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POLICY NOTE

Towards net-zero: Interoperability of technologies to transform the energy system

OECD BETTER POLICIES FOR BETTER LIVES

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Towards net-zero: Improving the interoperability of technologies to transform the energy system

To put the global economy on a pathway towards net-zero emissions by the middle of the century, fossil fuels must be replaced as the main source of energy with more sustainable alternatives such as wind or solar power. To do so, high levels of interoperability – that is, the ability for technologies to seamlessly integrate, effectively communicate, and undertake tasks to achieve desired outcomes – are required across the energy system. However, there is no universal approach to interoperability in the energy system, and as such interoperability must be determined in specific use cases. This Toolkit note discusses why interoperability is necessary in the energy system, the benefits and challenges to achieving interoperability in the energy sector, and the role of policy in fostering interoperability to achieve net-zero emissions in the medium-term. The note argues for greater use of open data to maximise electricity system efficiency, an increase in the use of low-carbon energy, and the minimisation of the long-term costs of increased electricity demand.

Why is interoperability necessary in energy systems?

Digital technologies and data are transforming economies globally, and incrementally changing almost every element of our lives, from how we communicate with one another, obtain healthcare, organise transport, or shop online. The energy sector is no different, and while there are important opportunities for digital technologies and data to transform energy markets, there are also challenges that need to be managed. To put the global economy on a pathway towards net-zero emissions by the middle of the century (the "energy transition"), it is necessary to replace fossil fuels as the main source of energy with more sustainable alternatives such as wind or solar power. Electric vehicles (EVs) are selling in increasing numbers, and households are also beginning to install heat pumps for space and water heating. However, while each element in isolation could potentially reduce greenhouse gas (GHG) emissions, there are hurdles to fully benefiting from these changes.

There is an increasing number of smart devices and sensors in our homes and businesses, such as digital thermostats operating heating and air conditioning, and chargers for electric vehicles among others. There is also a growing number of these devices that have the potential to connect to the Internet and possibly offer additional functionalities. This diverse constellation of connected devices is commonly referred to as the Internet of Things (IoT). Individually, each device could increase our relative comfort or perhaps offer improved energy efficiency. However, while not a given, there is a possibility that when integrated into a larger "systems of systems" approach, there is the potential for all these connected devices to offer unique capabilities that could not be achieved individually. Change is beginning to take place across both the consumer demand side, as well as the energy supply.

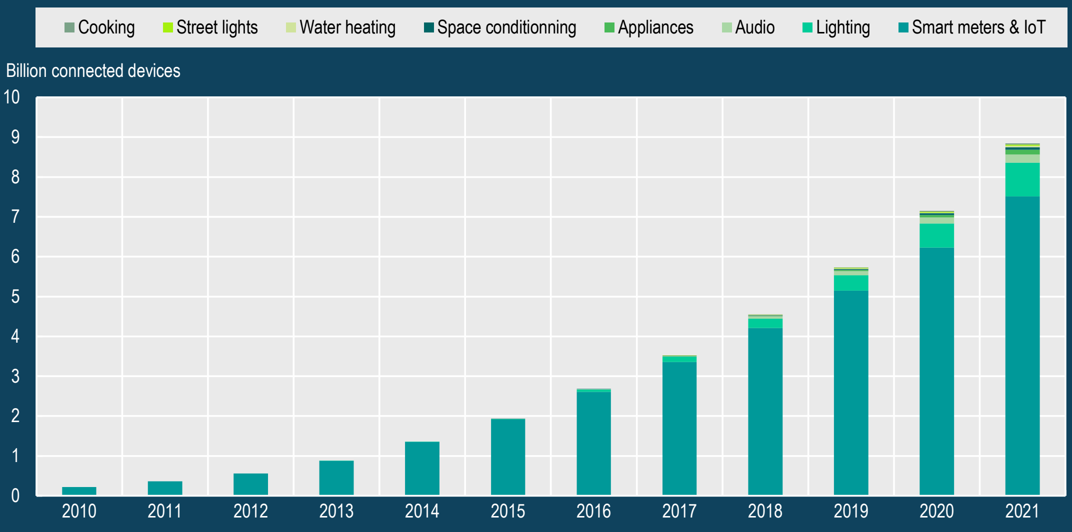
Large numbers of utility-scale wind and solar photovoltaic (PV) plants are increasing the amount of variable renewable electricity generation in many countries globally, but this is also happening together with distributed rooftop solar PV being installed on many domestic and commercial properties. There are challenges posed by increased amounts of renewable energy systems (RES), but there are also strong opportunities with both digital demand management and a diverse renewable energy portfolio. The challenges for electricity system operators on the supply side are due to variability in the generation by RES such as solar or wind, and there is a need to provide additional services to ensure that supply and demand are perfectly balanced every second of the day. On the demand side, a future increase in demand from the electrification of transport and heating could result in sections of the grid not having sufficient capacity to satisfy demand at certain times of the day.

To respond to these challenges, many national grids are undergoing the process of digitalisation towards the development of so-called "smart grids". The modernisation of electrical systems that are required to create smart grids includes electricity generation, transmission, distribution, and demand-side consumption, resulting in bi-directional flows of both energy and data. The International Smart Grid Action Network, one of the IEA Technology Collaboration Partnerships, defines a smart grid as an electricity network that can intelligently integrate the actions of all actors connected to it, generators, consumers and those that do both, to efficiently deliver sustainable, affordable, and secure electricity supplies (ISGAN, 2012[1]). However, to fully realise the potential of the smart grid and smart home, it is necessary to ensure that all of these advanced digital technologies can effectively communicate with each other and operate as designed. Interoperability is not the goal in itself, but rather is a useful tool working towards the modernisation of electricity grids.

