SMART METERS AND FLEXIBLE DEMAND IN NORTHERN IRELAND

Funded by Northern Ireland's Department for the Economy to contribute to the evidence base for the development of a new Energy Strategy.

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EXECUTIVE SUMMARY

The 20th Century model for energy systems, based around large-scale, centralised, investor-owned fossil assets, is being overturned by the emergence of decentralised, low-carbon technologies such as solar PV, wind power, thermal and battery energy storage, fuel cells, heat pumps and electric vehicles (EVs), collectively known as distributed energy resources or DERs[1][2].

DERs can be used individually or in aggregate and co-ordinated by smart digital technologies to complement output from variable renewable energy (VRE) resources with flexible demand to create new sources of system value. The low costs and small scale of DERs means that they can be customer- rather than investor-owned. While declining costs have contributed to the rapid uptake of DERs by homes and businesses, it is the power of digital communications, data analytics and artificial intelligence to co-ordinate their operation which has created the potential for consumers to provide flexibility and become significant actors in smart energy systems.[3]

In the context of energy in Northern Ireland, the Matrix Report[4] commissioned by DETI in 2013 identified "*a compelling opportunity for Northern Ireland to take a leadership role in the development of distributed energy solutions and their integration into Intelligent Energy Systems through establishing itself as an International Reference Site to demonstrate the commercial scalability of these solutions to the global market*".

The characteristics of the NI power system – dispersed, with a 'peaky' load profile and very high levels of decentralised, small-scale renewable generation connected at network voltages – mean that it is ideally suited to the intelligent management and co-ordination of flexible demand to manage variability where it arises – at local network level.

To allow consumers to create and monetise value by flexing energy demand it is first necessary to know not just how much energy is being consumed, but also when, where, and by whom. Deploying intelligent metering devices which can gather and communicate this information in real time is therefore a critical building block in enabling smart energy systems. While the rollout of Smart Meters

[1] https://www.ubiquitypress.com/site/books/e/10.5334/bcf/
[2] https://www.sciencedirect.com/science/article/pii/S2214629617303572
[3] https://www.iea.org/reports/digitalisation-and-energy
[4] https://matrixni.org/documents/the-2013-sustainable-energy-report/

has been problematic in some countries, most notably in GB, the basic need for real-time, two-way communication to unlock the value of flexible consumer demand remains.

There are several key characteristics which make Northern Ireland the ideal place to deploy smart, consumer-led energy systems. Firstly, it has connected a very high proportion of Variable Renewable Energy (VRE); over 1,400 MW of onshore wind and over 250 MW of solar power by the end of 2020, to a system with a peak load of around 1,600 MW, and a minimum load of 500 MW. This resulted in the Assembly's 2020 target for 40% of electricity consumption to be served by renewable resources being reached ahead of schedule; in fact, in 2020 over 49% of NI electricity came from renewable (overwhelmingly wind) resources.

However, it is not just the scale of VRE capacity that is important. NI's low-density, dispersed population means that it has a disproportionately high level of low-voltage (long and stringy) network connected to remote homes and businesses. NI has more than twice amount of Transmission & Distribution (T&D) infrastructure per head of population compared with the rest of the UK (GB has an average 28m of T&D wire per customer, compared with 58m in NI, almost all of which is lower voltage distribution network).

NI's VRE resources are almost entirely connected at these lower, distribution (rather than transmission) voltages. Windfarms here are consequently on average much smaller than windfarms elsewhere. The result is highly decentralised and variable generation, which compounds an already variable (or 'peaky') demand profile, largely shaped by domestic consumer demand. The efficient management of the resulting volatile demand profile requires high levels of flexibility from both supply-side (conventional generation, interconnection) and demand-side (demand response, flexible loads to absorb excess wind generation, peak-reduction market products) measures.

However, while NI has been successful in connecting high levels of VRE, flexibility is still largely limited to the dynamic operation of fossil generators. The relative lack of other supply-side resources such as interconnection (most notably the seemingly interminable delay to construction of the North-South interconnector), combined with the failure to deploy any significant consumer-side flexibility has resulted in a highly inefficient system. The inability to provide flexible demand to complement VRE output means that currently the main method of managing excess wind generation is to dispatch down wind generators, effectively dumping indigenous clean energy. In 2020 465 GWh (15%) of NI's available wind energy was rejected, enough electricity to power over 140,000 homes for a year, or the equivalent of 23 million electric vehicle journeys Belfast to Derry.

The lack of flexibility means that as well as periods of too much generation, the system also sees periods of insufficient generation. Over the 2020/21 winter, four Amber Alerts[5] were issued by SONI due to high energy demand at times of low wind availability. No consumer-side resources like Critical Peak Reduction tariffs[6] exist to allow consumers to contribute to (and be rewarded for) system management at such times of stress.

As well as heightened risk of supply shortages, the failure to develop a full suite of flexible resources has driven increased capacity payments for fossil generators. Current system planning rules mean that the absence of the North-South Interconnector acts as a multiplier for the value of new fossil generation in capacity auctions. As a result, EP Power Europe will receive £647 million between 2023 and 2035 for the provision of 330 MW of gas capacity. This equates to a capacity payment rate of over £178k per MW over 11 years. For comparison, the most recent GB Capacity Auction for 2024/25 settled at £18k per MW[7]. While the total cost will be spread across all SEM consumers, around a quarter (c. £160 million) will be borne solely by consumers in NI.

Overall, there is a serious mismatch between variability and flexibility in the NI power system. NI has a highly distributed and variable energy supply, managed by highly centralised and relatively inflexible resources. The lack of market access for consumer resources results in the waste of clean local energy and the over-procurement of and over-reliance on investor-owned fossil capacity.

Northern Ireland urgently needs to empower consumers and to develop its untapped energy resource - flexible demand. The following recommendations are made to address these challenges:

- **Establish flexible demand as an asset class**. Energy demand can have value, and energy demand at the right time and right place can have very significant value. Flexible demand should become an asset class, in the same way as renewable energy over a decade ago. Consumers, as the owners of this asset class, should be

[5] https://www.sem-o.com/documents/general-publications/BP_SO_09.2-Declaration-of-System-Alerts.pdf

[6] https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/The%20Value%20of%20TOU%20Tariffs%20in%20GB%20-%20Volume%20II.pdf

[7] https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/Capacity%20Market%20Auction%20T4%20DY2024-25%20Final%20Report.pdf

empowered to monetise the value of their resource by generating and owning data to make their assets investable, and by regulators and policy makers creating the conditions for a market with large numbers of participants and significant cash flow.

- **Design from the bottom up**. Smart Meter rollouts and the wider deployment of smart technologies have tended to follow the traditional 'top-down' approach to system design, focussing on system benefits and technology choices. The result has often been that consumers have been subjected to changes, rather than empowered by them. The first consideration in designing and deploying smart systems should therefore be to maximise the role of and benefits to the owners of flexible demand – business and domestic consumers.
- **Prioritise low-income households**. Tariffs and other incentives which rely on ownership of flexible technologies could become 'middle class subsidies', which create the risk of people who are not homeowners or have no access to capital being left behind. Initial markets should be designed to prioritise the social rented sector in general and vulnerable households in particular. As the NI social housing sector accounts for more than 120, 000 homes, this could rapidly bring deployment at scale. See Appendix I on the joint UU and NI Housing Executive RULET project.
- **Monetise the capacity value of energy efficiency** by allowing energy efficiency to compete against traditional fossil generation assets in auctions designed to ensure that future energy needs will be met. This creates a new category of grid asset by co-opting consumers into becoming a merchant generator of demand reductions or 'negawatts', reducing the need for fossil capacity. Such markets have already been established in the US, for example in PJM[8].
- **Consider the circular economy**. Economic analysis should consider the wider benefits of flexible demand to the NI economy. For example, current capacity market arrangements prioritise fossil generation over demand reduction, and will lead to significant monetary benefits for international investors. Alternatively, money invested in demand response products like Critical Peak Reduction incentives could be paid to NI consumers and remain in the local economy. Similarly, rather than simply ascribing wholesale market costs to constrained and curtailed wind energy, it should

[8] https://learn.pjm.com/three-priorities/buying-and-selling-energy/capacity-markets.aspx

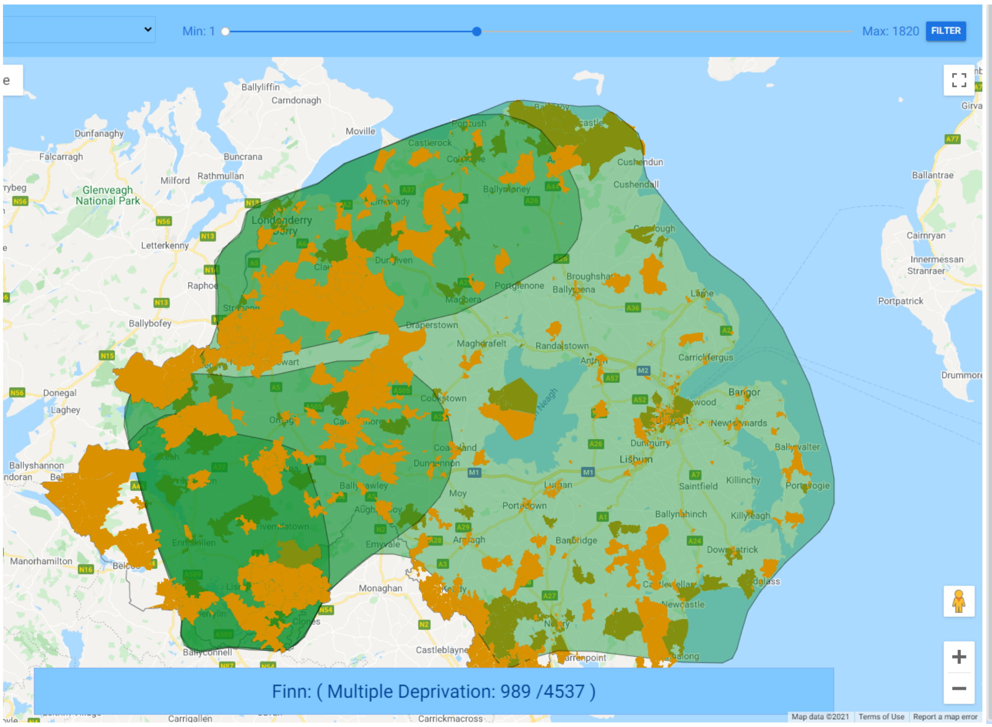
be valued in terms of the benefits that it would bring to the NI economy (in energy savings, reduced carbon emissions and fuel poverty, displacement of and less reliance on imported fossil fuels) if it were consumed locally, rather than dumped.

- **Exploit synergies (1).** As discussed above, the NI system is unique in terms of its highly distributed and highly variable nature, creating a need for intelligent systems to manage variability where it arises, at the local level. The 2013 Matrix report identified the potential for NI's internationally recognised IT industry to develop products and systems that could have global impact in the transition to smart energy systems[9]. A recent report identified Belfast and Cambridge as the UK's most tech-centric cities[10]. Research organisations cite a range of values for the global smart energy market but figures between $250 billion[11] and $500 billion[12] by mid-decade are common. The characteristics of the NI power system provide the perfect test bed for the development of new products and market offerings to exploit this synergy.
- **Exploit synergies (2).** NI has a relatively large public sector and associated estate. It also has a part-publicly owned water utility, which is by some distance the largest electricity consumer in NI, and which shares a regulator with the electricity network operator. Opportunities for the public sector (in particular water utilities and the health sector) to deploy flexibility at scale have improved system resilience, optimised joint investment and reduced costs for customers in California, Rhode Island and other US states[13]. NI should learn from successful implementation of cross-utility efficiency and flexibility elsewhere.
- **Invest in smart networks**. The electricity network is a crucial enabler for empowering consumers, with significant investment needed to accommodate increases in demand for low carbon technologies, such as electric vehicles and heat pumps, and to connect new sources of low-carbon generation. The changes required to the electricity distribution system means that the next distribution price control is of particular

[9] https://technation.io/insights/report-2018/belfast/
[10] https://technation.io/news/uk-tech-jobs-growth-data/?utm_content=139723469&utm_medium=social&utm_source=twitter&hss_channel=tw-279144084
[11] https://www.alliedmarketresearch.com/smart-energy-market-A09434
[12] https://www.technavio.com/report/smart-energy-market-industry-analysis
[13] https://www.jstor.org/stable/resrep17240?seq=1#metadata_info_tab_contents

importance, particularly for the establishment of flexibility markets and for the deployment of smart systems to maximise the utility of network assets.

- **Establish new ways of collecting, analysing and sharing data**. Data will be required to make flexibility markets investable and to optimise the utility of networks in the future. Policy makers and regulators should recognise and implement the Energy Data Task Force recommendations on the adoption of network digitalisation strategies, and establish licence conditions that promote the openness and interoperability of network data.
- **Recognise locational value**. There are some areas of NI where the potential for the deployment of smart consumer-led technologies is very high. Rural western areas see the highest levels of constrained wind and typically have higher levels of social need, including fuel poverty. Ulster University's Interreg-funded SPIRE 2 project has developed a Demand Flexibility map, an interactive tool designed to help develop an effective flexibility strategy and implementation pathway for Northern Ireland. The tool provides a whole energy system model, linking socio-demographic, housing, heating and transport data with known congestion and constraints on the electrical transmission and distribution systems. The tool currently has 12 map layers with over 110 sub-layers and contains features to assist with filtering and visualisation. It has various map views such as satellite, terrain and street view for a more detailed picture and geography tour. The map is in active development and updated frequently with new features. For illustration, in Figure 19 below the map shows in brown the 1,820 (of 4,537) most socially deprived areas of NI by small area postcode. The green overlays represent constraint groups, areas which see high levels of wind turn down due to network bottlenecks. Note that three constraint groups and higher levels of social deprivation are concentrated in the west and north west, suggesting that these areas have the highest potential for using currently wasted wind energy to address social need. More details on the flexibility map can be found in Appendix II.



The value of flexible demand made possible through the introduction of products like time-varying and peak reduction tariffs, and increased consumer empowerment leading to better-functioning retail markets, has been identified by BEIS as a key factor in its Smart Meter Policy Framework Post-2020. Smart metering infrastructure will play a central part in the UK's post-Covid recovery, "*As we emerge from the pandemic, innovative products and services that rely on smart metering, such as tariffs that reward consumers for using energy when cheap, renewable generation is available, will be more important than ever. Smart meters have a crucial role to play in our clean recovery, ensuring cost-effective progress towards our net zero commitment in the next five years and for generations to come*."[14]

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14 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/893124/delivering-smart-system-post-2020-govt-response-consultation.pdf

Contents

1. SMART ENERGY SYSTEMS AND FLEXIBLE DEMAND

Developed economies are transitioning from centralised, relatively inflexible, fossil-based energy systems to decentralised, flexible and decarbonised energy. Digitalisation is the key enabler of this move to smarter, cleaner and more resilient systems; intelligent metering devices to enable real-time visibility and control of demand is a necessary step in its development.

Historically, the primary source of variability in power systems came from demand, which rises and falls over predictable daily and seasonal cycles. Traditional fossil generation fleets were able to provide sufficiently flexible output to match generation with demand by switching units on and off, and ramping output up and down in line with well-understood patterns of energy consumption.

As variable renewable energy (VRE) resources like wind and solar power are connected to power systems however, they create additional variability which fossil generators are poorly equipped to manage. VRE creates variability in both the time and location of generation. The time at which generation occurs depends on environmental conditions (wind speed and solar radiation); it creates locational variability as wind and solar generators are highly distributed across the energy system and in Northern Ireland, unlike fossil generators, are almost entirely connected at distribution (rather than transmission) voltages.

As VRE connections rise, so the need for flexibility increases. As well as changing the output from fossil generators, additional flexibility can be provided by centrally controlled, investor-owned infrastructure like interconnectors (which can shift bulk energy between power systems) and large-scale storage assets like Pumped Hydro, Compressed Air Energy Storage and MW-scale Battery Energy Storage Systems (BESS)[15]. Developments in ancillary services such as the all-island DS3 Market have incentivised investment in resources to manage the system with high levels of VRE[16]. Capacity Markets have also created an opportunity for large industrial consumers to become Demand Side Units (DSU) rewarded for turning down demand during system peaks (often by switching to high emissions diesel back-up generators)[17].

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15 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

16 https://www.eirgridgroup.com/how-the-grid-works/ds3-programme/

17 https://www.sem-o.com/documents/legacy-modifications/MOD_30_09/DemandSideUnitsintheSEMV2.0(428KB).pdf

However, the emergence of new technologies like digital communications, Big Data, Artificial Intelligence and Machine Learning (collectively Digital Energy[18]) has created a new and potentially much more significant means of managing the variability of renewables; dispatchable domestic and business demand, which can complement output from VRE resources by either reducing or increasing consumption in line with availability. When enabled by smart energy technologies and appropriate market structures, domestic and business consumers can create value by flexing loads to help manage high levels of VRE, reducing the need for conventional investor-owned, supply-side solutions like fossil generating plant and network infrastructure.

The 2013 Matrix Report commissioned by DETI provided the following definition of smart energy systems which was not improved upon in an extensive review of the literature: "*Intelligent Energy Systems incorporate technologies that can measure, analyse, communicate and control the multi-directional flow of energy at a variety of scales. They exploit the symbiotic relationships between technologies, improving efficiency (matching supply and demand), and enabling a new set of stakeholders (including consumers) to become active participants in the energy market. Intelligent Energy Systems include electrical and heat distribution networks, remotely controllable loads, modern energy storage, power electronics technology and computerised control system management.*"[19]

By managing VRE with smart consumer demand the use of supply-side assets can be optimised, increasing their utility and deferring or averting the need for investment in generation and grid capacity. Not only does this put downward pressure on bills and open new value streams to consumers; it also creates the potential to create a positive link between customers and renewable resources, empowering them to become system actors, engaged with the transition to clean energy systems.

Globally, consumer power is driving the transition to smart, clean energy systems and disrupting established markets in the same way that mobile telephony disrupted telecommunications in the 1990s and early 2000s. This means increased complexity for regulators and policy makers, but creates the potential for greater consumer power, and a wider choice of new products and services which could benefit both individual citizens and the energy system as a whole.

