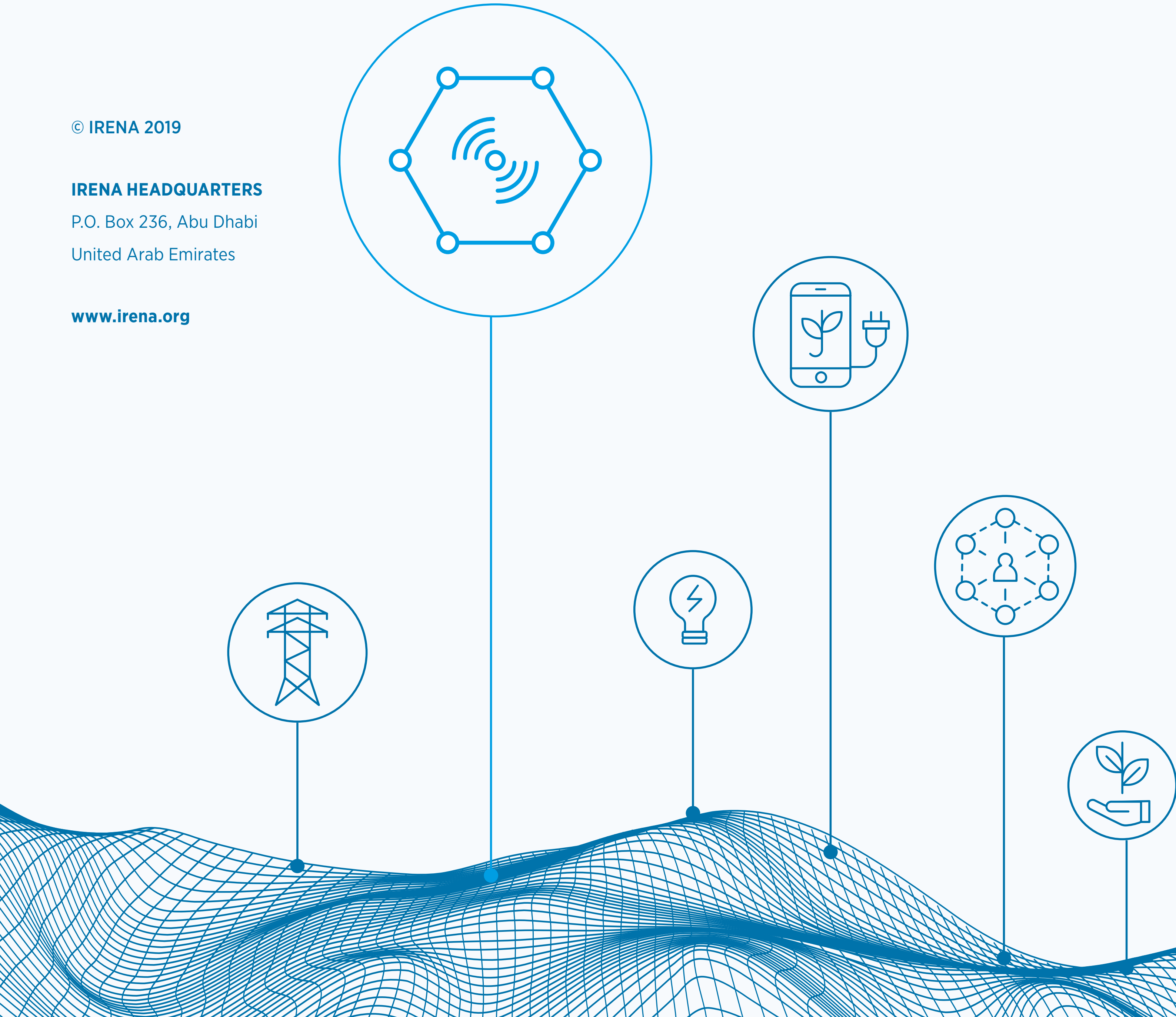

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