The number of connected devices is growing rapidly. Over the last 5 years, the number of connected devices has grown on average by 33% each year, and in 2021 the number of connected devices was estimated to be around 9 billion devices, higher than the number of people on the planet (IEA, 2021[2]). Smart meters make up a significant share of such devices, highlighting their important role in the IoT ecosystem.

Figure 1. Global stock of connected devices

2010 - 2021



Source: IEA's Electronic Devices and Networks Annex (EDNA) Total Energy Model.

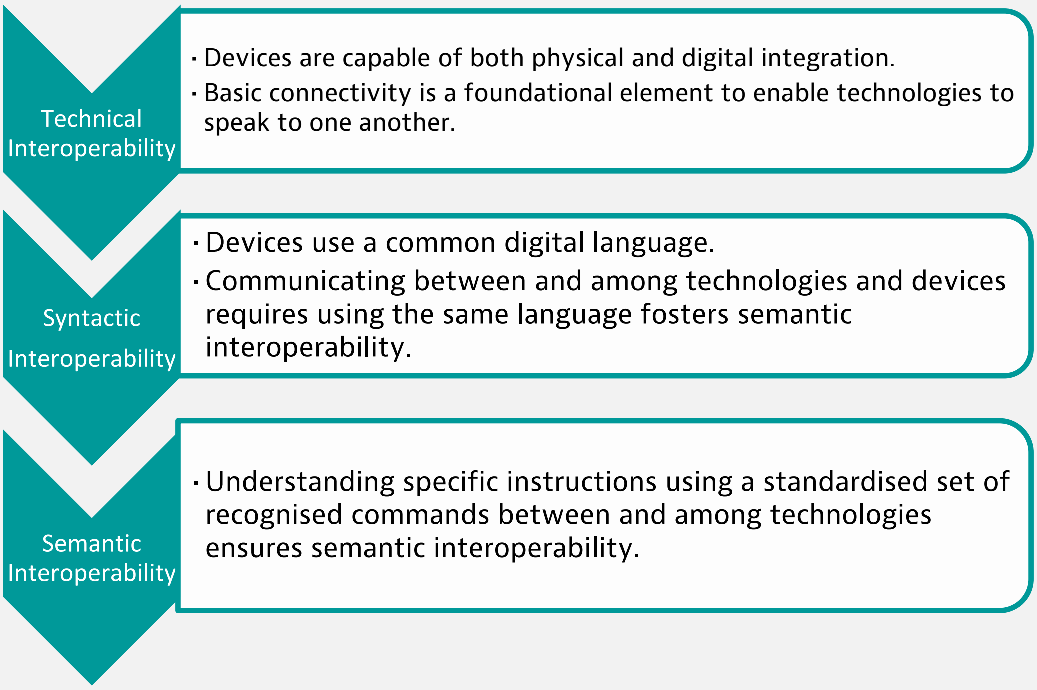
Currently, there are many types of devices operating independently of each other, particularly on the consumer end behind trade-protected proprietary hardware or software interfaces. Known as behind-the-meter equipment, devices such as electric vehicle chargers, or rooftop PV solar systems when deployed in large numbers, can have a detrimental effect on electricity grid stability if unmanaged. In most cases, these technologies are neither visible to the electricity system operator nor controllable. Moreover, as consumer demand for electricity is expected to increase as consumers switch from conventional internal combustion engine (ICE) vehicles to EVs, or replace fossil fuel heating with electric alternatives, additional stress might be placed on the electric grid.

To ensure the resilience of electricity grids, all of these embedded technologies in the IoT ecosystem must work together, or interoperate (Box 1). Interoperability is not a given, and there is a risk that companies will develop proprietary systems that will only work in silos. In the United Kingdom (UK) for example, by 2035 there could be as many as 10 million electric vehicles, which could potentially increase electricity demand by 3 gigawatt-hours (GWh). This might require costly infrastructure investment to increase the capacity of the electricity system to manage local constraints. However, by using smart charging to manage where and when to charge vehicles, the potential increase in demand could be as little as six times lower at around 0.5 GWh (Aurora, 2018[3]). Ensuring interoperability means taking actions to develop standards and facilitate data exchange. It is critical to realise the efficiency and flexibility potential of smart devices and appliances to reduce energy consumption and associated emissions from electricity supply globally.

Box 1. What is interoperability?

There are three aspects needed to achieve the interoperability of different technologies: 1) technical interoperability, 2) syntactic interoperability, and 3) semantic interoperability. These aspects reflect practical differences such as plugs, cables, devices, and hardware. There are also many different syntax or languages used by devices and platforms. And there is a need for standardised instructions or semantic exchange.

These three aspects can be applied to all manner of technologies to better understand interoperability, but to achieve greater interoperability, all three areas need to be closely aligned. The first step, technical interoperability, is the ability for technologies to speak to each other. The second step, syntactic interoperability, is the ability to understand the same language. The third step, semantic interoperability, is the comprehension of the same vocabulary so that the full context of the conversation is understood by all technologies.



- Devices are capable of both physical and digital integration.
- Basic connectivity is a foundational element to enable technologies to speak to one another.

- Devices use a common digital language.
- Communicating between and among technologies and devices requires using the same language fosters semantic interoperability.