[18] https://www.gov.uk/government/groups/energy-data-taskforce
[19] https://matrixni.org/documents/the-2013-sustainable-energy-report/

2. SMART METER TECHNOLOGY

Overview

In basic terms, a Smart Meter can be described as a combination of an electronic meter and a communications link. The electronic meter computes how much electricity, gas, water or heat is consumed and sends this information to network and utility companies, customer agents like aggregators, and other smart devices in real or near-real time.

Smart Meters make energy consumers aware of their consumption, and by managing what is consumed and when, can minimise costs, reduce greenhouse gas emissions and increase energy security by helping to reduce demand peaks. From a technical perspective, a Smart Meter can be considered as a monitoring and control system which provides near-instant feedback and response, potentially turning passive consumers into energy system participants.

Smart Meters may also be connected into a network of smart infrastructure, with the ability to collate and distribute data from many thousands of individual homes. When combined with smart technologies within distribution and transmission networks, these wider systems are referred to as Smart Grids.

Traditional domestic gas and electricity meters are simple electro-mechanical devices that use induction coils and a rotating disc to record the cumulative volume of energy consumed over time. The total is read manually at monthly or quarterly intervals, indicating how much energy has been consumed in the intervening period. This type of technology was developed in the 19th Century and could be described as a 'living relic' of the energy systems that existed before the emergence of digital communications. Electronic dumb meters based on Digital Micro Technology (DMT) have widely replaced the original 'coil and disc' meter in Northern Ireland but do not provide any additional functionality (some prepayment meters can record consumption at half-hourly intervals, but this capability has not so far been exploited).

As utility metering systems have evolved, more metering functionalities have been added, providing benefits for both consumers and providers. However, the paradigm shift created by the emergence of Smart Meters is a result of communications, and their ability to send and receive data in real time. The selection and design of appropriate communication networks and devices which must satisfy multiple overlapping and complex requirements is therefore a critical consideration in the deployment of smart energy infrastructure.

2.1. Communications

Advances in communication beyond dumb technologies for metering systems have in general proceeded in two stages:

- One-way communication. The first step away from dumb meters was to meters that could be read remotely (these were originally referred to as 'Advanced Meters' – although this term is now archaic). Also known as Automated or Remote Meter Reading (AMR or RMR), these meters monitor consumption at a given time resolution (typically 15 minutes) and transmit the information to a central location such as an energy supplier. Alternatively, the meter may store information and transmit it in weekly or monthly batches. Limited numbers of advanced meters were deployed in the first decade of the 21st Century in countries which were early adopters of smart technology.
- Two-way communication. The next advance was to two-way communication through Advanced Metering Infrastructure (AMI). AMI allows energy suppliers or other actors (such as aggregators) to send information or instructions back to the Smart Meter. This may achieve several things:
    a. The provision of information to consumers, such as the current energy price in time-varying tariffs.
    b. It can allow the remote disconnect of customers, for example if they wish to end a contract, switch supplier or where the supplier disconnects customers who have failed to pay bills.
    c. It may facilitate remote load control, to enable appliances in the house to be turned on or off, for example through connection to smart thermostats, heating, power storage devices, electric vehicles or other control devices (such as Home Energy Management Systems).
    d. It enables the transmission of firmware upgrades to the device.

2.2. Communications Technologies

Smart Meter systems use a range of both wired and wireless technologies for short- and long-range communications. In any single system, several communications technologies are typically used to transmit data from Smart Meters to control systems and retailers.

In general, the structure of modern end-to-end communications systems can be broken down into three main areas.

- Area 1: Home Area Network (HAN). Smart Meters link to devices within the customer premises (such as In-home displays, or Home Energy Management Systems controlling electric heating systems, EVs, etc) using short-range technologies. From these devices, the network needs data on consumption behaviour and energy usage. In order to provide it without significantly increasing energy consumption, low-energy communication technologies are required.
- Area 2: Neighbourhood Area Network (NAN). A local communications network link sends information from SMART METERs to a Head End System (HES) through a local data concentrator.
- Area 3: Wide Area Network (WAN). An operational management system connects the HES to a control centre or Meter Data Management System (MDMS), which in turn links to energy retailers.

One logical technology for Smart Meters is **Powerline Communication (PLC)**. This is a wired technology that makes use of existing power lines for transmission of data. Even though power lines are sometimes ‘noisy’ (which can create communication difficulties) they provide universal connection with electricity consumers, potentially reducing installation costs. PLC technologies can be categorised as Broadband PLC and Narrowband PLC. Narrowband systems can be used for outdoor and indoor control and telemetry of devices, switches, and meters over a narrow frequency band at a relatively low bit rate. NB-PLC is often used to link Smart Meters and data concentrators and are already used to create Home Area Networks (HANs) with data rates of around 20 kbps. BB-PLC devices have a much higher bit rate of hundreds of Mbit/s and have been used to connect HES, Smart Meters and devices in the customer’s home.

As well as PLC, **Cellular Networks** can also provide wide coverage with high rates of data transfer. Cellular networks can be used to connect Smart Meter, in-home devices, distant nodes, and other Smart Grid elements. Existing 4G networks can provide up to 100 Mbps downlink connections, while future 5G networks are expected to be capable of delivering up to 1 Gbps for entire urban areas. 5G is currently being assessed for its potential to support Wireless Area Networks for Smart Grids.

Digital Subscriber Line (DSL)/Optical Fibre are 'wired' broadband technologies that allow high-speed data transmission over the voice telephony network or optical fibres. Conventional DSL is a reliable and low-cost option as (like CPL) it makes use of existing infrastructure. A significant disadvantage however is that it is affected by the distance between the customer premises and the local communications exchange. This problem is overcome when conventional wired connections are replaced with fibre optics. Both DSL and fibre optics can be used to integrate smart grid elements in Home Area Networks and Wide Area Networks, offering advantages for power providers and customers due to its relatively low cost, high bandwidth and relative ubiquity in Northern Ireland.

Low Power Wide Area Networks (LPWAN) are used for Internet of Things (IoT[20]) technologies. LPWAN requires relatively little power to efficiently transmit information over long distances at comparatively low data rates (up to 50 kbps). An example is the Northern Ireland Low Power Wide Area Network[21] (LPWAN-NI) which uses LoRaWAN technology to offer a low power, wireless, wide-area, network for development of IoT services. LPWAN-NI enables commercial organisations and researchers to develop IoT solutions that can communicate with disparate devices and services across large geographic areas while using the least amount of energy possible.

Within the home **Wi-Fi** can be used for short-range communication, up to about 250 m, but is relatively power-hungry. Wi-Fi can operate on the 2.4 or 5 GHz frequency bands, featuring data rates of up to 600 Mbps. In NI Wi-Fi is commonly used for in home DSL/Optical Fibre internet access distribution.

Another short-range (c.10m) communication technology is **Bluetooth**, which is both a low-cost and low-consumption wireless communication technology commonly used in HANs. It uses the 2.45 GHz frequency range and provides a bandwidth of up to 3 Mbps. Bluetooth is installed on most smartphones and can be used for wireless local access for Smart Meters and other Smart Grid components.

Finally, **Zigbee** is another low-cost, low-consumption wireless technology, with a range of about 100m. As well as Smart Meter communication, Zigbee can be used to control home-appliances like smart lighting. It can operate on the 868 MHz, 915 MHz, or 2.4 GHz ranges, with data rates

[20] https://www.digicatapult.org.uk/for-startups/other-programmes/things-connected
[21] https://lpwan.ulster.ac.uk/

ranging from 20 to 250 kbps. There are some variations of ZigBee, such as ZigBee Smart Energy Profile (SEP) and Z-Wave. Wireless mesh networks can be created by turning each network node into a wireless router, extending the operating range.

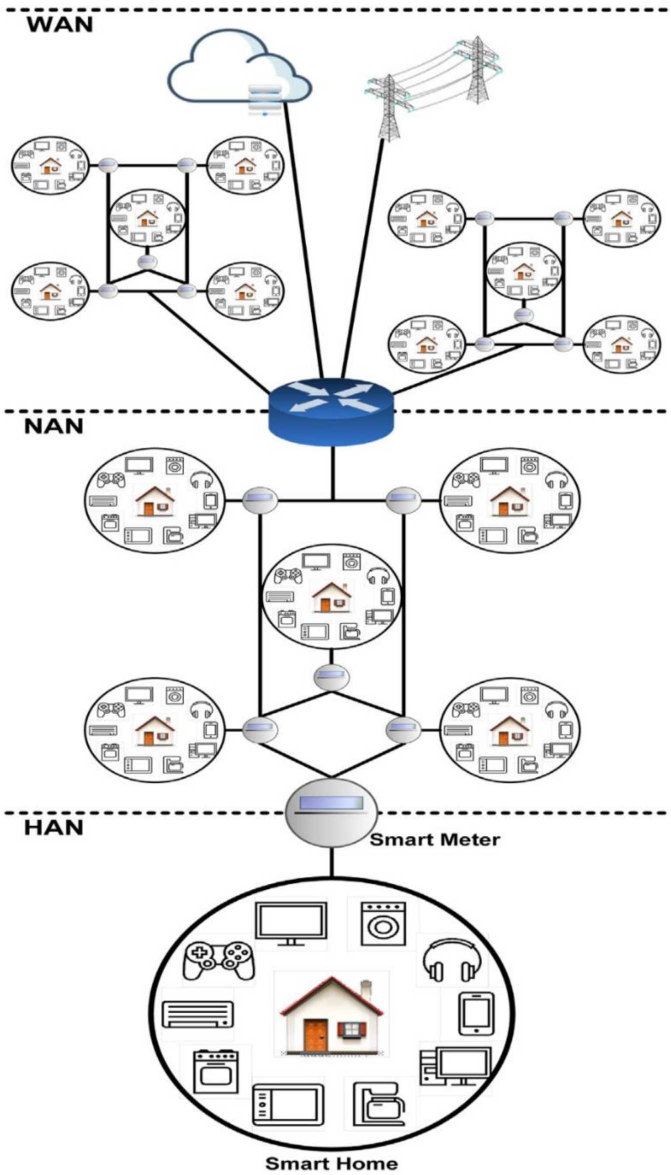

Figure 1: Schematic of Communications arrangement: Home Area Network; Neighbourhood Area Network; Wide Area Network (Avancini et al, 2019)[22]

2.3. Data

Smart Meter systems involve a huge amount of data transfer between utilities, consumers and smart home appliances. Such data is sensitive and must meet security guidelines which have been

[22] https://www.sciencedirect.com/science/article/abs/pii/S0959652619302501?via%3Dihub

formulated for its transmission, collection, storage and maintenance. Data must also be precise and complete, accurately reflecting exact information regarding energy consumption by the customer and status of the grids without being exposed to miscalculation or manipulation.

In general terms, Advance Metering Infrastructure (AMI) is composed of smart meters, concentrators or collectors and some form of Meter Data Management System (MDMS). Smart Meters also store information such as keys and passwords locally. An MDMS is basically a database which stores a huge amount of data linked to Smart Meters and concentrators.

AMI also supports communication between the energy supplier and the Smart Meter so that it can react to remote commands. Due to the sensitivity of exchanged information, deploying AMI brings significant data privacy implications. For example, some studies have demonstrated the potential for power consumption patterns to reveal detailed information about householders (number of family members at home, sleeping routines, eating routines, etc). Potential misuse has created a need for privacy measures such as anonymising data or reducing the amount of data required for some applications.

Consumer privacy is not the only concern. Like any other device connected to an extensive network, electrical devices in smart grids are vulnerable to attack. Smart grids are considered critical infrastructure and consequently detecting and preventing attacks is a high priority.

In April 2019, the European Commission published Recommendation 2019/553 with respect to information security in the energy sector[23]. The recommendation urges the implementation of new strategies to avoid malicious attacks that could cause severe consequences and recommends that every device connected to the Smart Grid is properly secured.

In this context, Information Security Management Systems (ISMS) become essential. ISMS implement measures aimed at preventing unauthorised access to information and minimising its misuse in the event of fraudulent access. ISMSs are designed to provide the three pillars of security, known as CIA: Confidentiality, Integrity and Availability. Confidentiality ensures that information is accessed only by authorised agents. Integrity ensures that information cannot be inappropriately altered. Availability ensures that the information carrier guarantees access to the data for authorised use. ISMs should also adhere to the requirement of non-repudiation or accountability, which means that an approved action (communication, exchange of data, reading, etc.) cannot be denied.

[23] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32019H0553&from=EN

UK Energy Data Task Force

The UK Energy Data Task Force (EDTF[24]) was established to provide stakeholders with a set of recommendations on how data can assist with unlocking the opportunities provided by a modern, decarbonised and decentralised Energy System, in line with the Industrial Strategy, Clean Growth Strategy, and the Smart Systems and Flexibility Plan[25]. It also aligned with programmes and initiatives being undertaken across the sector including the range of 'Prospering from the Energy Revolution' projects. In all these strategies and ambitions, data is recognised as crucial to building a smart, decentralised system that supports decarbonisation and creates opportunities for innovation and economic growth.

The EDTF's aim was "*to provide a set of recommendations that will support the delivery of a Modern, Digitalised Energy System unlocking the benefits of decarbonisation and decentralisation through better use of data*".

The EDTF identified challenges around the current fragmented and imbalanced arrangements for data, in which incumbents often have disproportionate control and influence over how value can be realised. Undue risk aversion among regulators and policy makers tends to favour the traditional centralised 'command and control' structure rather than more collaborative (or democratic), smart, data-driven solutions.

The report warned of the risks of the current outdated arrangements; a slower, more expensive energy transition, system inefficiency, the danger of system instability without real-time asset visibility, the stifling of innovation and enterprise, and the monopolisation of value by incumbent organisations. It also highlighted the problem of inertia and reluctance to implement change among governing bodies due to inappropriate concerns over data security.

The EDTF recognised the opportunities that decentralised, cross-vectoral smart technologies for heat, mobility and home services can deliver to create a consumer-centric system and made the following recommendations:

[24] https://es.catapult.org.uk/news/energy-data-taskforce-report/
[25] https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan

- Government and Regulators to direct the **Digitalisation of the Energy System**
- **Maximise the Value of Data** through adoption of the **Presumed Open** principle; that data should be *'Discoverable, Searchable, Understandable', with common 'Structures, Interfaces and Standards' and 'Secure and Resilient'.*
- Establishment **Data Visibility** and a **Data Catalogue** to drive standardisation across government, regulators and industry
- An **Asset Registration Strategy** to co-ordinate and simplify registration of assets and improve consumer experience
- Develop a unified **Energy System Digital System Map** to drive investment and creation of new markets

The EDTF completed its work in 2019. The UK Government is working collaboratively with Ofgem, Innovate UK and other industry stakeholders to implement the vision described in the EDTF report through the Modernising Energy Data programme[26].

2.4. Functionality

Economic assessments carried out by countries that have embarked on or completed Smart Meter deployments cover a wide array of benefits ranging from savings for suppliers from reduced home visits for meter readings, to behavioural change as consumers reduce their demand or shift load to cheaper periods in response to price signals. Many Cost Benefit Analyses (CBA) have found that both gas and electricity smart meters are cost-effective due to the 'passive' benefits they are likely to yield; for example reduced energy consumption through improved customer awareness, remote meter reading instead of home visits, better information for distribution and transmission system operators yielding savings on grid costs, savings for energy suppliers from a diminished requirement for call centre capacity and lower complaint costs resulting from errors with bill readings.

However, there are benefits that are solely associated with electricity smart meters that are more 'active' in nature. These reflect the lower value of demand-side flexibility in gas networks due to supply-side flexibility leveraged through latent pipeline storage capacity (linepack). Because power systems have to be managed at much higher time resolution than gas grids, and because electricity storage is relatively expensive, flexible demand for electricity has a much higher value than that for gas. Where additional variability from high levels of wind and solar generation compounds variability

[26] https://www.gov.uk/government/groups/modernising-energy-data

from consumption (as in the Northern Ireland system), Electricity Smart Meters act as a multiplier for this value by enabling the integration (as opposed to simply the connection) of these resources. Electricity Smart Meters can also enable Distribution System Operators (DSOs) to manage network events in real-time by communicating locational values for voltage, phase angle and frequency. The value of Electricity Smart Meters and flexible demand in power systems increases in line with the connection of additional renewable energy capacity.

The EU defined common minimal functionalities for electricity smart meters in its Recommendations for Smart Meter Rollouts [27] (see also Section 4 below) which are:

1. Provide readings directly to consumer and/or any authorised 3rd party
2. Upgrade readings frequently enough to use energy saving schemes
3. Allow remote reading by the operator
4. Provide 2-way communication for maintenance and control
5. Allow frequent enough readings for network planning
6. Support advanced tariff systems
7. Remote ON/OFF control of the supply and or flow or power limitation
8. Provide secure data communications
9. Fraud prevention and detection
10. Provide import/export and reactive metering

Electricity Smart Meters can help DSOs to react to and manage network faults, improving network security and reliability. This capability enables smart protection, which in turn improves network resilience, makes faults more predictable, allows the identification and precise isolation of unrecoverable faults (minimising the number of affected customers) and ultimately reduces costs.

However, in order to achieve such benefits, high resolution data about network condition must be available in real (or near-real) time for effective prevention and recovery. This requires live locational data on local amplitudes of voltages and currents, thermal variations, as well transient and steady state parameters. Such data can be collated by phasor measurement units, Electricity Smart Meters and other sensors working together to take action to prevent faults when possible or to allow timely and geographically contained response when required.

[27] https://op.europa.eu/en/publication-detail/-/publication/a5daa8c6-8f11-4e5e-9634-3f224af571a6/language-en

However, beyond benefits to energy suppliers and DSOs, automated or direct human engagement with Smart Meter data can deliver opportunities for significant changes in retail markets and enables new propositions for alternative business models to those currently available in Northern Ireland.

Bidirectional communication allows Smart Meters not only to send data measurements, but also to receive instructions. This allows users and providers to manage consumption, providing flexibility to the power system. Smart in-home controls can alert consumers or automatically reduce the use of home appliances such as heating and air-conditioning systems, washing machines, dishwashers and tumble dryers at peak demand times, when demand and prices are high, turning them on again when demand is low or when VRE is available.

When combined with energy storage such as hot water buffers and other storage devices, peak loads can be reduced without any impact on the provision of service or levels of customer comfort. Using the thermal inertia of buildings themselves to store heat can help to reduce network congestion and system stress during peak demand periods (reducing energy consumption during peak periods is known as peak clipping; increasing consumption during low demand periods is called valley filling; collectively known as load shifting).

Smart Meter functionality continues to expand to the point where metering systems can now integrate so many new functions that they are nearly unrecognisable when compared to their conventional analogue predecessors. Many home appliances are now manufactured with default smart capabilities, expanding the role that households and businesses can play and changing the way that Smart Meters are produced and deployed. This includes monetising new sources of system value, including:

- Domestic and business consumer-generated value, created by shaping demand to increase security of supply by minimising fossil peaking capacity requirements, reducing network congestion and maximising uptake of renewable energy. This is enabled by the integration of new technologies in homes, such as heat pumps and thermal and battery storage systems.
- Within this value stream, burgeoning demand for EVs and the delivery of services to this emerging market has repeatedly been identified as a key driver in the market-wide penetration of new services based on Smart Meter data.
- Realising value from flexibility in consumers' use of energy, for example enabling households with solar generation and storage to benefit from responding to price signals on when to use electricity from the grid, when to use energy generated onsite and when to provide power to the grid

- Facilitating remote monitoring services on household behaviour and routines, for example to support carers in the delivery of assisted living services

Additional applications and functions which can be leveraged through Smart Meters include:

In-home Displays

In addition to the Smart Meter itself, most systems can be connected to an in-home display (IHD). IHDs allow consumers to monitor their energy use in real time. When combined with price information, which may be set in advance (as part of a time of use [ToU] tariff, for example) or which updates in real time (through a dynamic or 'agile' tariff), consumers are able to see the cost of their energy consumption in real time. In addition to displaying real time information, many in-home displays allow consumers to see stored data and compare their consumption and expenditure on energy over periods of time.

Interface with price comparison websites and other services

Energy data from Smart Meters can be integrated into other services, for example by supplier or network company websites that allow customers to view their energy consumption through a web portal. These web applications allow customers to download spreadsheet records of their energy use over periods of time, which can be uploaded to price comparison websites to allow consumers to select more competitive tariffs, based on their typical consumption patterns.

Non-energy applications.

Smart Meters can perform other important health and social care functions, for example monitoring how elderly or vulnerable people are using home appliances and other devices in order to detect unusual activity or inactivity before they become critical. They can also be linked with home security systems to control access, activate cameras, notify homeowners of unusual activity, etc.

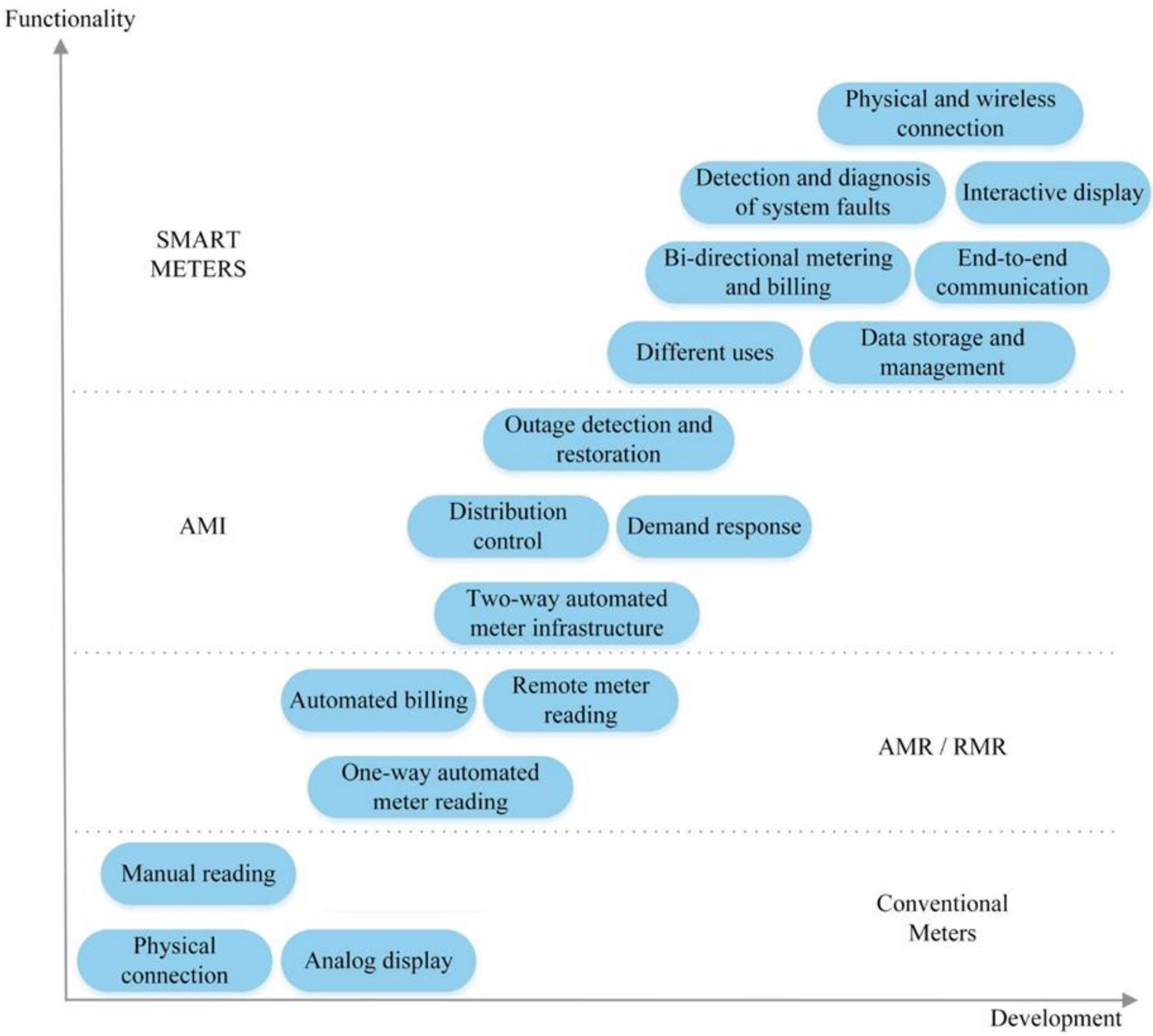

Figure 2. Evolution of Smart Meter Functionality([22])

3. SMART METER DEPLOYMENT

Smart Meters of varying types have been rolled-out in a number of jurisdictions around the world, in Europe and the USA in particular. These have primarily been Electricity Smart Meters, although Gas Smart Meters have also been deployed in some countries. Smart Meters have been rolled out for a range of reasons. Many countries have been motivated by environmental issues due to the potential for reducing energy consumption and for developing new market offerings to integrate renewable energy. Other drivers are the elimination of the substantial costs of manual meter reading, to be better able to cope with system stress during peak demand periods and preventing fraud and energy theft.

Early rollouts involved less sophisticated meters, for example with one-way rather than two-way communication, or without in-home displays. Later rollouts have two-way communication and in-home displays; more recent rollouts have integrated connections with web-portals, smartphone apps and other online methods for monitoring and reacting to energy availability and price fluctuations.

The following sections examine deployment in the United States and Europe, and include a summary of deployment in an early adopter in each, California and Italy.

3.1. Smart Meters in the United States

The U.S. government's 2007 Energy Independence and Security Act codified policy for modernising the nation's electricity transmission and distribution systems, after which rollouts began in individual states. The Energy Information Administration (EIA) and the Federal Energy Regulatory Commission (FERC) estimated that by December 2018, around 87 million Electricity Smart Meters had been installed, representing a national penetration rate of 57% (of 154.1 million meters in total)[28]. There were however marked differences in penetration across the country, ranging from 12% in the Northeast Power Coordinating Council region to 93% in Texas.

[28] https://cms.ferc.gov/sites/default/files/2020-12/2020%20Assessment%20of%20Demand%20Response%20and%20Advanced%20Metering_December%202020.pdf

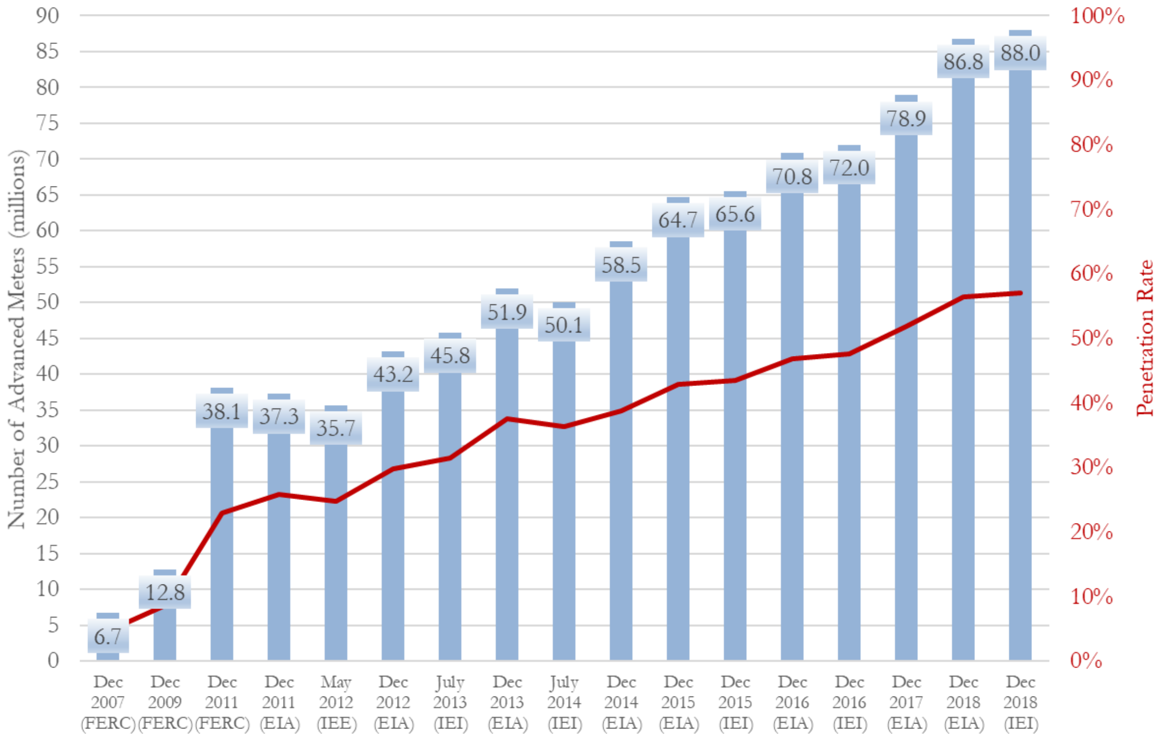

Figure 3. Penetration rate of Smart Meters in the US 2007-2018 (88 million Smart Meters; 57% penetration) [29]

In tandem with the rollout of Smart Meters, FERC has promoted the use of demand response as a means of improving system efficiency by reducing the need for generation capacity. Some US states have achieved considerable success in mitigating peak demand and system emergencies through demand response programs. Over the last decade, the original utility schemes developed for providing load reductions during system emergencies have evolved into more sophisticated programmes capable of providing a wide range of market offerings and targeted services.

Along with the static ToU tariffs which are available by default with most Smart Meter deployments, more than 9.2 million US customers were enrolled in dynamic pricing programmes in 2018; and more than 9.7 million were engaged in demand response programmes. Dynamic tariffs, designed to integrate distributed energy resources like wind and solar power, have been developed by sculpting specific rates for electric vehicles and heating systems owned by residential customers to track the

[29] https://cms.ferc.gov/sites/default/files/2020-12/2020%20Assessment%20of%20Demand%20Response%20and%20Advanced%20Metering_December%202020.pdf

availability of renewable energy. Demand response has transitioned from simply a means for shaving peak demand into a valuable and flexible tool for system management.

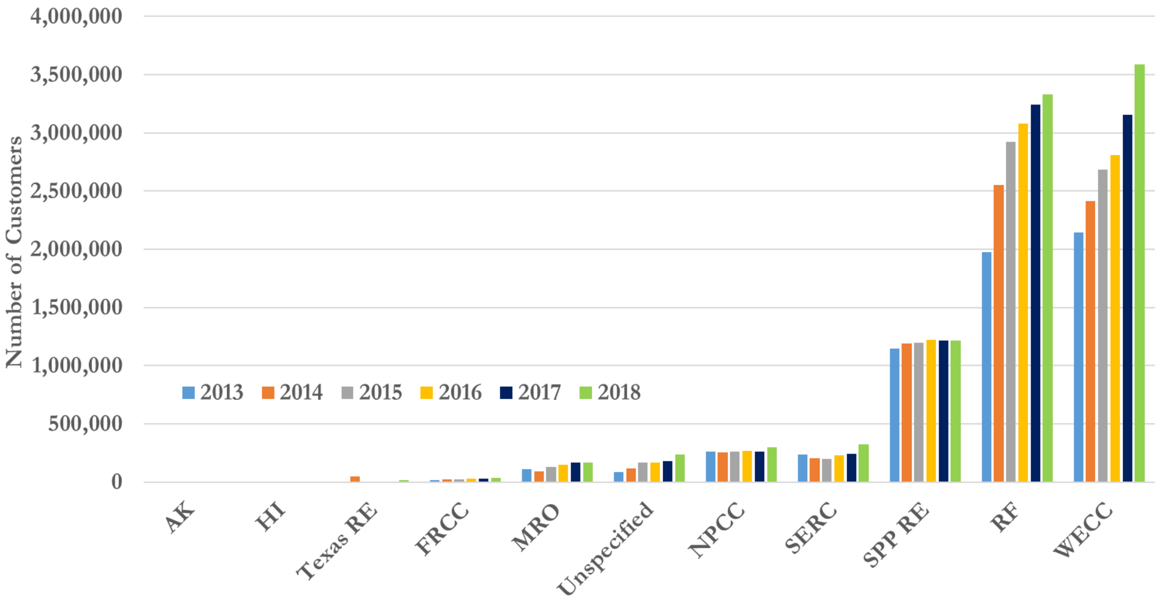

Figure 4. US Customers engaged in retail dynamic pricing programmes in 2018 (9.2 million) [Florida Reliability Coordinating Council (FRCC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), Reliability First (RF), South Eastern Reliability Corporation (SERC), Southwest Power Pool Regional Entity (SPPRE), Texas Reliability Entity (Texas RE), and Western Electricity Coordinating Council (WECC)]

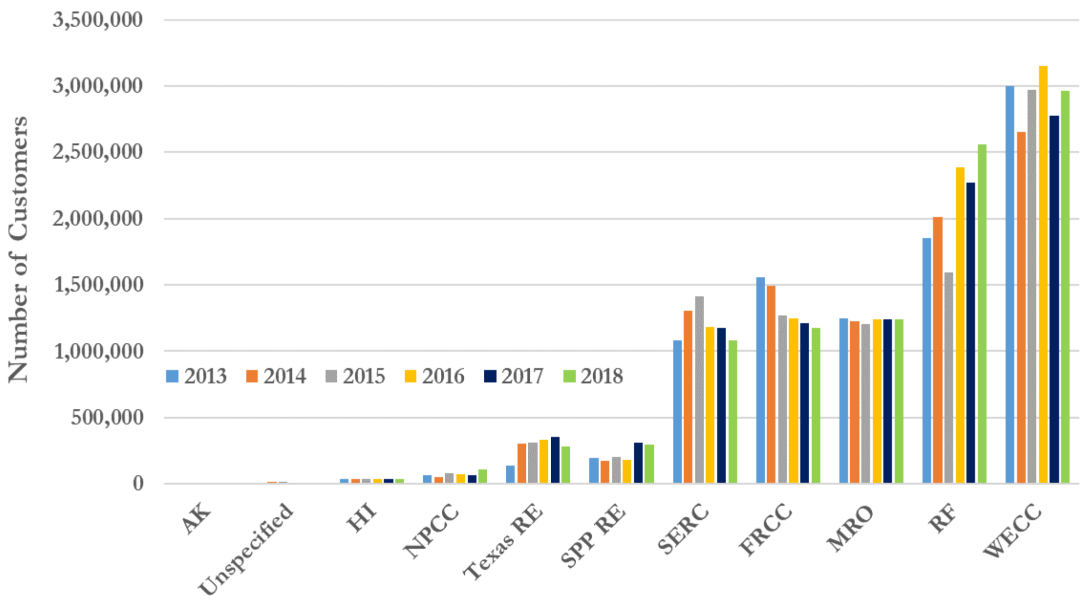

Figure 5. US Customers engaged in Demand Response programmes in 2018 (9.8 million)

3.2. Early adopters – California

Electricity in California is predominantly distributed and supplied to customers by three large investor-owned utilities, the Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE Corp) and San Diego Gas & Electric (SDG&E). There is no retail competition and prices are set by the regulator, the California Public Utilities Commission (CPUC). In the early 2000s, the utilities each submitted business cases to the CPUC for smart meter rollouts, which were approved and largely complete by 2011.

The key motivations for California's Smart Meter rollout were to increase system security by creating retail products that could help to reduce peak demand and to cut costs associated with manual meter readings. California has a longstanding issue with high electricity demand for air conditioning during summer months.

While tariffs were successful in achieving peak reductions, uptake was limited because in CPUC's judgement, utilities did not encourage customers to move to these products. In 2015 CPUC mandated that from 2019 all customers were to be moved to ToU products on an opt-out basis. This has made a significant contribution to system security, providing c. 3 GW of demand response in peak times, around 6% of a peak load of 50 GW. As well as retail products, aggregators are now able to use app-enabled products which allow customers to be paid for reducing demand during grid stress events.

3.3. Smart Meters in Europe

The European Commission, as part of the liberalization of energy markets and the development of an Internal Market for Energy, has promoted the uptake of smart metering systems as an effective tool to increase transparency and competition in retail markets for electricity, to support self-generation and the integration of DERs, demand side flexibility and storage.

Significant EU Policy developments since 2006 are listed below.

2006 Energy End Use Efficiency Directive

Early EU policy drivers for the development of demand-side solutions, including the roll out of smart meters, can be found in the 2006 Directive on Energy End Use Efficiency[30]. Article 7 states, "*The aim of this Directive is not only to continue to promote the supply side of energy services, but also to create stronger incentives for the demand side*."