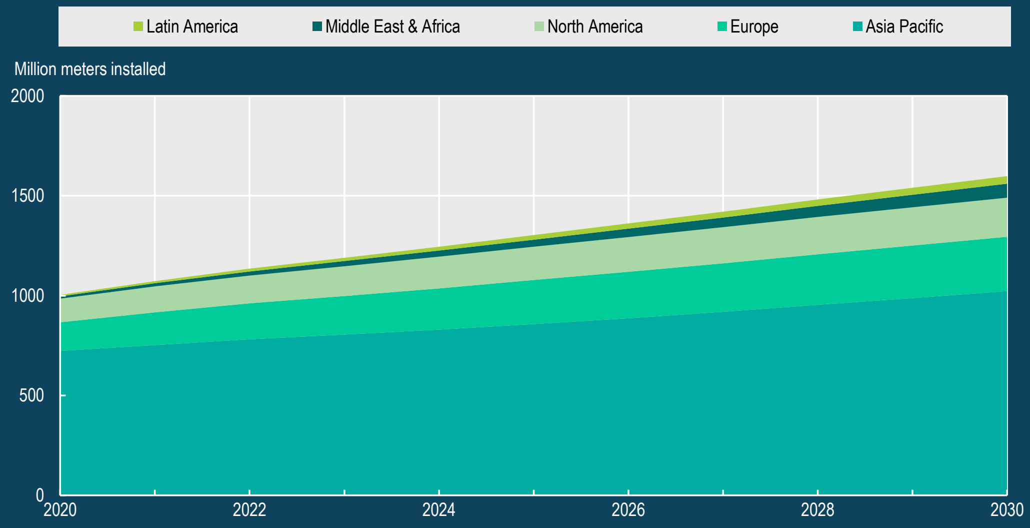
- Understanding specific instructions using a standardised set of recognised commands between and among technologies ensures semantic interoperability.

Source: IEA Technological Collaboration Programme - International Smart Grid Action Network.

The introduction of digital smart meters that replace traditional analogue meters is one of the first steps to increasing the visibility of behind-the-meter demand. In the past, electricity utilities only had real-time aggregated electricity demand for a substation, which could include thousands of individual connected properties, and retrospective consumption data from physically collecting meter readings to enable customer billing. Smart meter deployment is progressing at a steady pace (Figure 2), changing the dynamic.

Figure 2. Policy-driven increase in global smart meter deployment

2020 - 2030



***Source*:** IEA analysis based on Guidehouse Insights data.

Smart meters are now installed in approximately half of all properties in Europe (Smart Energy International, 2021[4]), and around 4 in 5 households in the United States (US) (Edison Foundation, 2021[5]). Smart meters show real-time demand for each property, enable automatic billing, and have the potential to enable energy providers to integrate the available data into their planning systems to optimise network operations.

However, the deployment of smart meters is not distributed equally. For example, at the end of 2020 coverage was only around 1% in India (IOT, 2021[6]), and in Africa and Latin America the coverage was low as well (Smart Energy International, 2021[7]). Expanding the use of smart meters is the first step to better understanding energy demand at the granular level globally. It is thus necessary for electric utilities to increase the deployment of smart meters globally to avoid regions being left behind. Following smart meter deployment, the next steps to be taken on the road towards greater higher levels of interoperability are less clear. Further co-operation domestically and internationally is necessary to achieve consensus on what steps need to be taken to maximise energy efficiency and accelerate the decarbonisation of electricity systems (FSR, 2020[8]).

Potential implications for the energy transition: What is the role of interoperability in clean energy transitions?

Increased interoperability of the electricity grid and IoT enabled devices, appliances, and sensors have the potential to further support the energy transition, increase energy efficiency system-wide, and reduce GHG emissions. The road transport sector is currently one of the main sectors lacking interoperability. Indeed, it is a crucial requirement for EV charging infrastructure to ensure charging stations are reliable and trustworthy to the user. Poor standards of interoperability and usability of EV charging infrastructure could reduce consumer confidence and slow down the transition away from ICE vehicles. In the UK, for example, a recent survey exploring how to improve driver's confidence in public charging infrastructure found that 98% of respondents stated that they could reduce time spent locating a suitable charger if there was better data on EV charger availability, working condition, or peak use times (EVA, 2021[9]).

With targeted control settings in regions with a large number of renewable energy systems, interoperability of components in energy systems could increase the consumption of low carbon energy. This could be achieved by increasing the efficiency of devices and appliances through intelligent operation, and by unlocking customer flexibility where possible to shift demand from peak hours to off-peak hours with the right billing incentives. This can happen by pre-cooling or pre-heating spaces before peak demand, or by heating water before use when demand is lowest to maximise the use of low carbon electricity generation sources such as RES or nuclear and prevent the need for a more carbon-intensive generation source coming online.

Another efficiency gain could come in the form of reducing the "curtailment" of renewables. Curtailment is when the amount of renewable energy available for supply is more than the total demand of the electricity system or the local electricity system is designed for, and the electricity operator requires solar or wind farms to disconnect from the grid to stop exporting. This opportunity cost of disconnecting low carbon generation has a cost both financially and environmentally. From 2010 to 2017, over 250 Terawatt hours (TWh) of variable renewable electricity was curtailed globally, equivalent to Spain's annual electricity demand, and equating to GHG emissions of 180 Mega tonnes (Mt) CO2 (IEA, 2020[10]). Achieving increased interoperability of devices could reduce the overall carbon intensity of the electricity grid by increasing flexible demand when renewable generation is abundant, such as at midday when there is a lot of solar PV generation, or when there is a lot of wind but low demand.

Benefits of increased interoperability

There are potential benefits of increased interoperability of technologies within the electricity system across four categories: 1) customers, 2) electricity grid operators, 3) businesses, and 4) society more broadly. There are potential symbiotic relationships between and among actors to provide new services.

Customer benefits include:

- Flexibility to automate shifting demand from peak prices to off-peak prices (or other periods of low prices), reducing household bills through energy arbitrage. For households with solar panels in self-consumption mode, it also enables shifting consumption towards times when energy production is at its highest.
- Improved customer experience as advanced technologies optimise household energy consumption based on consumer preferences and market signals with little or no intervention necessary by the individual.
- Better EV charging experience for customers from the public network with reduced proprietary connectors and improved digital payment platforms that require fewer mobile apps and an ability to 'roam' internationally. Private home chargers optimise "time of use" charging to reduce bills, while ensuring that the batteries are charged as required.
- Optimisation of the existing electric distribution and transmission grid infrastructure by delaying or avoiding reinforcement expenditure. This reduces the need for the socialisation of costs, thereby mitigating customer exposure to increased bills. As many sectors decarbonise, if unmanaged, there is the potential to create further distributional financial pressure on commercial and domestic customers who will ultimately bear the burden of higher prices.

Electricity grid benefits include:

- Increased visibility of real time demand enables improved spatial planning by identifying locations in the electricity grid that are most under pressure and the optimisation of resources to maintain and reinforce the network more effectively and at the least cost.
- Full digital integration of sensors and monitors in the existing network, including as dynamic line monitoring which measures the temperature of sections of the electricity system, improves system reliability thereby enabling early fault detection, and the optimisation of existing infrastructure.
- Flexibility of demand maximises the output of infrastructure when loads are temporarily shifted from high demand to lower demand and increases the longevity of existing infrastructure.

- Improved ability to monitor or remotely access behind the meter resources such as solar PV or smart EV charging in emergency situations, improve grid stability, and a lower chance of grid blackouts.
- Fully interoperable space heating and cooling reduces the impact on local networks by pre-cooling or pre-warming in advance of peak demand or where excess renewables are available through load shifting with market signals. This is important as energy demand for air conditioners alone, for example, could triple by 2050 (IEA, 2018[10]).

Business grid benefits include:

- Access to secure, anonymised, real-time data creates an environment for new business models to optimise energy consumption to increase total electricity system efficiency.
- Standardisation of interoperability protocols and the removal of proprietary "walls" from devices controlled by the vendor under trade-protected patents, thereby opening market access to reduce monopolistic behaviour and increase competition.
- A single agreed standard allows for scalability of business models to apply to many jurisdictions, thus enabling rapid deployment to facilitate accelerated decarbonisation through system efficiency.

Wider societal benefits include:

- Reductions in the consumption of fossil fuels such as coal and gas as more renewable energy and low-carbon sources are maximised with reduced curtailment. This results in positive externalities of improved carbon intensity on average for each unit of electricity produced. This could improve air quality and contribute to a reduction in fossil fuel related air pollution which is responsible for the deaths of one-in-five people worldwide (NRDC, 2021[11]).

Open access to data could enable the market to provide digital solutions, reduce energy consumption at the household level, shift demand from peak to off-peak, and reduce energy bills. This optimisation could reduce pressures on the electric grid at peak demand, and potentially postpone or avoid costly infrastructure reinforcement investments. Additionally, where the electric grid already has renewable or other low carbon sources available, it may be possible to minimise the amount of carbon-intensive generation required to cover peak demand.

Increased digitalisation and interoperability of electricity grids raise several risks that should be addressed through appropriate policies. The requirement to exchange data between various nodes will increase energy use, thus putting increased pressure on data centres required to handle increased data flows. Previous advances in the energy efficiency of data centres and their processes have helped curb the absolute growth in data demand. Since 2010, the volume of global internet traffic has increased fifteen-fold, however, the demand for energy to process that same data remained at around 1% of global electricity demand which increased less than double in the same period (IEA, 2021[12]). However, further efficiencies will be required to continue reducing energy consumption as demand for data processing grows.

Another risk to a critical system such as electricity infrastructure is cybersecurity. In 2021 alone there were approximately 500 million ransomware attacks registered, with an average of over 1 700 attempted attacks per client (Toolbox, 2022[13]). Ransomware attacks use malware which encrypts the targeted individual or organisation's data systems. In May 2021, a ransomware attack targeted Colonial Pipeline, the largest pipeline for refined petroleum products in the US, which transports approximately 2.5 million barrels of fuel per day (Bloomberg, 2021[14]). The result was a complete halt of the transport of fuel by pipeline, leading to fuel shortages as panic buying led to fuel stations running out of fuel.

The decentralised nature of our energy systems, many components of which are still in analogue format, offers greater protection against a catastrophic disruption to entire cities or nations from losing control of critical assets. However, as our lives become ever more digitalised, so do our energy systems. To protect the power system against this risk, safety protocols can be designed within the ways that various technologies can communicate with each other to enable them to be interoperable, but not necessarily inter-dependent.

What are the main barriers to improving interoperability?

There are a range of challenges to ensuring greater interoperability of energy systems and thus achieving net zero in the medium-term. The main barrier to achieving energy interoperability is that which presents itself as a wicked problem (Rittel & Webber, 1973[15]). This is a scenario where due to the multitudes of interactions of the many participants in the electricity system, there is no one definitive roadmap. Indeed, what precisely interoperability in electricity systems means has not been defined in this Toolkit note, precisely because there is no agreement among the many different stakeholders in the energy sector. Other barriers are more technical in nature.

No means of communication

A major barrier to achieving interoperability is the absence of a common language to adequately describe system processes. Policymakers and energy regulators often use loose language when referring to various concepts around interoperability, whereas system engineers and software developers use a highly technical language that is difficult to interpret to an outsider. It is necessary to agree on reference common vocabulary for all actors to make progress in system integration.

It is even more important to agree on the syntax and semantics when dealing with integrating system change in many different countries. For example, increased amounts of RES within the Integrated Energy Market in the European Union (EU) requires the interconnected participating Member countries to adapt to changing requirements to increase system efficiency, support further RES integration, and support network planning to strengthen electricity grids to enable high voltage direct current connections (HVDC) network development. This reduces grid congestion through interconnection, provides real-time information to facilitate improved balancing services, increases cross-border trading, and increases energy efficiency through improved resource management. To work towards greater interoperability, standardising data exchange is essential. The model of data exchange chosen by the EU is based on the International Electrotechnical Commission's Common Information Model IEC TC 57/WG13 (IEC, 2020).