However, instead of mandating the deployment of smart meters or smart grid measures, the directive requested (rather than required) that competitively priced individual meters, capable of providing information on time of use, should be provided for consumers of electricity, natural gas, district heating and/or cooling and domestic hot water, where it was "*technically possible, financially reasonable and proportionate*".

Internal Market for Energy 2009 (IME3 – The Third Energy Package)

Following this indication of the direction of travel, the roll out of smart meters in the EU was mandated in the 2009 directives for electricity[31] and gas[32] in the Commission's Third Package for energy market liberalisation, which came into force on 3 September 2009.

IME3 was a landmark in the liberalisation of European energy markets which led to the unbundling of formerly vertically integrated power utilities across Member States in order to stimulate competitive markets and to remove conflicts of interests between incumbent generators, suppliers and Transmission System Operators (TSO).

While much of the focus was on creating conditions for competition in wholesale and retail markets for generators and suppliers, IME3 also "….*charted out the vision of integrated infrastructure management which will allow the markets for electricity and gas to evolve further, in particular to allow the uptake of renewable energy, also produced at micro level, in order to increase security of the networks, create opportunities for energy saving and energy efficiency and give a more active role to energy consumers in a liberalised energy market*."

As well as creating the potential for a smarter, more flexible grid, the rollout of smart meters was intended to improve consumers' understanding and awareness of their energy consumption, and to allow them to take advantage of time-varying electricity prices.

[30] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006L0032&from=EN
[31] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009L0072&from=en
[32] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009L0073&from=EN

IME3 identified several barriers to citizens' ability to participate in and be rewarded for providing demand-side flexibility including:

- access to suitable tariffs
- an outdated, supply-side approach to system management
- a lack of information on real time prices.

As part of the development of a more active role for consumers, Article 3 of the Electricity Directive encouraged the deployment of smart grids and smart meters in member states where economic assessment indicated that consumers would be 'positively affected'.

Annex 1 of the Electricity Directive provided guidance on the economic assessment of the long-term costs and benefits of intelligent metering systems, which had to be completed by 3rd September 2012. Annex 1 also states; "*Member States shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market.*"

In the case of electricity, Annex 1 states; "*Where roll-out of smart meters is assessed positively, at least 80 % of consumers shall be equipped with intelligent metering systems by 2020.*"

While Annexes to both directives allowed member states to forego implementation if economic analysis found that it was not cost effective for specific consumer groups, the directives made clear that the expected outcome was a high level of roll-out of electricity smart meters across member states by 2020, particularly in those where there was a strong economic case to do so (the Gas Directive also mandated an economic assessment by the same date but made no order regarding the timetable for roll out).

Recommendations and Guidance (2012/148/EU)

While the directives in IME3 set targets for the roll out of smart electricity and gas meters, they gave no guidance as to how this was to be achieved, nor a definition of smart metering systems, or the minimum functionalities required.

National smart meter rollouts are complex undertakings, requiring co-ordinated action across a range of private and public organisations, and significant investment of public money. If poorly managed, they have the potential to create serious negative impacts for consumers (see Section 3.4 Smart Meter Rollout in GB below).

To address these issues and in order to set minimum standards, in 2012 the EU published Recommendations on Preparation for Smart Meter Rollouts[33].

These included common minimal functionalities for electricity smart meters concerning frequency/time resolution of meter readings, two-way communication for maintenance and control, the ability to support advanced/dynamic tariffs, to allow remote control of power and/or power flow limitation and provide data export/import facilities.

The Recommendations defined 10 common minimum functionalities for smart metering systems, mainly applicable for electricity, which are relevant for different market actors (see Section 2.4 above).

The Recommendations defined a smart metering system as, "*an electronic system that can measure energy consumption, adding more information than a conventional meter, and that can transmit and receive data using a form of electronic communication*"; and also provided an approved methodology for the economic assessment (Cost Benefit Analysis) of the deployment of smart meters in Member States to meet the requirements of the 2009 Electricity and Gas Directives.

Energy Efficiency Directive 2012/27/EU

As well as the requirements of IME 3, and the recommendations in JRC 2012, Article 9 of the Energy Efficiency Directive[34] re-emphasises obligations on Member States to deliver data security and to ensure that the "*objectives of energy efficiency and benefits for final household consumers are fully considered when establishing the minimum functionalities of smart meters and the obligations imposed on market participants*".

Technical Standards 2014/32/EU

In addition to the provisions set out in energy-specific directives, measuring instruments (including smart meters) need to comply with directive (Measuring Instruments Directive[35] - MID) which harmonises legislation across member states on common standards that must be satisfied.

Regulation (EU) No 1025/201234 on European standardization designates the International Organisation for Standardisation (ISO), the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU) as legitimate bodies to adopt international standards.

[33] https://op.europa.eu/en/publication-detail/-/publication/a5daa8c6-8f11-4e5e-9634-3f224af571a6/language-en
[34] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012L0027&from=EN
[35] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014L0032&from=EN

It also designates the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC) and the European Telecommunications Standards Institute (ETSI) as legitimate bodies to adopt EU-wide standards.

The MID applies to ten different type of measuring devices, including electricity and gas meters.

Electric Vehicles 2014/94/EU

Smart electricity meters are also affected by Directive 2014/94/EU (Deployment of Alternative Fuels Infrastructures) as it makes provisions for intelligent metering systems for the public charging of electric vehicles (EVs). The provisions are intended to enable EVs to provide system flexibility by charging at times of low demand, and eventually to discharge power back to the grid at times of low demand (known as vehicle-to-grid, or V2G, charging and discharging).

Clean Energy for All Europeans/Recast Electricity Directive

The European Commission made the transition to smart, decentralised energy a core objective of the 2016 Clean Energy Package (CEP). This led to the 2019 Recast Electricity Directive (2019/944/EU), which updated rules for generation, transmission, distribution, storage and supply of electricity. The Recast Directive updates existing provisions relating to smart meters and their use as a tool to provide consumers with a role in electricity markets by delivering demand side management and system flexibility. Articles in the directive establish a level playing field for both supply-side and demand-side measures in power systems, as well as requirements for cost-reflective tariffs, data protection and consumer outcomes and entitlements. The burgeoning digital economy and emergence of data as an economic and strategic asset has created the need for citizens' personal data to be protected. However, the collection, processing and management of non-personal data from smart meters needs to be managed such that system value can be created and monetised.

The Recast Electricity Directive is of particular relevance to Northern Ireland as it will still be implemented to allow the SEM to function following Brexit. The Recast Directive includes the following Articles that consolidate the central role of smart metering and flexible demand in delivering decarbonisation and system flexibility.

- Article 17 – establishing a level playing field for aggregated demand response in wholesale markets
- Article 19 – cost-reflective network tariffs; consumer outcomes/benefits; periodic CBA updates at least every 4 years in case of negative CBA
- Article 20 – Data Protection and Security; ensuring competition in retail markets

- Article 21 – consumers' entitlement to smart meters

The Recast Electricity Directive reiterates the requirement of the 2009 Directive that in the case of a positive CBA, at least 80% of customers will have smart meters within 7 years of the CBA or by 2024 (for states which commenced roll out before July 2019).

3.4. Deployment of Smart Meters in Europe

Electricity Smart Meters. By the end of 2018 six Member States had achieved an 80% (or higher) roll out of smart electricity meters (Estonia, Finland, Italy, Malta, Spain and Sweden). Denmark and Luxembourg had attained a penetration of just under 80% and were both on track to reach close to 100% by the end of 2020. Eight Member States will therefore have met or surpassed the IME 3 target for 80% penetration by the end of 2020 (Finland and Sweden will have attained a 100% rollout; Estonia, Italy and Spain will have attained over 90%).

France, Latvia, the Netherlands and Portugal expect to reach targets of at least 80% penetration by 2023. Austria, Belgium, Cyprus, Germany, Greece, Ireland, Slovakia and UK-GB are expected to reach the 80% target by 2024 or shortly after. Germany's roll out has been slower as the German government adopted a more complex programme by including an obligation to install meters which could communicate with smart meter gateways, providing early access to market products as soon as they became available.

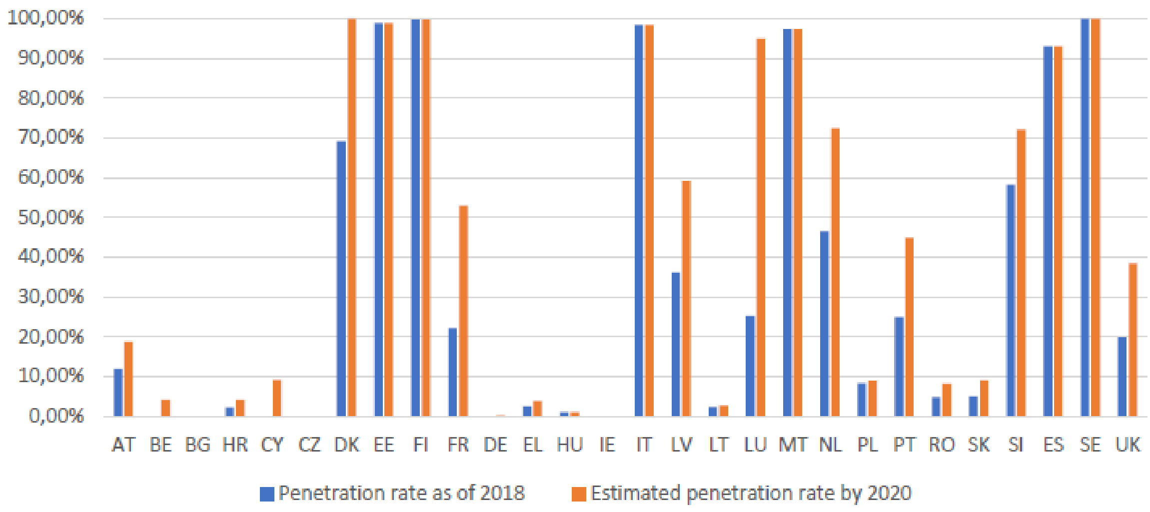

Figure 6. Smart Electricity Meter Penetration in the EU[36]

[36]https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1/language-en

The EU estimates that approximately 123 million Electricity Smart Meters had been deployed across Europe by the end of 2020, corresponding to a penetration level of 43%. This is significantly lower than the 72% target in the 2014 benchmarking report.

The EU now assesses that by the end of 2024, 223 million Electricity Smart Meters will have been deployed, equivalent to 77% penetration – close to the original 80% target for 2020. That figure is expected to rise to 266 million (92% penetration) by 2030.

Gas Smart Meters. Unlike the Electricity Directive, the Gas Directive did not specify a target date for the completion of the roll out of gas meters. While around 25% of Member States have conducted CBAs and begun the roll out, these are in general still at an early stage in comparison to Electricity Smart Meters. There is also a much lower total number of gas meters when compared to electricity meters (about 29%), and gas is not available in all Member States.

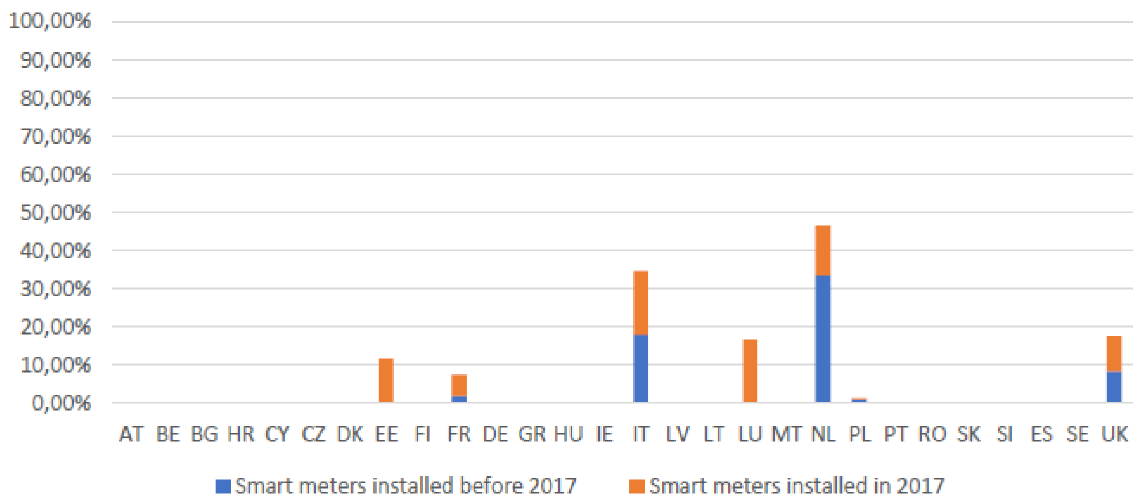

Figure 7. Smart Gas Meter Penetration in the EU[36]

3.5. Early adopters - Italy

Italy is the European leader in Smart Meter deployment, as it was the first EU country to introduce a large-scale rollout of electricity smart meters (ESM) for domestic and small business customers, and currently has over 35 million Electricity Smart Meters in operation. The deployment programme for low voltage customers began in 2000, when Enel Distribuzione (the national DSO that distributes electricity to around 85% of Italian customers) electively began a national rollout, ahead of both national and EU legislation.

Between 2001 and 2006, Enel Distribuzione provided Electricity Smart Meters for almost 85% of Italian customers (approximately 31 million meters). In 2006, recognizing the benefits of smart metering, the Italian Regulator (ARERA, later AEEG) extended a mandatory rollout to all Italian DSOs. This allowed Italy to meet and surpass the electricity Directive 2009/72/EC target (i.e. 80 % of all households equipped with smart meters by 2020) almost a decade ahead of time by reaching a 95 % penetration rate in 2011.

Alongside the Smart Meter rollout, from 2010 ARERA/AEEG mandated a ToU tariff for smaller low voltage (mainly domestic) Enel Distribuzione customers with three time bands: on-peak, off-peak and intermediate (larger low voltage customers were metered hourly).

Even though Italian first generation (1G) meters installed in the 2000s were not able to communicate with IHDs, or provide 15-minute granularity, most of the 10 key functionalities recommended in (2012/148/EU) were available and were activated by default. However, 1G meters used powerline communications (sending signals through electricity cables, rather than via digital networks) which limited the amount of information that could be transmitted (it is important to note that the term First Generation/1G is mutable and has different meanings in different jurisdictions).

By 2014 the original units were approaching the end of their design life (15 years) and ARERA was assigned responsibility for defining the functional and performance specifications of second generation (2G) Smart Meters. The Italian DSOs subsequently began a replacement programme with second generation (2G) Smart Meters that are able to deliver near-real time information to consumers and third parties via separate digital communication channels, (making it possible to offer advanced market services) at the same cost as 1G units.

3.6. The GB Smart Meter Rollout

The roll out of smart meters in Britain was unique in that it was led by energy suppliers rather than distribution network operators (DNOs). The UK government believed that DNOs would be less motivated to keep costs low, and so instructed energy suppliers to conduct the roll-out instead. However, as described in the subsequent Cost of Energy Review in 2017, this was "*a mistake with* *profound consequences*"[37]. Not only have suppliers not kept costs low, but flawed commercial agreements, mismanagement of meter development, and major capacity issues have seriously hindered rather than facilitated the efficient roll-out of energy smart meters. In contrast to the GB approach, every other EU nation and US state examined in this study implemented a more controlled and centralised roll out through the electricity network companies.

The Cost of Energy Review noted that, "*The distribution businesses would have had, like in other countries, the opportunity to drive replacement of existing meters as part of their functions, and the result would have been a more co-ordinated and comprehensive programme. The meters could have gone into the RAB at a much lower cost of capital. Instead, the supply approach meant that it would be voluntary and supplier-led. The result is that the roll-out is haphazard, patchy and high-cost – ironically, with the costs being passed through to customers as they would have been in the distribution RAB case, but at higher levels.*"

The Energy Act 2008 original created the powers necessary for the DECC Secretary of State to implement a smart meter roll out in GB. The original rollout plan was split into two stages; Foundation and Main Roll-out. Two types of smart meter were to be deployed in each stage; first- and second-generation devices, known as SMETS 1 and SMETS 2 (Smart Metering Equipment Technical Specification) in stage one and stage two respectively (note that SMETS is GB-specific legislation and does not relate to 1st Generation (G1) and 2nd Generation (G2), Smart Meters which are defined differently in other jurisdictions. See previous section on Italy).

The Foundation (trial) stage involved the installation of a small number of SMETS 1 meters and was intended to do two things;

1. To 'iron out' any technological or commercial problems, and
2. To establish the regulatory and commercial frameworks required to implement the main part of the programme.

The trial was therefore intended to be somewhat experimental and mainly aimed at informing the design and development of both the technology and the commercial offerings which Smart Meters would enable.

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37 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/654902/Cost_of_Energy_Review.pdf

During the trial phase, energy retailers were permitted to make their own individual arrangements for sourcing meters with Meter Asset Providers (MAPS), and for communications with mobile network companies. This decision subsequently led to major problems.

Under the original timeline, the trial stage was due to be completed by 2014, with start of the main roll-out to begin later in the same year. The intention was that the Main Roll Out would see the wide-scale installation of market-ready SMETS 2 meters, with the programme planned to be completed by 2019.

During the Foundation stage trials, design and interoperability issues with different meter models and communications networks led to significant delays, and in 2013 the Secretary of State announced that the roll out plan had been revised. The GB trial phase was extended to 2016, with the main roll out planned to be completed by 2020. Note that by 2013, successful DSO-led rollouts had been largely completed to over 80% of consumers in Finland, Italy, Sweden, California and Texas.

As alluded to above, a major problem which became apparent as the trial progressed was the difficulty of integrating services across the multiple communications network providers. This led to the decision to abandon the option of suppliers using multiple networks and to establish a single dedicated network, to be developed by the Data Communications Company (DCC, a subsidiary of Capita PLC). DCC was expected to go live in 2015 as part of the revised trial process, and to confirm its operability with the SMETS 2 system before the main roll out.

As mentioned, SMETS 1 meters were intended to be deployed during the Foundation Stage only. However, the problems with networks and subsequent delays while DCC was established meant that suppliers continued to install SMETS 1 meters even after the trial phase ended. Although SMETS 1 and 2 are similar in appearance, SMETS 1 units are in many cases host-specific, i.e., incapable of operating with wireless networks other than that specified by the supply company that installed them.

Limitations also include SMETS 1 meters going 'dumb' in areas with poor mobile signals. Around 30% of SMETS 1 meters installed in properties with communications issues (eg, properties with thick walls, or in high rise flats etc.) have reverted to dumb mode. For around 70% of consumers provided with SMETS 1 units, switching supplier has also resulted in the meter reverting to 'dumb' mode, requiring them to revert to submitting monthly meter readings by text or email.

After further delays, the switch date (after which no SMETS 1 meters should be installed) was pushed back to December 2018 (for pre-payment smart meters it was March 2019). The first SMETS 2 meters were installed in July 2017 by British Gas. While the official end-date for the installation of SMETS 1 has passed, it is currently unclear at this stage whether all energy suppliers have actually stopped installing them.

The GB rollout has understandably attracted criticism, particularly from consumer groups. Martin Lewis, Founder of MoneySavingExpert.com in 2018 said *"The rollout of smart meters has been a cock up and a catastrophe. Energy firms are now using it as a soft form of trapping people into poor deals as they can't switch providers without their meters going dumb."*[38] The British Infrastructure Group, a cross-party group of parliamentarians which champions UK infrastructure improvements, concluded that the rollout had been, "*plagued by a series of technical, commercial, economic and regulatory issues. The result of these has been repeated delays, cost increases, and reductions in expected consumer savings. While energy suppliers can be confident they will see significant savings from the roll-out, consumers have been left with outdated meters, presently bear all the programme's risks, and have been left with no guarantee they will see a return on their as yet £11bn investment*".

The UK Government carried out several CBAs on Smart Meter deployment, including in 2007[39], 2016[40] and 2019[41], as well as impact assessments.

According to BEIS figures, by the end of Q1 2020 (prior to the Covid lockdown), a total of over 19.5 million smart meters had been installed in GB homes[42]. However, this comprised around 4.3 million SMETS 2 meters, with the remainder (15.2 million, around 7 million more than originally planned) being SMETS 1. While some SMETS 1 meters can be 're-awakened' by migrating them onto the DCC network, by May 2020 this had happened with only 313,000 meters. Where it is not possible to migrate SMETS 1 meters, suppliers are supposed to replace them with SMETS 2 units.

Figures from Electralink indicate that 15 million smart meters actually operating in smart mode had been installed by February 2021[43].

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[38] https://www.moneysavingexpert.com/news/2018/07/smart-meters-will-save-consumers-just-11-a-year-says-new-report/

[39] https://webarchive.nationalarchives.gov.uk/20090609005007/http://www.berr.gov.uk/files/file45794.pdf

[40] https://www.gov.uk/government/publications/smart-meter-roll-out-gb-cost-benefit-analysis

[41] https://www.gov.uk/government/publications/smart-meter-roll-out-cost-benefit-analysis-2019

[42] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/887809/Q1_2020_Smart_Meters_Statistics_Report_FINAL.pdf

[43] https://www.electralink.co.uk/2021/03/smart-meter-installs-pass-15-m-feb/

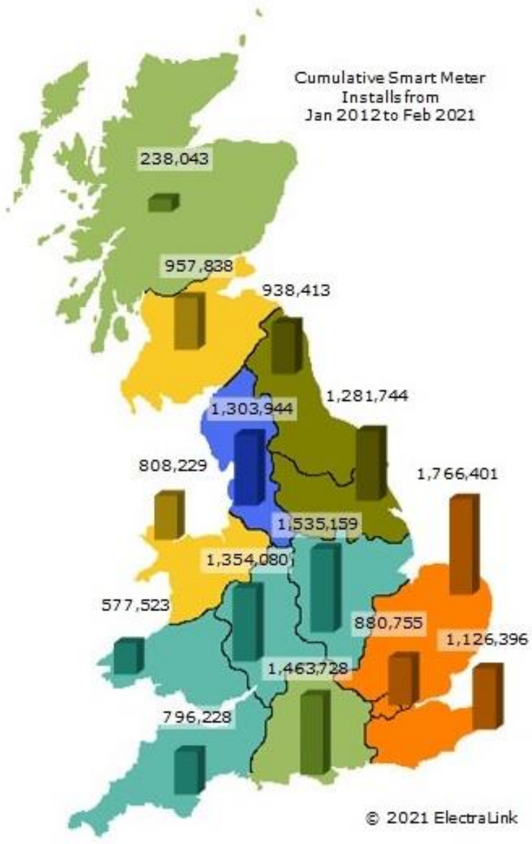

Figure 8. Cumulative GB Smart Meter Installations February 2021
Source: Electralink.co.uk

3.7. Smart Meters in Ireland

The Commission for Energy Regulation (CER; now known as the Commission for Regulation of Utilities, CRU) undertook an extensive large-scale ESM trial in 2009/10[44]. It included a 6-month pre-trial benchmarking study to establish a baseline of electricity use in the absence of ESM-enabled tariffs and incentives. The trial assessed a number of different smart metering enabled tariffs and energy efficiency measures with a view to measuring their impact on overall energy consumption and peak demand. The trial was designed to produce statistically robust results and sampled a wide range of domestic and business consumer types as well as control groups. A 2012 review of Smart Meter trials commissioned by DECC described the CER study as one of the most comprehensive and well-designed trials that it examined[45].

[44] https://www.cru.ie/wp-content/uploads/2011/07/cer11080ai.pdf
[45] https://www.cru.ie/document_group/smart-metering-cost-benefit-analysis-and-trials-findings-reports/

The trial included assessments of static ToU tariffs, creation of customer web accounts, detailed monthly or bi-monthly billing, IHDs which showed real-time, daily, weekly and monthly consumption data and allowed comparison with previous periods and financial incentives for demand reduction. It found that the static ToU tariffs combined with peak reduction incentives reduced total domestic electrical energy consumption by an average of 2.5% and peak demand by 8.8%. At the end of the trial 54% of participants stated that the trial had made them more aware of energy usage (18% stated there had had been no impact on energy use).

Following analysis of the trial results, in 2014 the Department of Communications, Climate Action and Environment (DCCAE) legislated for the Smart Meter rollout in line with the EU Electricity Directive. CRU set the high-level functionalities that the smart metering systems would have to deliver, selecting a so-called 'thin' solution, whereby most functionality would be provided by cloud-based back office systems, rather than by the Smart Meter itself[46]. Functionalities mandated by CRU included[47];

- Daily collection and provision of half hourly consumption data by the network company to suppliers
- Provision of consumption data to third parties upon customer request
- Seamless switching between credit and prepayment modes
- Provision of real-time consumption to customers data over a Home Area Network (HAN)

CRU also obliged suppliers to offer customers ToU tariffs, including as a minimum an approved standard smart tariff, which all suppliers must offer. The CRU standard is a simple form of ToU tariff, designed to be easy to compare across suppliers. The CRU also stipulated that price differences between the time bands must be 'meaningful and cost reflective'. The intention is that these relatively simple early tariffs with three time phases (Day 8am to 11pm, Night 11pm to 8am, Peak (within day) 5pm to 7pm) will help customers to become familiar with ToU offerings and so pave the way for future, more sophisticated market products.

In 2017, ESB Networks (the Irish DNO which is responsible for the rollout) submitted a proposal to the CRU recommending a phased approach. The proposal recommended that the rollout should be conducted over a six-year period and that added functionality could be switched on sequentially.

[46] https://www.crf.ie/wp-content/uploads/2013/07/cer131514.pdf
[47] https://www.cru.ie/wp-content/uploads/2014/07/CER14046-High-Level-Design.pdf

Previously, a national upgrade where all functionality would be switched on at the same time had been recommended.

The CRU conducted a CBA (CRU/17/32411[48]) to determine whether the phased upgrade was economically efficient. While the CBA showed that the overall net present value (NPV) of the upgrade was broadly neutral on the €1 billion project (with some benefits perceived as unquantifiable), it confirmed the adoption of the phased approach.

The rollout commenced with an initial deployment of 250,000 meters which was due to be completed by the end of 2020 (although it is currently unclear how this has been affected by Covid). It is planned that around 500,000 meters per year will be installed between 2021 and 2024 to achieve a 95% penetration target. The 'thin' Smart Meters which are being deployed have communications capacity to eventually allow intelligent metering of gas consumption and other modular products. Further policy work is underway, covering for example the use of actual consumption data rather than estimates in wholesale settlement. This work will be supported by ongoing engagement with customers and other stakeholders and includes behavioural economics research.

3.8. Smart Meters in Northern Ireland

2020 Demand Side Vision

The need for flexible demand was identified at the start of the deployment of high levels of wind into the all-island system. In 2010 NIAUR and CER commissioned a review of Demand Side Management (DSM) to inform the development and publication of a Demand Side Vision for the all-island electricity market in 2020. A consultation paper proposed a range of options, with support mechanisms and implementation plans for its delivery. The consultation examined a wide range of areas relating to DSM, including;

- Energy efficiency
- Consumer behaviour change
- Smart metering
- Load automation
- Market arrangements for DSM
- New loads for electrification of heat and transport

[48] https://www.cru.ie/wp-content/uploads/2017/11/CRU17324-Smart-Meter-Upgrade-Cost-Benefit-Analysis-Information-Paper.pdf

- Aggregation
- Energy storage

A Decision Paper[49] included the regulatory authorities' RAs' final view of the 2020 Vision, along with lists of the measures required, and the decisions which needed to be made to enable its delivery. The 2020 Vision included cost-reflective pricing for electricity and incentives for load management, as well as a level playing field for demand-side resources in system balancing, and the inclusion of dispatchable demand and DERs in price formation.

The 2020 Vision also identified the need to develop smart systems and tariffs to manage load for heat pumps and EVs, in order to;

- contribute to avoided investment in peaking plant by delivering peak load reduction;
- avoid the curtailment of wind by increasing demand in the off-peak periods;
- provide flexibility to mitigate the uncertainty of wind output;
- contribute to providing frequency response and similar ancillary services at times when thermal generation does not run;
- help mitigate transmission and distribution network constraints

The 2020 Vision foresaw that "*Flexibility of demand would play a key part in balancing the output of the variable sources of generation, alongside interconnection, flexible thermal generation (including distributed generators) and perhaps bulk electricity storage. This would enable a move away from the present 'predict and provide' arrangements – in which generation is varied to meet demand – towards a world where demand is able to flex to match the output of variable sources of generation*."

Energy efficiency, smart metering with advanced in-home displays and dynamic time-of-use tariffs, and industrial and commercial demand side response were assessed as measures that would deliver the highest value for consumers.

Strategic Energy Framework 2010

The 2010 Strategic Energy Framework[50] (SEF) was the last significant piece of energy policy developed in Northern Ireland. It referred to "*A vision of a smarter grid that encompasses not only smart meters but a myriad of new technologies that empower people to take responsibility for their own use of*

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[49] https://www.semcommittee.com/sites/semcommittee.com/files/media-files/SEM-11-022%20Demand%20Side%20Vision%20for%202020.pdf
[50] https://www.economy-ni.gov.uk/sites/default/files/publications/deti/sef%202010.pdf

energy will be a crucial building block in developing an electricity system that is responsive to need and that is integrated across all sectors of our society."

The SEF recognised the important role of smart metering and stated DETI and the UR's intention to implement a Smart Meter rollout in line with IME3. The SEF highlighted the role of Smart Meters, IT and digital communications as the key tools in developing a smarter and more efficient grid, capable of managing high levels of VRE. The SEF created a list of 43 actions related to delivery, which included SEF Action Number 20: *Work with the Northern Ireland Authority for Utility Regulation to develop a cost-effective smart metering solution for Northern Ireland by December 2011*.

Smart Meter Cost Benefit Analysis 2012

Energy policy (other than for nuclear power) is fully devolved to the Stormont Assembly. NI was therefore not included in the CBAs carried out by BEIS or BERR (Department for Business, Enterprise and Regulatory Reform) and submitted in line with the requirements of the Third Energy package, and these examined GB only.

However, although unpublished and unavailable for this report, DETI carried out and submitted a Northern Ireland-specific CBA in 2011. There are therefore two separate CBAs listed in the country fiches report supporting the 2014 Benchmarking Report on Smart Meter deployment in the EU[51], UK-GB and UK-NI[52].

The NI CBA was based on a mandatory rollout of Electricity Smart Meters carried out by NIE Networks, with costs recovered through network charges. The CBA examined six rollout scenarios;

(a) ESM only rollout with PLC as communications technology (reference scenario)
(b) Combined ESM and GSM rollout with PLC
(c) Combined ESM, GSM and Water Smart Meter rollout with PLC
(d) ESM only with DSL as communications technology
(e) Combined ESM and GSM rollout with DSL
(f) Combined ESM, GSM and WSM rollout with DSL

All but (b), the combined ESM, GSM and WSM rollout with PLC as communications technology showed a positive NPV. While the reference scenario (a) showed a positive NPV of 11%, the CBA found that

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[51] https://ses.jrc.ec.europa.eu/publications/reports/benchmarking-smart-metering-deployment-eu-27-focus-electricity
[52] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014SC0188&from=EN

scenario (d) (an ESM only rollout using DSL for communications) showed the highest net benefit, outweighing costs by approximately 25%.

The estimated cost of the roll out was €489 per meter for a total of 860,000 metering points, resulting in an overall total cost of €336 million. Benefits were estimated to be €502 per metering point, for a total benefit of €346 million. The relative share of benefits and costs are shown in Figure 9.

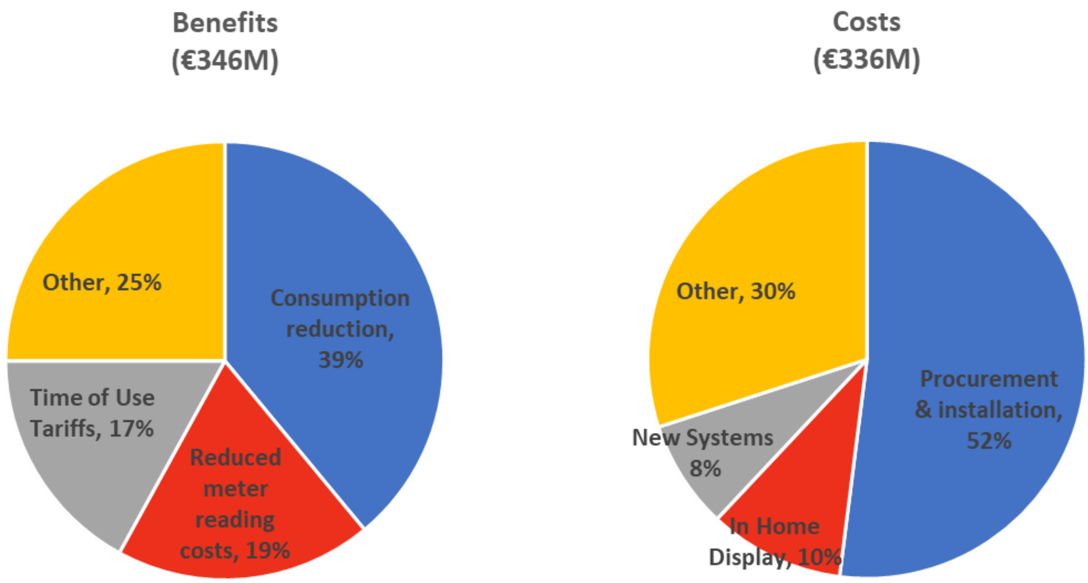

Figure 9. NI Smart Meter Cost Benefit Analysis 2012 Results

While the CBA addressed known values relating to the costs and benefits of Electricity Smart Meters, it described several benefits as 'intangible', including smarter management of NI's high levels of distribution-connected renewables, reduced need for generation capacity through demand response programmes and the easier accommodation of consumer-side resources like EVs and domestic energy storage.

Following the submission CBA, at the end of July 2012, the then DETI Minister Arlene Foster announced that there would be a roll out of smart electricity meters in NI, achieving 80% penetration by 2020 in line with the Electricity Directive and Recommendations[53].

[53] https://www.smart-energy.com/regional-news/europe-uk/northern-ireland-to-get-smart-meters/

A subsequent CBA was carried out in 2015 which produced a negative NPV, however this also is unpublished and not available for the preparation of this report.

2013 Matrix report

Matrix is an industry led panel convened to advise government and inform academia and industry on the commercial exploitation of R&D and science and technology. In 2012 DETI commissioned Matrix to identify opportunities for economic growth in Northern Ireland through sustainable development.

Matrix recognised the unique characteristics of the energy system and the opportunity for intelligent systems to integrate a range of renewable resources. A headline finding in the subsequent report published in 2013 was "*a compelling opportunity for Northern Ireland to take a leadership role in the development of distributed energy solutions and their integration into Intelligent Energy Systems through establishing itself as an International Reference Site to demonstrate the commercial scalability of these solutions to the global market*".

While the report identified specific opportunities in onshore and offshore wind, marine and bio-energy and integrated building technologies, it found that across all segments of the market, system integration and intelligent network management was the key to unlocking economic potential. It states "*The development and deployment of intelligent systems will be fundamental to matching supply and demand across increasingly complex energy networks, and in facilitating the paradigm shift whereby current consumers of energy will become energy generators. The overall functioning of the system will become increasingly important, not just the performance of the individual technologies. As a result, the commercial demonstration of the grid integration of renewable and sustainable distributed energy technologies using intelligent energy systems (IES) was identified as providing an attractive and flexible platform for future exports for Northern Ireland*."

The Matrix report recognised that intelligent communications and control were not only an opportunity, but a requirement if 2012 levels of wind curtailment and network constraints were not to increase. Matrix defined Intelligent Energy Systems as the 'common denominator' for successful commercialisation of sustainable energy in Northern Ireland.

4. POLICY AND REGULATION

4.1. UK Policy on Smart Energy Systems

Notwithstanding the problems with the smart meter rollout in GB described earlier, smart decentralised energy systems are a central focus of several themes within UK Industrial Strategy including Clean Growth[54] and Artificial Intelligence and Data[55].

The Industrial Strategy describes the need to remodel the electricity grid to enable the integration of high levels of renewables needed to meet the UK's Net Zero targets. "*Smart systems can link energy supply, storage and use, and join up power, heating and transport to increase efficiency dramatically. By developing these world-leading systems in the UK, we can cut bills while creating high value jobs for the future*".