The missed opportunity of underutilised connected IoT devices

Smart appliances and devices can realise the potential of increased efficiency through digitalisation. Many smart devices and appliances in homes and businesses today can connect to an app on a smartphone or tablet through a Wi-Fi connection. However, the ability to connect these devices to the Internet does not in itself necessarily provide useful connectivity. There is a great opportunity to reduce energy demand as household appliances are responsible for around one-quarter of the total electricity used in buildings (IEA, 2020[17]). There may be individual household benefits, such as smaller bills from reduced consumption from domestic smart devices, but to realise the full potential of integration into the energy system it is necessary to improve interoperability to respond to signals from the electricity system operator to reduce peak demand or to reduce curtailment of renewables. For example, heating water when there is an excess of generation in the middle of the afternoon when demand is low can go a long way towards improving energy system efficiency.

The dominance of proprietary tools

The integration of smart appliances and devices within the wider energy system presents challenges. It requires collaboration from consumers, electric utilities, and the wider industry. Consumers need more awareness of their energy consumption patterns. Utilities can provide necessary and useful information to the homeowner to understand if there is some flexibility which could reduce their absolute demand, or if there is the possibility to shift electricity use away from peak demand periods, both of which should reduce customer bills. There is also the need for energy providers to offer time-of-use tariffs as a means of price signalling to incentivise customers to modify their behaviour. However, in addition to the availability of better information, it may also be necessary to transition from the current landscape of locked proprietary devices to a more open system. Smart meters, devices, and appliances must offer the proper communications and functionality to react to price signals. Currently, many are locked behind proprietary walls, support a specific communication protocol, and are not able to communicate between different devices.

The use of proprietary tools is often preferred by businesses to enable a quick route to market and to provide a high-quality product, but often proprietary platforms do not provide as high a value to the consumer as open-source platforms, which offer the potential for new market actors to emerge to act as energy efficiency disruptors. The continued use of proprietary tools also raises the possibility of monopolistic lock-in of consumer data.

In India, to avoid this scenario in the nascent evolution of the electric vehicle transition, steps have been taken toward creating an ecosystem for battery swapping for two and three-wheeled electric vehicles (NITI, 2022[18]). This policy is intended to support the development of a battery standard to enable battery swapping at scale at charging stations across the country. Battery swapping, whereby spent battery packs can be swapped for fully charged ones in a matter of minutes, aims to reduce the number of fossil fuel consuming vehicles and increase the efficiency of the EV fleet due to reduced downtime charging. The full transition to electric two and three-wheeled vehicles in India from internal combustion could alone see non-methane volatile organic compound air pollution reduced by over 90% (Hakkim et al, 2022[19]).

Many different standards of energy infrastructure

Progress in advancing interoperability is being made in energy infrastructure standardisation. For instance, IEC 61850 is an international standard for communication in electrical substations (Automation, 2009[20]). This standard aims to: 1) unify communications by avoiding proprietary protocols, 2) provide interoperability to integrate equipment from different manufacturers using a substation configuration language, and 3) provide flexibility for the standard to evolve as new use cases emerge. From its inception in 2009 as a means of enabling computers in electrical distribution control centres to be able to monitor and operate remote assets, IEC 61850 has expanded and will in the future also cover other areas such as wind, solar, and hydro generation, battery storage, and EV integration.

With EVs, for example, there is still no standardised means of communication between the vehicle and the station for smart charging (Energies, 2021[21]). The digital and physical EV charging infrastructure must be adequate to manage the potential challenges facing electric system operators caused by an increase in demand for EV charging. For example, most private passenger vehicles will likely connect to the electricity system between 17:00 and 19:00 which is the peak demand period as owners return from work and connect their EV to their home charger.

This could require additional electricity generation sources to come online, often with higher emissions compared to the sources of generation at lower demand times of the day or could require costly infrastructure reinforcement upgrades to manage the extra demand. This would ultimately raise costs for all customers, including those without electric vehicles. However, it is possible to mitigate this risk by utilising 'smart charging'. This would manage when a vehicle would connect to the electricity system to commence charging to reduce the number of vehicles connecting at peak demand time. In response to a 2019 consultation on electric vehicle smart charging, the UK government recently became the first country to mandate that all new EV charge points must have smart functionality and meet minimum device level requirements (UK Gov, 2021[22]).

Closed data

Both traditional electricity retail models and nascent emerging digital services require data and information to be accessible by relevant stakeholders and exchanged among multiple actors, applications, components, devices, networks, and systems. To enable effective data sharing, secure open-source data could be made available. For example, smart meters are now providing real-time demand data to electricity operators, but this data is not currently available for analysis. The UK government's Energy Data Taskforce published *A Strategy for a Modern Digitalised Energy System* with the key findings around data visibility, operational optimisation, open markets, and agile regulation (Catapult, 2021[23]). The main findings were that to maximise the potential of smart meters in a modern digitally transformed energy system, it is necessary to:

- Fill in the data gaps around what is available and what is needed;
- Open up data access for analysis to maximise the efficacy;
- Make it easier to understand how system assets are layered across the system; and
- Identify how assets can participate in supporting system optimisation at all levels of the system.

In response, the Data Communications Company (DCC), a company managing the smart meter data and communications infrastructure and regulated by the UK energy regulator OFGEM in collaboration with the Open Data Institute, has published *Data for Good* to initiate the creation of a smart meter platform. DCC plans to increase smart meter data availability whilst being safeguarded by the National Cyber Security Centre (DCC, 2021[24]). This system data exchange of anonymised information could pave the way for access to a wider range of analysis, to maximise the public benefit to further system interoperability, increase system efficiency, reduce household bills, increase system flexibility, and accelerate the decarbonisation of the electricity system.

The lack of data exchange has also been recognised by the Australian Energy Market Commission, who in 2021 launched the Smart Meter Data Access Framework Options (AEMC, 2021[25]). It recommended the establishment of a DCC style body, setting minimum standards for bilateral engagements between retailers and electricity distribution operators, and the establishment of a data exchange architecture with defined roles to allow parties to freely participate. Additionally, global member organisation oneM2M (machine to machine) is working with academia and both small and large technology companies, to develop open standards for interoperable and scalable IoT systems (OneM2M, 2022[26]).