A key development was BEIS and Ofgem's publication of the Smart Systems and Flexibility Plan (SSFP) in July 2017[56]. The SSFP was a central part of the UK Government's Industrial Strategy and Clean Growth Plan, and a core component of Ofgem's future-facing work to enable the energy system transition.

The plan is centred around the central role of smart metering systems and was supported by a substantial increase in public research and innovation spending, including investment in the development of new market structures and non-traditional business models. It focussed particularly on encouraging innovators and SMEs, and addressing the challenges of access to energy markets for disruptors.

The SSFP assessed how a range of consumer types, from large industrial to domestic, could provide DSR and participate in a smart energy system by shifting the time that they use energy, or turning their consumption up or down in response to instructions or price signals. It examined how new billing arrangements in combination with smart meters and new cost-reflective tariffs could benefit the system as a whole by helping to balance supply and demand in high VRE-penetration scenarios. It

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54 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

55 https://www.gov.uk/government/news/new-strategy-to-unleash-the-transformational-power-of-artificial-intelligence

56 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633442/upgrading-our-energy-system-july-2017.pdf

identified the importance of half-hourly settlement in encouraging consumers move their consumption away from peak times.

The SSFP detailed 29 actions, detailed under three main objectives:

- Removing barriers to smart technologies
- Enabling smart homes and businesses
- Making markets work for flexibility

The SSFP aimed to empower consumers by creating a "*best in class regulatory framework"* so that customer-owned smart technologies can compete on a level playing field with traditional assets to deliver improved system efficiency. By enabling households and businesses to shape their demand to use energy when it is cheapest, and to monetise the value of flexibility. It was closely tied to the roll out of smart meters which allowed suppliers to offer smart tariffs, and to exploit the power of data and digital communications in home appliances to make it easier for consumers to lower their bills.

BEIS published a progress update[57] in 2018 which assessed that 15 of the 29 actions had been implemented, mainly by Ofgem. This included modifications to licence conditions for storage, co-location of storage with renewable generation, changes to planning guidelines, the publication of a Code of Practice on storage and the development of flexibility as a solution for DNOs (as opposed to conventional reinforcement).

Regarding the objective of 'Enabling Smart Homes and Businesses', the progress report described Smart Meters as a 'critical building lock' for consumer accessibility to new market offerings. Ofgem launched a Significant Code Review to examine half-hourly settlement with a decision due to be published in 2020[58]. Currently, most customer billing is settled using estimates of when electricity is consumed, based on a profile of the average consumer usage and weekly or monthly meter reads. Because Smart Meters can record the amount of energy consumed or exported at half-hourly (or higher) resolution, this provides an opportunity to, a) make the settlement process more accurate, and b) act as an enabler for new products and services, for example supporting smart domestic heat

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57
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/756051/ssfp-progress-update.pdf

58 https://www.ofgem.gov.uk/electricity/retail-market/market-review-and-reform/smarter-markets-programme/electricity-settlement-reform

or power storage, or EV charging. However, due to Covid disruption, the SCR decision has not yet been published.

As well as the SCR, the update examined a range of technologies and market products which are now available to GB consumers, including;

- Octopus Energy launched a half-hourly tariff called 'Agile Octopus'[59], which is tied to wholesale prices. This tariff uses Smart Meters to communicate market prices throughout the day, and prompts customers to shift consumption to low-price periods. Agile also features 'plunge pricing', periods when customers can take advantage of negative prices in wholesale markets, and be paid to consume energy. Agile customers are also protected by a price cap of £0.35/kWh, regardless of spikes in wholesale market prices.
- Ovo Energy launched a smart charging trial with Nissan to demonstrate a Vehicle-to-Grid (V2G) product. The trial asks customers to set times when they want their EV to be available for transport. It uses the Kaluza[60] web app to optimise the charging/discharging profile of the EV battery by importing from the grid only when prices are low, and powering the home or exporting to the grid when prices are high.
- Good Energy launched a renewable electricity-sourced Heat Pump Tariff[61], with seasonal rates which link exploit the correlation of increased seasonal demand for heat with higher availability of renewable (wind) generation during winter. The tariff has higher prices during summer when wind energy and heat demand are lower.

In terms of Markets for Flexibility, the ESO reviewed arrangements for creating a level playing field and increasing market access for consumer-owned technologies, as well as committing procure 30-50% of balancing services from demand-side resources by 2020. Ofgem, the ESO and BEIS committed to enabling greater market access for aggregators and other flexibility providers. BEIS and Ofgem simplified metering requirements to enable demand-side resources to 'stack' value by monetising both Capacity Market and Balancing Mechanism services. As part of the ongoing transition of electricity distribution utilities from the traditional Delivery of Service-model to becoming active network managers or Distribution System Operators DSOs, network companies changed their requirements to make tenders for flexibility services (also known as Non Wires Alternatives or NWAs)

[59] https://octopus.energy/agile/
[60] https://www.kaluza.com/flexibility-platform/
[61] https://www.goodenergy.co.uk/lp/our-new-heat-pump-tariff/

a Business as Usual option. In order to widen markets to consumer-owned assets, Ofgem also clarified its position that DNOs could not become owner/operators of generation (including storage).

4.2. Regulation for Smart Energy

Smart meters are merely a tool and cannot on their own deliver resilience or flexibility. For consumer-owned, demand side resources to deliver and monetise system value, new market and regulatory arrangements are required along with metering systems, data and digitalisation.

Tariffs

A long-standing inefficiency in energy markets is the disconnect between retail prices paid by consumers and the marginal costs of supplying electricity. Digital technologies like Smart Meters enable real-time, two-way communication, removing the technological barriers to setting prices that reflect costs of production. Smart Meter-enabled consumers can participate in energy markets by shifting the time that they use energy, and by increasing or decreasing their consumption in response to a signal. This can be related to the real-time price of energy, or an instruction from an aggregator as part of a TSO or DSO contract for demand response. Intelligent controls can flex energy demand without any interruption in service delivery, as well as allowing consumers to monetise new value streams.

TOU tariffs[62] [63] more accurately reflect the time-varying nature of electricity costs than current 'flat' tariff offerings. Rather than charging customers a flat price regardless of when electricity is consumed, prices in TOU tariffs vary by time of day. The price signal can be static (i.e., the same every day, as in Economy 7, a very basic two-rate TOU) or dynamic (i.e., changing in response to system conditions). The price signal in TOU tariffs gives customers an incentive to shift their electricity consumption to lower-priced hours, providing bill savings opportunities and an associated potential reduction in overall power system costs. TOU tariffs are also often discussed as an important enabler of the adoption of new home automation technologies. Various types of tariffs are described in the next section.

Static TOU tariffs charge customers a higher price during peak hours of the day and a lower price during off-peak hours. The tariff is static in the sense that the price schedule is fixed and known to customers. In the case of Economy 7, the 7 refers to seven hours of a reduced night-time rate combined with 17 hours at a higher daytime rate. However, unlike the simple day/night split in Economy 7, most static TOU tariffs have three or more price bands, which may apply at different times

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62 https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/The%20Value%20of%20TOU%20Tariffs%20in%20GB%20-%20Volume%20I.pdf

63 https://energysavingtrust.org.uk/time-use-tariffs-all-you-need-know/

of day. The peak to off-peak ratio in Static TOUs generally range between 1:2 to 1:4, depending on the value of offset capacity costs.

While system capacity costs are so far the main influence on peak to off-peak ratios, a recent UU study which examined the value of flexible consumer demand on the Loguestown 110 kV Bulk Supply Point in Coleraine found an optimum ratio of 8.9:16.8 (with a two period shoulder period price of 13.1) for local network congestion management only. [64]

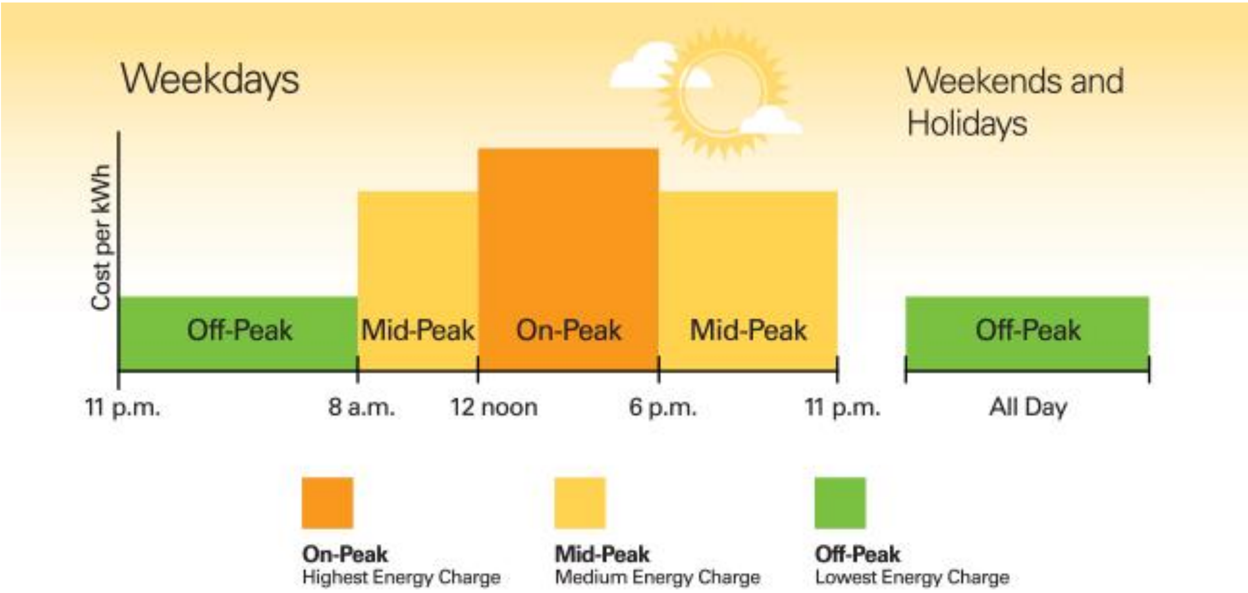

Figure 10. Typical Triple-rate TOU Tariff Arrangement
Source: Southern California Edison

Dynamic pricing is a form of tariff which is closely tied to price movements in wholesale Day Ahead, Intraday and Balancing Markets. An example is Octopus Energy's Agile Tariff[65]. Customers are notified of unusually high or low prices ahead of time to allow them to modify consumption by for example charging or discharging storage devices. Periods of very low load and high renewable generation can result in negative prices in wholesale markets. During such periods customers on dynamic tariffs are paid to consume energy[66]. The trial tariff for Ulster University and NI Housing Executive's RULET project is based on SEM Day Ahead Market prices.

64 https://www.mdpi.com/1996-1073/13/22/6085
65 https://octopus.energy/agile/
66 https://octopus.energy/blog/social-distancing-renewable-energy-negative-pricing/

Critical peak pricing (CPP) tariffs charge significantly higher peak period prices during a limited number of peak events per year, and lower prices during all other hours. The peak price signal is dynamic, with customers being notified of a peak price event one day in advance. Like industrial DSU notifications, CPP events are normally limited to, for example, events per year. Depending on the capacity value that they offset, peak to off-peak price ratio can be as high as 10:1.

Critical Peak Rebates (CPR) are the inverse of CPP tariffs. Rather than charging a higher price during peak events, credits are paid to customers for load reductions. The underlying tariff design is identical to CPP; however, in this case consumers are paid a credit for reducing their consumption against a known baseline, rather than paying the same amount for unabated consumption. The number and duration of events is the same as for CPP. NIE Networks recent Flexibility Services Tender[67] tenders with Piclo Flex are a form of CPR. Research by Citizens Advice and others described CPR as 'the most consumer-friendly tariff, because costs do not increase for those who are unable or unwilling to reduce their demand.

Performance Based Regulation

Electricity supply is among most capital-intensive industries in the world. Historically, cost-of-service based regulatory frameworks developed and evolved to provide a stable business environment to promote efficient capital spending by utilities to meet the energy and reliability needs of customers. Historically this was achieved through a revenue-cap regulatory regime to determine the appropriate level of revenue required to allow the DNO to operate the distribution network. Regulatory Authorities set revenues ex-ante for a regulatory period of typically five to seven years. There were several key components required to estimate the level of revenue including Opex, pass-through costs and adjustments between regulatory periods. The main determinant of revenue however was the rate of return decided by the regulator and applied to capital expenditure on the utility's Regulated Asset Base (RAB).

Performance Based Regulation (PBR) represents an evolution from this traditional regulatory approach in which regulatory goals, utility earnings opportunities, capital investment incentives and regulatory processes are sculpted to focus on performance, rather than the magnitude of the RAB. While continuing to provide for the recovery of investments needed for a reliable, low-cost grid to serve consumers and businesses, PBR provides incentives to promote investment in new technologies or the development of new market structures.

[67] https://www.nienetworks.co.uk/flexibility

Regulators establish PBR by creating links between regulated utility financial incentives and desired outcomes. These outcomes are tied to an index of performance in addition to, or in place of, the cost of providing services. Implemented coherently, these enhancements to cost-of-service regulation can better align regulated utility earnings with desired outcomes, like decarbonisation, consumer empowerment or increasing both system and energy efficiency.

PBR frameworks can also improve the way regulation reacts to market and technological innovation. Traditional regulatory processes usually lag technological developments, unintentionally creating system inefficiency, restricting opportunities for new businesses, slowing technological advances and creating unnecessary risks and costs for consumers.

The differences between Cost-of-Service and Performance Based Regulation are summarised in Table 1.

	Cost of Service Regulation	**Performance Based Regulation**
Goals	Reliability, affordability, security of highly centralised supply. Consumers protected through revenue limts.	CoS goals, as well as attainment of policy goals, such as reduced levels of fuel poverty and GHG emissions; increased opportunities for value creation by consumers.
Incentives	Revenues designed to match costs which are recovered against volumetric energy consumption. Utilities are disincentivised to reduce consumption.	Revenues designed to facilitate reliable services, innovation and technology development. Earnings aligned with delivering policy outcomes rather than consumption.
Earnings	Regulators assess utility costs, earnings primarily based on Capex.	Utilities optimise Totex, Ras reward delivery of outcomes. Capex-based revenue remains but is enhanced by performance against defined metrics

Table 1. Cost of Service vs. Performance Based Regulation

Performance Based Regulation in GB – RIIO

In GB, RIIO (Revenue = Incentives + Innovation + Outputs), a new revenue paradigm for Network Operators, was implemented in 2013. Its newest iteration, RIIO 2 is currently underway and will be delivered in 2023. An Ofgem review[68] of the traditional price capped revenue RPI-X (Retail Price Index minus a negotiated variable value) revenue control mechanism[69] concluded that although there was a need for large-scale investment in low-carbon energy infrastructure and more effective engagement with customers, UK utilities were risk-averse, too slow to innovate, and focused on maintaining their RAB and appeasing regulators rather than satisfying customers. There were also concerns that the previous regulatory framework encouraged a focus on capital costs containment rather than outputs, and that the RPI-X framework had become too narrow in its focus.

RIIO was intended to begin a transition away from the traditional 'Cost of Service' approach of simply rewarding investment in networks (sometimes called the "predict and provide mentality") under the prior regime, to an outcomes-based approach—a shift from inputs to outputs through revenue-based regulation, overlaid with a system of financial rewards for achievement of specified goals (performance).

Ofgem changed its price and revenue control mechanism to remove any bias that would normally have existed between capital expenses (CAPEX) and operational expenses (OPEX) that would tend to lead utilities to prefer CAPEX.

This approach has been referred to as "TOTEX" (total expenditures). This means there is an incentive to deliver outputs rather than simply building new infrastructure. There was also an associated move from the previous five-year price control term to eight years as a reflection of the long-term nature of the investments necessary for a low-carbon transition. RIIO was designed to be a framework which retained strong cost control incentives while attempting to focus on long-term performance, outputs, and outcomes, with less focus on ex-post review of investment costs.

Whether the original RIIO programme achieved its objectives is questionable. However, while RIIO2 will enforce stricter limits on network incomes, RIIO was a change to the regulatory model which envisioned the '*timely delivery of a sustainable energy sector at a lower cost to consumers than would be the case under the existing regimes*'.

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[68] https://www.ofgem.gov.uk/network-regulation-riio-model/current-network-price-controls-riio-1/rpi-x20-review
[69] https://www.ofgem.gov.uk/ofgem-publications/51984/supporting-paper-history-energy-network-regulation-finalpdf

5. THE ROLE FOR SMART METERS AND FLEXIBLE DEMAND IN NI

5.1. Characteristics of the Northern Ireland Energy System

NI has a dispersed, largely rural population. Population density is one third that of GB; 132 people per square km, compared with GB average of 398, with 36% of the NI population living in rural areas [70].

Total annual demand for energy was just over 47 TWh in 2017, representing 3.3% of total UK energy demand[71]. Energy is overwhelmingly supplied by imported fossil fuels; 62% oil (29 TWh) and 13% gas (6 TWh). Annual electrical energy demand is less than 8 TWh (7,806 GWh for 2017), representing 24% of all-island demand[72].

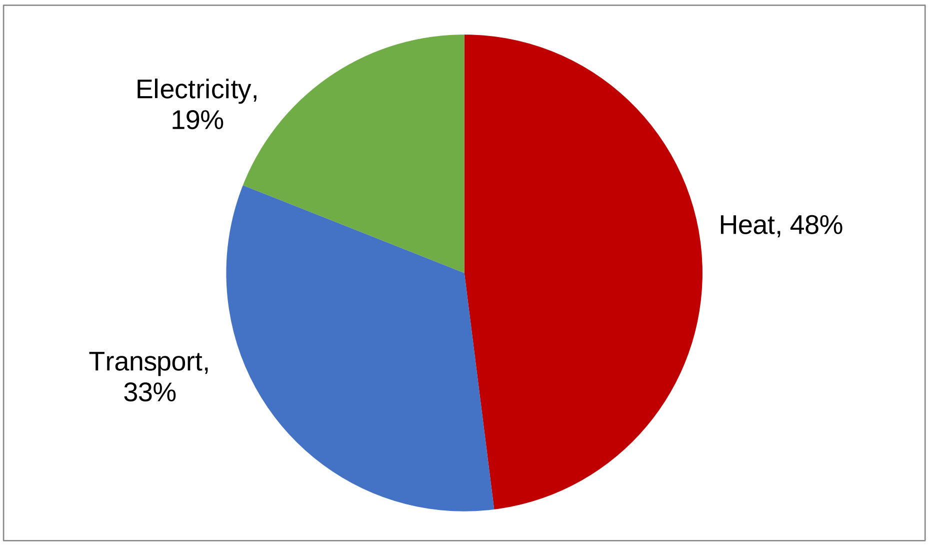

Figure 11. Energy End Use in Northern Ireland

Source: DETI, Envisioning the Future - Considering Energy in Northern Ireland to 2050.