Closed markets

There is the potential to enable access to open data to begin modelling energy usage and the localised effect that consumer demand has on distribution systems and transmission systems, including at different times of the day. This type of analysis could contribute to the understanding of which flexibility mechanisms could emerge to reduce peak demand to lower the carbon intensity of the electricity grid to reduce emissions as well as household bills. However, current electricity markets are mostly not structured in a way which enables data sharing, and to accommodate flexible platforms the design of electricity markets would need to be adapted (Energies, 2021[27]). Much more efficiency and cross-sectoral synergies could be realised by allowing new market mechanisms to harmonise flexibility mechanisms to balance grids. There is a large potential for improvements in grid operations to balance generation output using real-time data of utility-scale and behind-the-meter customer smart device data to provide flexible services, and in the case of battery storage, to also offer system capacity potentially by exporting power back into the grid if necessary.

To date, there are some small-scale pilots underway in addition to larger industrial flexibility markets but they remain fragmented. INTERRFACE, an EU-funded project, aims to create a common architecture that connects electricity market platforms. It also seeks to design an Interoperable pan-European Grid Services Architecture that will connect these platforms to enable a pan-European electricity exchange that will link wholesale and retail markets for the trading of energy services (Interrface, 2019[28]).

How can policymakers foster interoperability?

There are a range of ways that policy can support interoperability. Learning from the experiences with interoperability in other sectors, designing and implementing standards, good governance at the national and sub-national levels, and encouraging investment in the infrastructure needed to make interoperability of energy systems a reality.

Learning from other advances in interoperability

There is much to learn from other sectors that have already undergone many transformations towards greater interoperability such as telecommunications or healthcare. The global standard in the healthcare sector, ISO/TR 28380, sets out a standard for health informatics and the process required in global standards adoption for tasks within healthcare that depend on information exchange (ISO, 2014[29]). Many advances may lead to achieving synergies by examining the existing structures built whilst integrating into challenging environments such as EV charging, with multiple actors, in multiple regions, and with multiple unique infrastructure designs. Interoperable open standards-based public EV charging infrastructure can also improve the overall customer experience, enable improved EV to electricity system integration, and support consumer adoption of EVs (EPRI, 2019[30]).

While now commonplace, early adoption of mobile phones faced issues when moving to different regions due to system differences and lack of interoperability. International co-operation and technological innovation have enabled mobile roaming to allow users to move between regions with global coverage. There is a similar challenge now to achieve EV roaming harmonisation to improve consumer experience and improve price transparency. The evRoaming4EU Work Package 6 pilot project is an initiative with two defined goals. First, to maximise interoperability of the EV charging market with a focus on how devices communicate with each other and, second, to work towards a harmonised charging protocol as opposed to the current heterogeneous mix (evRoaming4EU, 2020[31]).

Design a set of standards to address well-defined use cases

In the EU, where progress towards greater interoperability of energy services has been made following the creation of the Internal Energy Market, the Smart Grid Task Force was established by the European Commission (EC) in 2009 and consists of representatives from industry, national regulators, consumer groups, and the EC (EU, 2021[32]). The expert groups have focused on regulatory and standards recommendations for privacy, data protection, cybersecurity, and smart grid industrial policy. The goal of the expert group regarding data access and management was to identify obstacles toward interoperability frameworks at the EU level for a potential industrial initiative on a common format for energy data exchange. The conclusion was that any transition towards interoperability should:

- Be adaptable to handle different time resolutions;
- Have inbuilt flexibility for individual variability and support different use cases relevant to each member state;
- Be scalable to incorporate future variables;
- Be easily implementable; and
- Avoid sticking rigidly to one single data format, but instead allow for compatibility or alignment with existing systems (EU, 2016[33]).

Rather than be too prescriptive, it may be prudent to set a series of minimum standards that are required to achieve a specific goal. In Australia, for example, there are over 3 million rooftop solar PV panels installed, covering around 30% of all residential properties (Australian Gov., 2022[34]). Following advice from the Australian Energy Market Operator of a potential electricity system risk due to unmanaged domestic energy generation, *Regulatory Changes for Smarter Homes* were introduced mandating that new residential solar PV panels must be designed for remote operation to disconnect from the electricity grid in the event of an emergency to increase grid stability (Gov. South Australia, 2020[35]). Instead of providing a prescriptive list of approved components, the regulations were focused on the use case, were technology agnostic, but also required an approved third party 'relevant agent' be appointed by the customer to remotely disconnect the heterogeneous installations if necessary.

Regulate to align business processes and recognise the end-user

To increase interoperability in energy systems, it is necessary to align the data and data modelling standards with the goals of the policymakers and regulators. A common language may be necessary at the system engineering and information modelling level, and business processes aligned to achieve shared goals. The EU's 2019 Electricity Directive identified that it was necessary to recognise the important role of the consumer in the ecosystem and that "Member States shall ensure the deployment in their territories of smart metering systems that assist the active participation of customers in the electricity market" (EU, 2020[36]).

As the digitalisation of energy systems continues, stakeholder participation could increase system-wide. This is particularly true for customers who will play an important role in providing system flexibility and up until now have been considered only as a point of energy consumption and a revenue stream. However, it is necessary to require more than just the provision of smart meters to customers to initiate engagement. The EU and the Swiss Confederation co-funded U4IoT, which was established to support IoT large scale pilots to actively engage end-users in pilot design, deployment and assessment, and to analyse societal, ethical, and ecological issues for tackling IoT adoption, including skill-building (U4IoT, 2018[37]).