As shown in Figure 11, end use of energy in Northern Ireland is dominated by heat and transport, overwhelmingly supplied by fossil oil and gas and accounting for almost half of energy demand.

The characteristics which make the Northern Ireland energy system unique in Europe are examined in the following sections.

[70] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2016basedstatisticalbulletin
[71] https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[72] http://www.eirgridgroup.com/site-files/library/EirGrid/4289_EirGrid_GenCapStatement_v9_web.pdf

5.2. Network Infrastructure

Because of its dispersed population, Northern Ireland has a 'long and stringy' transmission and distribution (T&D) system, with a total of 2,200 km of transmission grid (275 kV and 110 kV only, unlike GB and RoI, NI has no 400 kV transmission) and 47,000 km of distribution network (33 kV and below). This low-density, dispersed population, with a disproportionately high level of low-voltage network connected to remote homes and businesses, means that NI has more than twice amount of T&D infrastructure per head of population compared with the rest of the UK. For example, GB has an average 28m of T&D wire per customer, compared with 58m in NI, almost all of which is lower voltage network.

5.3. Wind Energy

The Irish all-island system is a world leader in terms of the proportion of wind generation that has been connected to an island grid and managed using TSO-controlled resources. Variable here is defined as renewable energy that is both non-synchronous (irregular waveform) and non-dispatchable (output cannot be controlled to match demand). Unlike its neighbours, the island has no significant dispatchable, low-carbon energy resources like hydro or nuclear power. In order to meet climate change targets therefore, governments in the two jurisdictions have jointly sought to connect very high levels of the island's abundant indigenous renewable resource – wind power.

Over the past decade system and network operators in both jurisdictions have facilitated the connection of uniquely high levels of wind into the Irish all-island system. In large synchronous systems like the European Continental Synchronous Area (CSA), countries can share the challenge of VRE management. Ireland is a relatively isolated island power system, which has limited (and critically, only non-synchronous DC) interconnection with Britain and so far, no interconnection at all with continental Europe. Although energy can be imported and exported over DC interconnectors, the system inertia required to manage high levels of VRE cannot, so the challenge of maintaining stability at very high penetration levels must be met internally.

The all-island system currently has over 5,388 MW of wind capacity connected to a system with a winter peak load in 2019 of 6,558 MW and a minimum summer demand of 2,542 MW[73]. The system is exceptional in that it can accommodate up to 70% instantaneous penetration of non-synchronous generation (of which over 90% is typically wind power). Although other systems are now close to achieving this, the Irish system was the first to reach this remarkable milestone. The current all-island

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[73] https://www.eirgridgroup.com/site-files/library/EirGrid/All-Island-Transmission-System-Performance-Report-2019.pdf

system record for wind generation is 4038 MW on 18th December 2019. In Northern Ireland, the current record is 1020 MW on 11th March 2019.

There are six synchronously separate power grids in Europe. Figure 12 below shows the relative penetration of VRE in each; the Irish all-island system has the highest penetration by a significant margin.

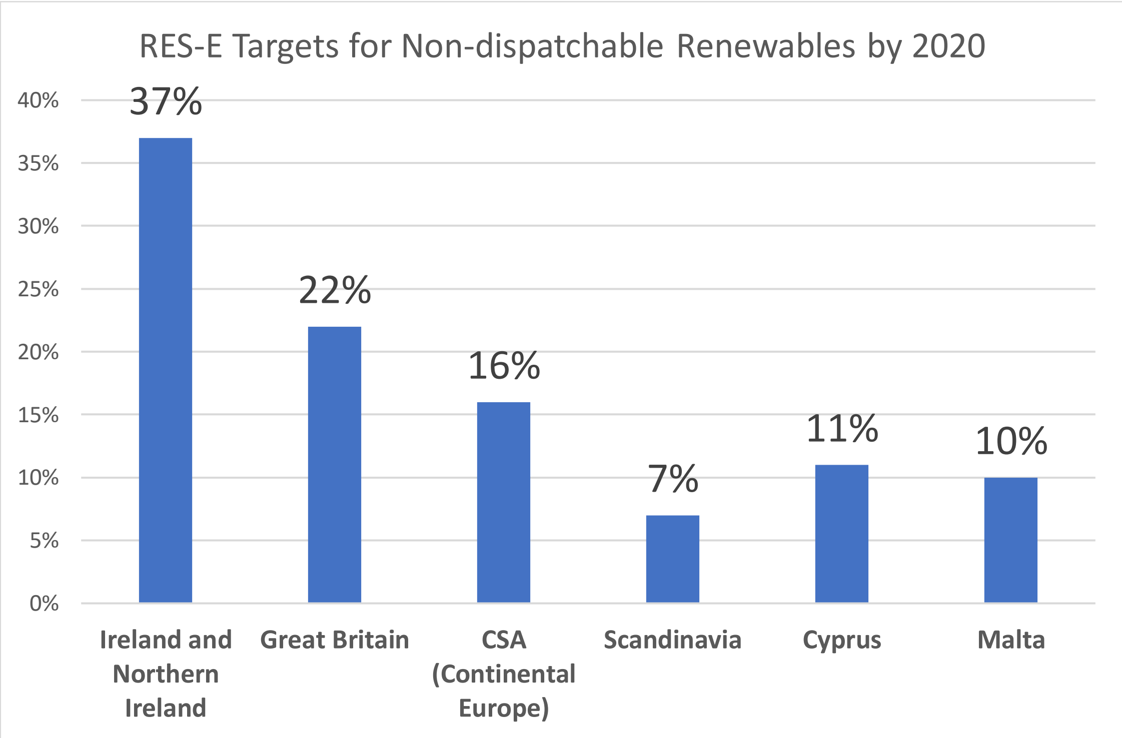

Figure 12. 2020 targets for non-dispatchable renewable electricity in EU power systems

The development of the all-island Single Electricity Market (SEM) and support mechanisms for wind generators have led to the governments' targets being met, and in the case of NI, exceeded by the 2020 deadline. Wind capacity connected in NI between 1990 and 2019 is shown in Figure 13.

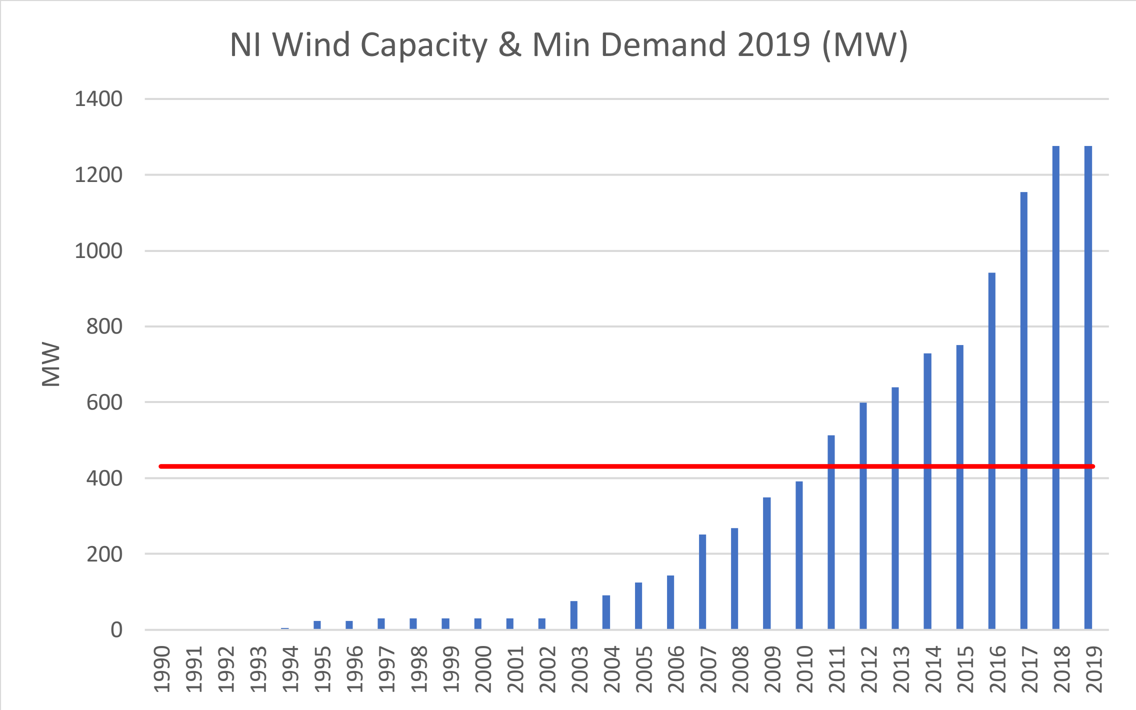

Figure 13. Northern Ireland Wind Capacity 1990-2019

Table 2 shows how in comparison with the rest of the UK, Northern Ireland has connected a much higher proportion of non-dispatchable energy and consequently has a much higher level of generation variability.

Region	Non-dispatchable %			Dispatchable %
	Onshore wind	Offshore wind	Solar PV	
England	12	24	43	21
Scotland	74	2	3	21
Wales	32	23	33	12
NI	76	0	16	8

Table 2. Percentage of dispatchable and non-dispatchable renewables in UK administrations

5.4. Scale and distribution of renewable energy

As well as its high proportion of distribution network (as opposed to transmission) infrastructure, VRE generation in NI is highly decentralised, small-scale and connected at distribution voltage. To compare with the situation in GB, 8,971 MW (48%) of GB wind generation is connected at transmission voltages (132, 275 and 400 kV), while NI's two largest wind farms, with a combined capacity of only 121 MW (9% of total wind) are connected at 110kV, with no wind at all connected at 275 kV, the system's highest voltage. All PV is connected at distribution voltages. The highly decentralised nature of renewables is shown in Figure 14. This does not include more than 17,000 micro PV (<50kW) generation sites.

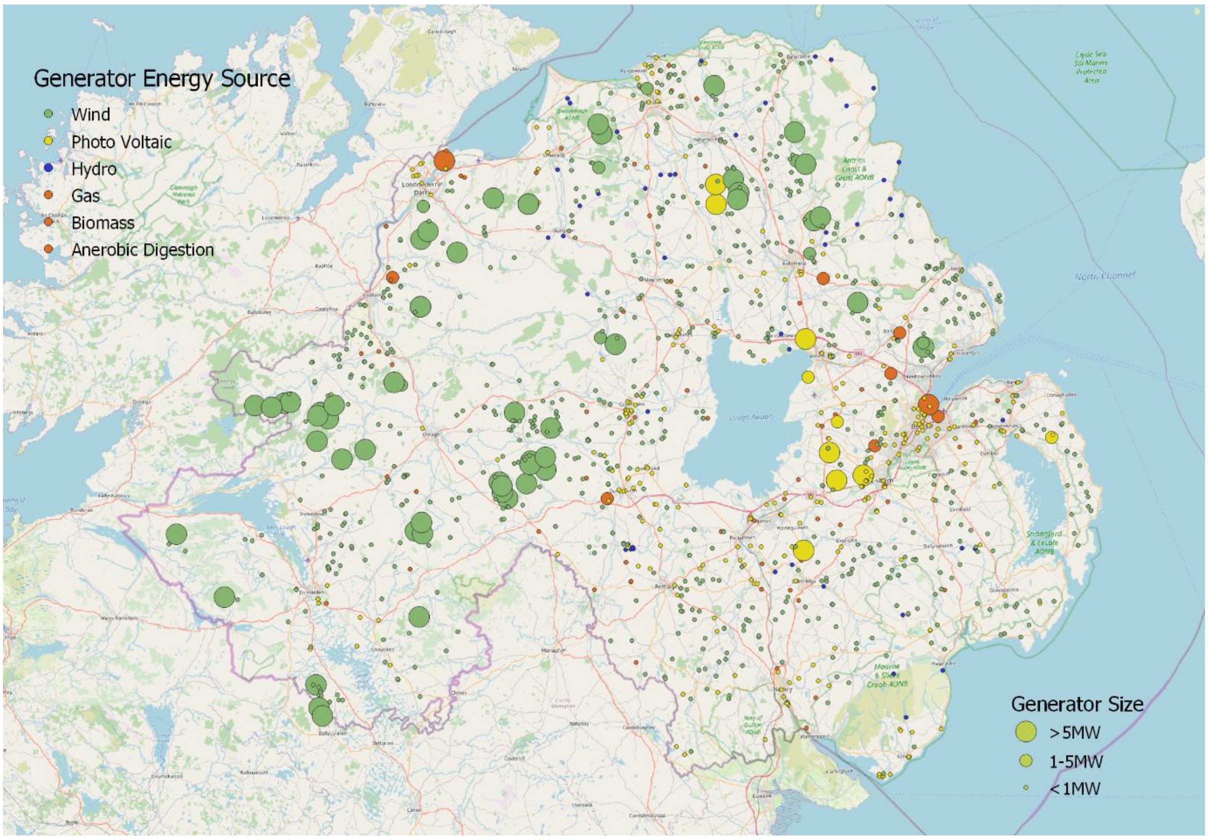

Figure 14. Renewable energy generation in Northern Ireland (DfE)

As well as being decentralised and connected at lower voltages, average windfarm capacity in NI is small - 16 MW, compared with a GB average of 25 MW. Although some areas of GB, notably in Scotland, also have low population density and high levels of wind power, an important difference is that Scottish wind farms are generally larger and transmission-connected, resulting in the highest average windfarm capacity for any UK region of 71 MW[74].

To illustrate this difference, the largest wind farm in NI is Slieve Kirk at 71 MW. In contrast, in Scotland 19 windfarms, which account for over 43% of total onshore capacity are larger than this, while the largest individual wind farm, Whitelee, has a capacity of 539 MW (closely followed by Clyde at 522 MW). In England the difference in size is even more pronounced, as two-thirds of wind capacity is

[74] mailto:https://www.gov.uk/government/statistics/energy-trends-september-2018-special-feature-article-renewable-electricity-in-scotland-wales-northern-ireland-and-the-regions-of-england-in-2017

provided by transmission-connected, large-scale, offshore wind farms, such as Walney (698 MW) and Race Bank (548 MW).

A further critical difference between NI and the rest of the UK therefore is not just that NI has a much higher proportion of VRE penetration, but that much more GB wind is large-scale and connected at the same high voltage as the centralised resources used to manage it.

This difference in connection voltages applies not just in comparison with GB; it also applies in the all-island system. In RoI there is a nearly even split between transmission- and distribution-connected wind. In NI the split is over 90% distribution-connected and 10% transmission-connected as shown in Figure 15.

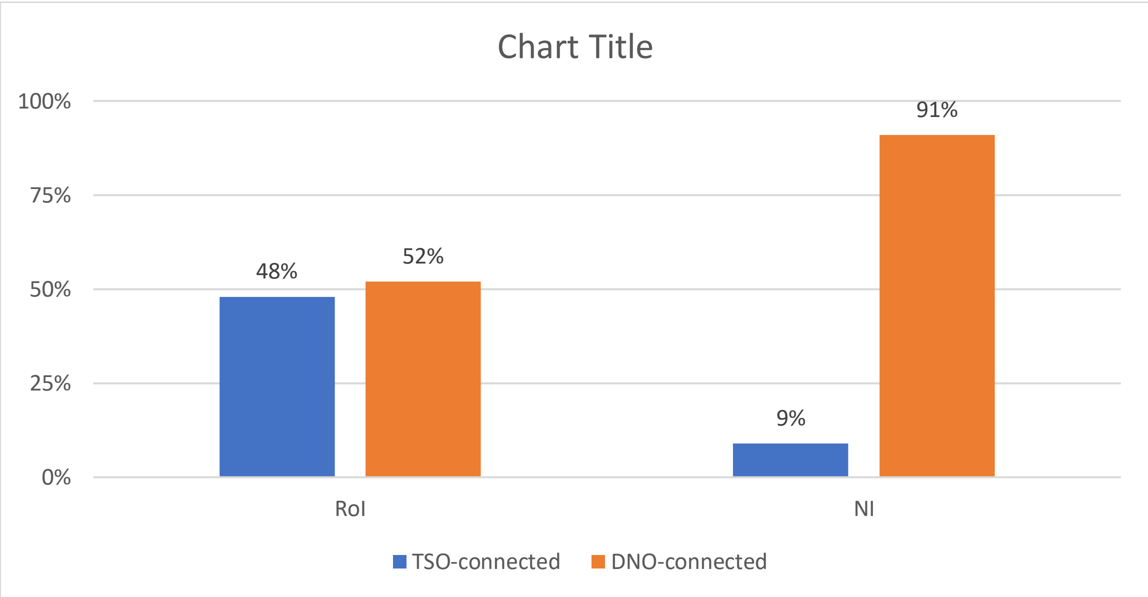

Figure 15. Transmission- and Distribution-connected wind farms in NI and RoI

5.5. Domestic demand-led profile

The NI economy is largely based on services and the agri-food sector; compared to GB it has little industrial baseload energy demand and consequently has a variable (or 'peaky') demand profile, largely driven by domestic consumption. A larger industrial base in GB, and an expanding baseload demand due to the connection of data centres in RoI means that NI has the lowest load factor and highest load range of the three systems.

Figure 16 below shows the demand profiles for the GB, RoI and NI systems as a percentage of their respective peak demand days in winter 2017/18. Winter peak demand for NI of 1632 MW occurred on 12th January 2018; for RoI it was 4940 MW on 13th December 2017[75]; while for the GB system peak demand was 48,582 MW on 11th December 2017[76].