An interoperability framework would be beneficial to identify how stakeholders interact with each other, what format data is stored and managed, and how data is exchanged An interoperability framework would be beneficial to identify how stakeholders interact with each other, what format data is stored and managed, and how data is exchanged betweenbetween actors. The framework should be focused on use cases, without a particular focus on prescriptive standards or specifications. An agreed portfolio of standards will be necessary to ensure conformity among all parties. International standards should form the backbone to enable the highest interoperability possible. Standards will also require constant revisions to adapt to the newest technological advances and additional use cases. An interim step might be a move to IoT 'Plug and Play'. This concept builds on the advances made in the 1990s to enable hardware in computers to operate through developing standardisation of components so that the operating system could recognise them once physically connected and is now able to use cloud-based solutions to manage diverse connected devices each with different proprietary specifications.

It is important when designing the structure of flexibility markets to ensure that all stakeholders are protected. It is also crucial that enterprise is not restricted so far which could reduce innovation and slow down the progress of the energy transition. It is essential to avoid monopolistic lock-in where one actor may capture a service, task, or function. Instead, harmonised roles would enable different actors to participate in electricity markets.

A framework for testing, certifying and monitoring interoperable solutions

In addition to standardisation, testing and certification will further reinforce systems and increase the security of data and infrastructure both digital and physical. Testing will validate to ensure that the proposed specifications meet the requirements, can verify the specifications through their development and validation of the test models, and verify the test model through its continued demonstration. Testing in real-world scenarios will be necessary to ensure compliance with standards and provide checks and balances to ensure that developers are conforming to specifications to achieve the goals of interoperability.

Governance at multiple levels is a key tool

Many disparate stakeholders are currently involved in interoperability but not coordinated in a goal-orientated way. To elevate the potential of higher levels of interoperability, the impact of a policy could be assessed on different levels of government: regional, national, and local. Governance could be top-down in the form of a regulator to oversee the progress of system interoperability, potentially requiring the creation of a new entity. Bottom-up self-regulation, on the other hand, could support predetermined use cases. A combination of both may also be appropriate. In 2021, for example, the UK government introduced the Automated and Electric Vehicle (AEV) Act to legislate that in phase one, all new EV chargers must be capable of smart charging with minimum design requirements to limit the pressure from EV adoption and charging on the electricity grid. Additionally, the intention in phase two is to address interoperability to enable customers to move freely between providers like how customers can transfer phones between telecom providers today (UK Gov, 2021[22]).

Investment needs to flow

Whilst it is accepted that a lack of interoperability generally corresponds with high transaction costs (NIST, 2019[38]), improving interoperability of the electricity sector also has direct costs. This especially impacts the incumbent firms who may need to be first movers. To enable progress, substantial investments will be required in both digital and physical infrastructure. Historically energy producers are compensated for satisfying electricity demand, and electricity system operators for ensuring there is sufficient network capacity to supply energy to the end-user. A new business case could be made for compensating for marginal efficiency gains, or a contract for difference to compensate for costs avoided. Market incentives or regulations may be required to focus on specific use cases to enable capital to flow from traditional energy actors which owing to limited mechanisms for recovery of investments would otherwise be deemed as sunk costs.

Conclusion

The digitalisation of many aspects of electricity systems - from generation, transmission, distribution and end-use demand - is generating significant amounts of data. Such data can help achieve net zero through interoperability, but only if the data is more open than closes. The flow of data between the various devices and sensors may require new roles to be created and could reshape the structure of existing electricity markets as electric system operators become data managers, new business models begin to emerge, and new players enter the market. However, due to the complexity of the nature of the electricity system, it is unlikely that there will be a disruptor emerge as witnessed in other sectors, but rather incremental advancements that may occur along the path toward higher levels of interoperability.

Whilst electricity markets are regionally diverse, we live in a connected global world and international co-operation to strive towards greater standardisation ultimately should be encouraged. Many challenges need to be overcome to achieve higher interoperability within the electricity system. Nevertheless, there are obvious potential benefits for increased interoperability for consumers, electricity system operators, businesses, and society more broadly in the form of reduced greenhouse gas emissions, improved system reliability, and reduced costs if further advancements are achieved.

Annex. A selection of interoperability initiatives and policy measures

Energy Data Taskforce

Responsible entity: UK Government

Description: The Energy Data Taskforce, commissioned by the UK government, Ofgem, and Innovate UK, has set out key recommendations that will modernise the UK energy system and drive it towards a net-zero carbon future through integrated data and the use of a digital strategy throughout the sector. The recommendations highlight that moving towards a 'Modern, Digitalised Energy System' is often being hindered by poor quality, inaccurate, or missing data, while valuable data is often restricted or hard to find. The Taskforce, run by Energy Systems Catapult, has delivered a strategy centred around two key principles: 1) filling the data gaps by requiring new and better-quality data, and 2) maximising its value by embedding the presumption that data is open. These two principles aim to unlock the opportunities for a modern, decarbonised and decentralised energy system for the benefit of consumers.

Read more: *https://es.catapult.org.uk/report/energy-data-taskforce-report/*..

Data for Good – White Paper on smart meter data access strategy

Responsible entity: Data Communications Company regulated by the UK Office for Gas and Electricity Markets

Description: This paper explores the potential benefits that securely enabled appropriate and permissive access to anonymised and aggregated smart meter data could deliver, identifies the barriers that would need to be overcome, and presents possible methods that could be used to achieve data sharing advancement.

Read more: *https://www.smartdcc.co.uk/media/1254/21037-dcc-data-for-good-paper_v8-final.pdf*..

Smart meter data access framework

Responsible entity: Australian Energy Market Commission

Description: The Australian Energy Market Commission (AEMC) launched a three-year review of the smart meter regulatory framework to determine whether further changes are needed to the regulatory framework to enhance its efficacy and efficiency. The review identified a challenge concerning smart meter data access to provide significant value to the system by providing near real-time power quality data to allow for more efficient management and maintenance of Australian power grids.

The framework presented the challenges surrounding data access and develops a series of options for new frameworks to allow for greater access.

Read more: https://www.aemc.gov.au/sites/default/files/documents/nera_smart_meter_data_access_framework_options_-_metering_review.pdf..

Interoperability of public electric vehicle charging infrastructure

Responsible entity: Electric Power Research Institute (US)

Description: This paper is a co-operative effort of the Electric Power Research Institute (EPRI), the Edison Electric Institute (EEI), the Alliance for Transportation Electrification (ATE), the American Public Power Association (APPA), and the National Rural Electric Cooperative Association (NRECA) to identify challenges, create awareness, and provide perspective to achieve greater interoperability and open standards in the burgeoning US EV charging market.

Read more: https://www.epri.com/research/products/000000003002017164..

Achieving interoperability for electric vehicle roaming

Responsible entity: EC

Description: This report is part of the evRoaming4EU project funded by the EC. The main objective of evRoaming4EU is to facilitate roaming services for charging EVs and provide transparent information about locations and rates of charging in Europe by making use of an open independent protocol. This will be demonstrated through regional and transnational pilots in four different regions, thereby promoting the creation of one European market for EV drivers and related products and services. The project works towards two distinct goals: 1) maximising the interoperability of the EV charging market, especially the ability of different charging infrastructures to communicate with each other efficiently either via a single protocol or multiple interoperable protocols, and 2) maximise adoption of a harmonised EV charging protocol, i.e., the number of parties using the protocol. The results of the project should give insight into how these goals can be achieved, and where trade-offs of achieving these goals must be made.

Read more: https://evroaming.org/app/uploads/2020/06/D6.2-Achieving-interoperability-for-EV-roaming-Pathways-to-harmonization.pdf..

Electricity digitalisation policies – Joint Research Centre on smart electricity systems and interoperability

Responsible entity: EC

Description: The EC Joint Research Centre has assembled a repository of some of the main EU policy and legislative initiatives in the energy and digitalisation fields, with a focus on how digital transformation is a key enabler to attain the Green Deal/Recovery objectives. In particular, the EU put forward two ambitious political initiatives in the green and digital fields that display clear synergies. First, the European Green Deal is the EU's plan for sustainable growth. It aims to achieve the Paris Agreement objective, which is to keep the global temperature increase below 2°C. Second, the EU has also issued a Digital Strategy since digitalisation requires preserving privacy, security, safety and ethical standards, further identifying the need for infrastructure fit for the future, with common standards, networks, and clouds. Accessible and interoperable data are at the heart of innovation. This data, combined with digital infrastructure and artificial intelligence, facilitate evidence-based decisions and expand the capacity to tackle environmental challenges.

Read more: *https://ses.jrc.ec.europa.eu/node/31970*..

Interface - Working towards an interoperable pan-European grid services architecture

Responsible entity: EC

Description: The European Commission adopted legislative proposals on the energy market that promote co-operation among power network operators as they procure balancing services and provide congestion management. To support the transformation, the INTERRFACE project will design, develop and exploit an Interoperable pan-European Grid Services Architecture (IEGSA) to act as the interface between the power system and the customers and allow the seamless and coordinated operation of all stakeholders to use and procure common services. State-of-the-art digital tools based on blockchains, and big data management will provide new opportunities for electricity market participation and thus engage consumers in the INTERRFACE proposed market structures that will be designed to exploit Distributed Energy Resources.

Read more: *http://www.interrface.eu/Objectives*..

User Engagement for Large Scale Pilots in the Internet of Things (U4IoT) - European large scale pilot programme

Responsible entity: EC and the Swiss Confederation

Description: U4IoT will enable a citizen-driven process by combining multidisciplinary expertise and complementary mechanisms from the European state-of-the-art. It will also analyse societal, ethical and ecological issues related to the pilots to develop recommendations for tackling IoT adoption barriers, including skill-building. End-user and societal acceptance is critical to the success of the IoT large-scale pilots. U4IoT combines social and economic sciences, communication, crowdsourcing, living labs, co-creative workshops, meetups, and personal data protection to actively engage end-users and citizens in the large-scale pilots (LSPs). It will develop a toolkit for large scale project end-user engagement and adoption, including online resources, privacy-compliant crowdsourcing tools, guidelines and an innovative privacy game for personal data protection risk assessment and awareness, and online training modules. It will also direct support to mobilise end-user engagement with co-creative workshops and meetups, training, “living labs”, and an online pool of experts to address LSP specific questions. In addition, it will analyse societal, ethical and ecological issues and adoption barriers related to the pilots with end-users and make recommendations for tackling IoT adoption barriers, including educational needs and sustainability models for LSPs and future IoT pilots’ deployment in Europe. Finally, it will support communication, knowledge sharing and dissemination with an online portal and interactive knowledge base gathering the lessons learned, FAQ, tools, solutions and end-user feedback.

Read more: *https://european-iot-pilots.eu/u4iot/*..

Regulatory changes for smarter homes – Guidelines for managing the integration of rooftop solar

Responsible entity: Australian Energy Market Operator

Description: The South Australian Government responded to a technical report highlighting several challenges arising from the increasing and unmanaged supply of electricity to the grid from rooftop solar from the AEMO with several new technical standards and requirements. These include: 1) voltage ride through standards for generating systems connected via an inverter to reduce impacts during disturbances; 2) remote disconnection and reconnection requirements that systems are capable of being remotely disconnected and reconnected by an agent registered with the technical regulator; 3) export restrictions for all new systems to be capable of export limitation to provide for fair sharing of network capacity; 4) Smart meter minimum technical standards for smart meters to be able to separately measure and manage generation and controlled load; and 5) tariffs to incentivise energy use in low demand periods that retailers offer plans which reward customers for shifting electricity use to support the grid.

Read more: *https://www.energymining.sa.gov.au/industry/energy-productivity-and-technical-regulation/smarter-homes/regulatory changes for smarter homes*..

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