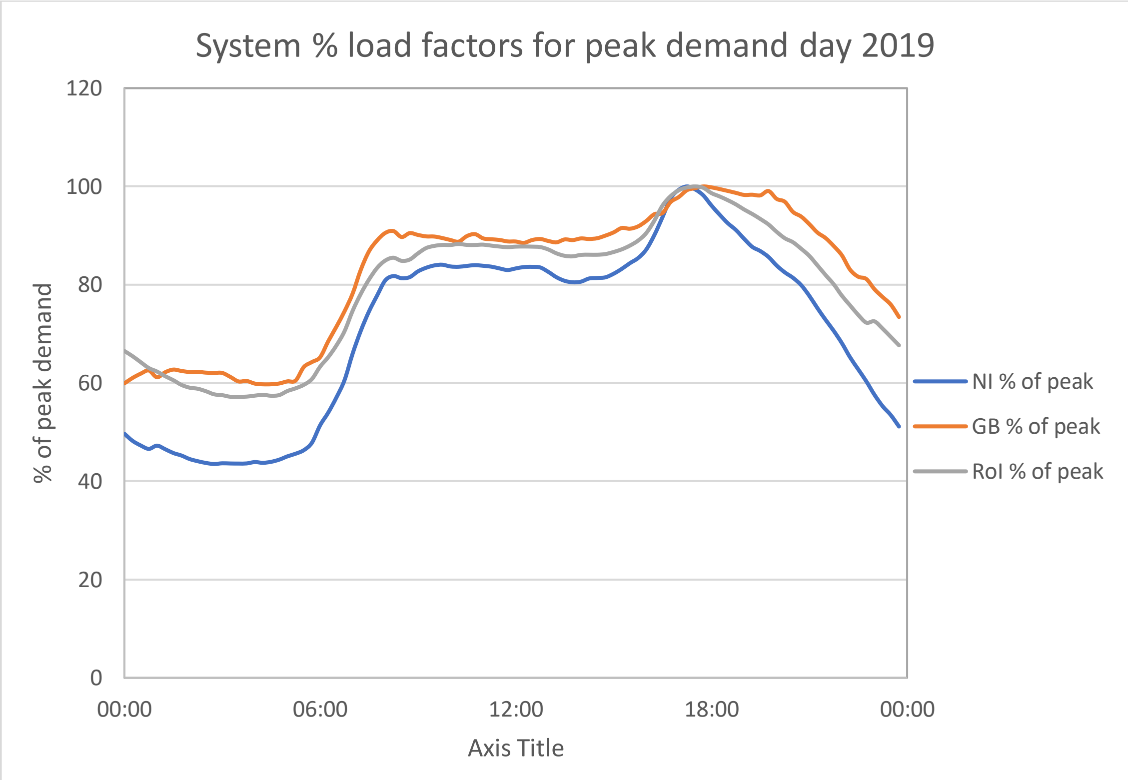

Figure 16. Comparison of load profiles for peak demand day winter 2019/20 for NI, GB and RoI

Load range (the difference between minimum and maximum demand) and load factor (peak load divided by peak load) for each system is shown in Table 3. Northern Ireland has by a significant margin, the highest load range and the lowest load factor of the three.

	Load range	Load factor
NI	58%	0.70
RoI	48%	0.77
GB	41%	0.82

Table 3. Load Range and Load Factor for NI, RoI and GB

[75] http://www.eirgridgroup.com/site-files/library/EirGrid/Winter-Outlook-2018-19.pdf
[76] https://www.nationalgrid.com/sites/default/files/documents/2017-18%20Triad%20Data.pdf

5.6. Variability Management in Northern Ireland

As discussed in the introductory section, the efficient management of variability requires flexibility from both supply-side and demand-side resources. Despite the early identification of flexible demand as a critical resource in integrating wind energy (the SEF, 2020 Demand Side Vision and CBA for Smart Meters in 2012 in Section 3.8), the flexibility that is currently available here is heavily skewed towards supply-side resources. These are examined in the following sections.

Flexible fossil generation

Electricity supply has evolved around three main fossil fuel-fired power stations; Kilroot (510 MW coal/HFO-fired steam, and 142 MW distillate peaking), Ballylumford (860 MW gas-fired steam and CCGT, and 116 MW distillate peaking) and Coolkeeragh (c. 400 MW gas-fired CCGT, and 53 MW distillate peaking)[77]. In order to serve its peaky demand profile, NI has a relatively high proportion of fast-start fossil generators; over 300 MW of open cycle distillate oil- and gas-fired generation which provides reserve power, along with generation at times of peak demand. Although it has a relatively high proportion of peaking fossil generators, when compared with Britain, Northern Ireland has a relatively low number of power stations for a low-density population of c. 1.8 million, meaning that conventional generation is strongly centralised.

Interconnection

In addition to fossil generation capacity, the system is connected to the GB system through the subsea HVDC Moyle Interconnector, and to the all-island system through a 275 kV overhead transmission line. There are also several lower voltage connections between the NI and RoI systems, however these are used mainly for system balancing, rather than the transfer of bulk energy.

Demand Side Units

A Demand Side Unit (DSU) is a single relatively large industrial load, or a combination of loads grouped across multiple sites that can be instructed to reduce consumption of grid electricity. A combination of paused plant operation and/or the start-up of on-site (typically diesel) generation is used to deliver the demand reduction in response to an instruction from the system operator. The current capacity of demand side response in Northern Ireland is 95 MW. However, this value is subject to the availability of individual sites which varies on a seasonal, daily and day/night basis. Total DSU capacity is assumed to have an availability factor of 40%, representing a firm demand reduction of 38 MW, or 0.02% of Northern Ireland's peak load of 1,564 MW in 2019.

[77] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633779/Chapter_5.pdf

System services – DS3

The need to maintain power system stability with very high levels of VRE in the all-island system led to the emergence of the DS3 programme (Developing a Secure, Sustainable System)[78]. This joint Eirgrid/SONI-led programme led to changes to the grid code and operating characteristics of generating units, as well as the creation of a ground-breaking ancillary services market which has incentivised the deployment of several large-scale BESS projects.

The all-island grid allows up to 65% instantaneous penetration of SNSP and has recently trialled 70%. Figure 17 below shows all-island demand (MW), wind generation (MW) and SNSP (%) for the 12th January 2019. At 01:45 demand was 3,441 MW, wind generation was 2,821 MW and 604 MW was being exported on the interconnectors to GB; System Non Synchronous Penetration (proportion of demand served by wind minus interconnector exports) was 64.43%. During the day wind generation rose to a peak of 3,328 MW at 12:45, however, at this time demand had increased to 4,875 MW and only 232 MW was being exported, so SNSP was reduced to 63.5%. At 23:30 that night, SNSP rose to its maximum for the day of 64.6%, as wind increased and demand fell.

For comparison, on the 8th February 2019 a new record of over 12,000 MW of wind generation was set by the GB National Grid[79]. However, SNSP (including all Interconnectors and solar generation) for the day peaked at only 54%.

[78] http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/
[79] https://www.bmreports.com/bmrs/?q=generation/fueltype/current

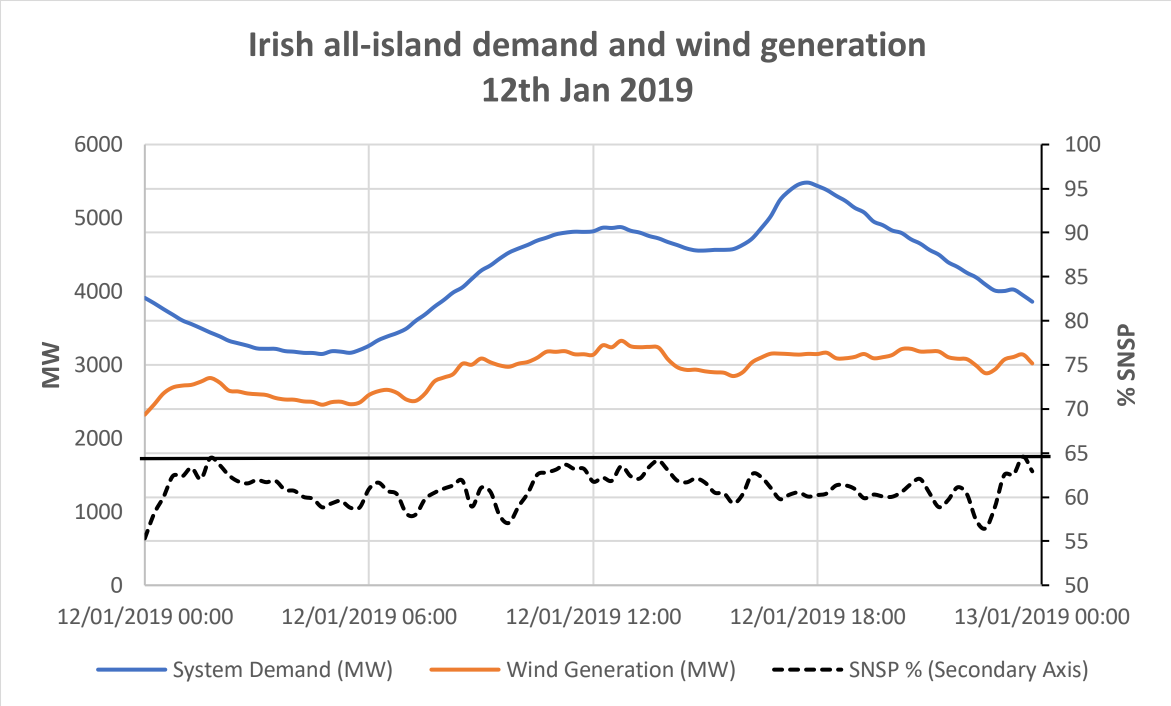

Figure 17. SNSP in the all-island system on 12th January 2019.

Curtailment and constraint

Despite the island's success in connecting wind power, this has not been matched by a corresponding growth in demand flexibility. Reducing output from wind turbines when generation exceeds SNSP limits, or when local transmission bottlenecks occur, is currently the primary tool used to manage high wind generation during periods of low demand. The levels of wind turn down in the all-island system are a significant and growing problem.

When wind generation exceeds certain limits, the output from wind turbines is turned down through;

a) curtailment (global/system-level, to keep System Non-Synchronous Penetration [SNSP] below 70%) and;
b) constraint (local, due to network capacity limits).

The near-total focus on TSO-controlled, centralised resources to manage wind energy over the past decade means that although the Irish system is a leader in the use of centralised, SO-controlled resources to maintain stability, it is a laggard in the use of demand-side flexibility.

While turn-down is an all-island problem, it is particularly acute in Northern Ireland. Figure 18 shows the percentage of available wind energy that has been turned down in GB, RoI and NI since 2016. Note that in GB, while wind generation has increased by over 40% in this period, turn-down has remained relatively constant as complementary flexible resources (including demand-side measures) have been deployed.

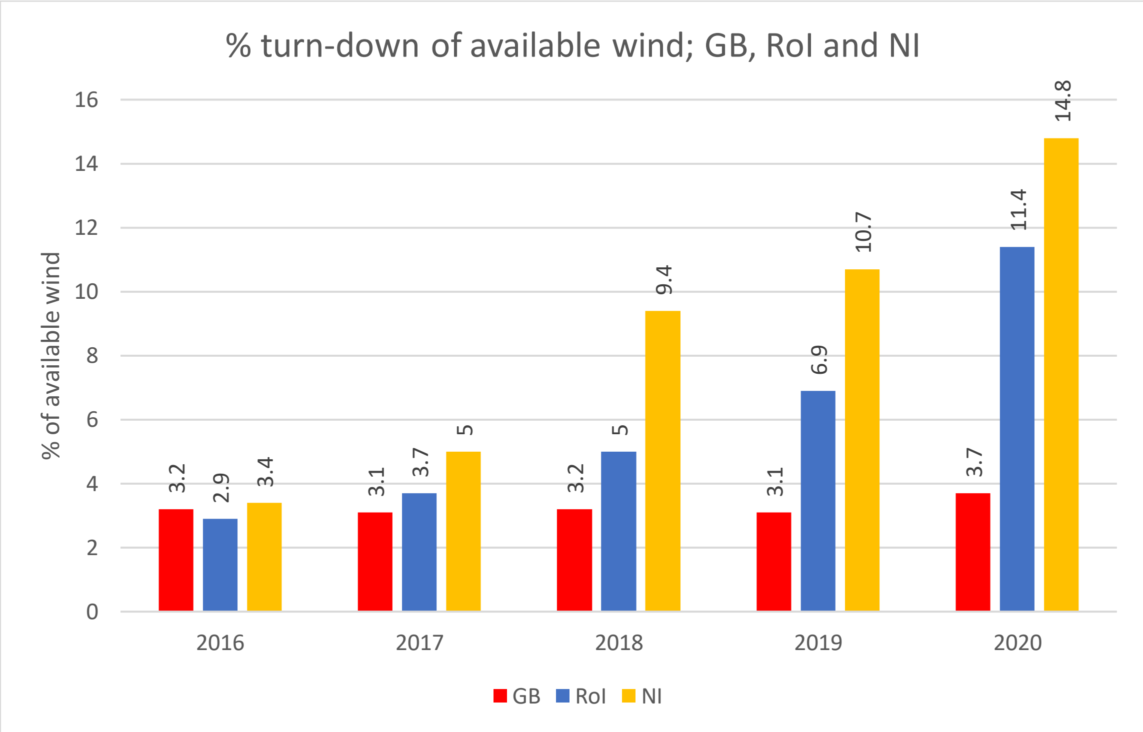

Figure 18. Comparison of wind turn-down in GB, RoI and NI
Sources: SONI/Eirgrid[80] REF[81]

According to the SONI/Eirgrid Annual Constraint and Curtailment Report and System and Renewable Data[82] 2020 a total of 465 GWh of available wind energy was turned down in Northern Ireland, representing 15% of available wind energy. Based on the UR's figure for average annual domestic electricity consumption of 3,200 kWh, that represents enough electricity to power over 145,000 homes.

[80] https://www.eirgridgroup.com/site-files/library/EirGrid/2020-Qtrly-Wind-Dispatch-Down-Report.pdf
[81] https://www.ref.org.uk/energy-data
[82] http://www.soni.ltd.uk/how-the-grid-works/renewables/

6. DISCUSSION AND RECOMMENDATIONS

Characteristics of the Northern Ireland Grid

The Northern Ireland power system is characterised by a combination of three key factors:

1. a long and stringy T&D network
2. high levels of variable, decentralised, small-scale renewable generation connected at lower voltages
3. a variable, domestic-driven demand profile

This combination of factors has resulted in a power system which has the highest levels of both locational and temporal variability in Europe.

As described earlier in this report, flexibility to manage variability can be derived from a range of resources, including investor-owned, supply-side assets like grid-scale storage, fossil generators and interconnectors; it can also be delivered by demand-side flexibility, enabled by smart metering, new business models and dynamic operation of consumer-owned technologies – EVs, microgeneration, electrified heat, and thermal and battery storage.

These resources are summarised in Table 4 below.

Investor-owned/supply-side	**Consumer-owned/demand-side**
Part-loading synchronised generators	I&C flexible demand
Standby fast-start generators (OCGT)	Dynamic charging of EVs
Curtailment of renewable energy	Smart domestic loads and appliances
Grid-scale storage	Dynamic charging of domestic thermal storage
Interconnection	Dynamic charging of domestic battery storage

Table 4. Flexible resources for power systems

In Northern Ireland, all the investor-owned flexibility measures in Table 4, and a limited volume of large-scale Industrial and Commercial (I&C) flexible demand have so far been incentivised and are monetised through existing market arrangements. There is also limited uptake of the simple two-tier Economy 7 tariff, which charges differential rates for daytime and night-time consumption. However, none of the domestic and small business consumer-owned flexible resources have so far been given market access.

Northern Ireland has connected a very high proportion of VRE, over 1,400 MW of onshore wind and over 250 MW of solar power by the end of 2020. This resulted in the Assembly's 2020 target for 40% of electricity consumption to be served by renewable resources being reached ahead of schedule; in fact, in 2020 over 49% of NI electricity came from renewable (overwhelmingly wind) resources[83].

Despite this very high level of connected wind, there has not been a commensurate increase in system flexibility, which has largely been limited to dynamic operation of fossil generators both to provide energy at times of low wind availability, and (with some BESS capacity) to provide ancillary services during periods of high availability. Despite a positive CBA in 2012 and the ministerial announcement of a 80% rollout by 2020 (as well as the findings of the 2013 Matrix Report) there has so far been no development of smart meter-enabled flexible domestic and business consumer demand.

Because of restricted export capacity on the Moyle Interconnector, and the near decade-long delay to the construction of the North-South Interconnector, the ability to import and export power between NI and both GB and RoI to manage VRE volatility is restricted, reducing flexibility still further. BESS deployment has so far been linked with power rather than energy applications through the DS3 market. While some DSUs provide services to the Capacity Market, this relatively simple form of demand response is limited to load reduction during peak events.

Mismatch between variability and flexibility

In general terms this means that there is a mismatch between variability and flexibility in the NI power system. NI has a highly distributed and variable energy supply, managed by highly centralised and relatively inflexible resources. The paucity of flexible resources means that NI's primary means of managing excess wind generation at present is to dump it when generation exceeds demand. Conversely, there is a heightened risk of power shortages during periods of low wind generation and high energy demand.

Some figures illustrate the scale of this mismatch. In 2020, 465 GWh, over 15% of NI's available wind energy was turned down. Based on UREGNI's assumed annual value for

[83] https://www.economy-ni.gov.uk/sites/default/files/publications/economy/Issue-18-Electricity-Consumption-Renewable-Generation-NI-Jan-2020-Dec-2020.pdf

domestic electricity consumption of 3,200 kWh[84], this represents enough energy to power more than 145,000 homes for a year, more than the entire NI social housing stock.

The lack of flexible resources means that as well as too much generation, the system also sees periods of insufficient generation. Over the 2020/21 winter, four Amber Alerts[85] were issued by SONI due to high energy demand at times of low wind availability. An Amber Alert is issued when "*A Single Event* (such as a power station trip) *would give rise to a reasonable possibility of failure to meet Power System Demand*", representing a significant risk of blackouts. No consumer-side resources like Critical Peak Reduction tariffs exist to allow consumers to participate in system management.

As well as heightened risk of blackouts, the failure to develop a suite of flexible resources has driven increased capacity payments for fossil generators. Northern Ireland peak demand is uninhibited by ToU tariffs, peak reduction incentives, energy efficiency as a capacity resource, or other demand-side market products.

The absence of the North-South Interconnector limits energy imports from RoI and has created a constraint which acts as a multiplier for new generation in capacity auctions. The consequent risk of supply shortages has resulted in the new gas-fired generation planned for Kilroot being awarded capacity payments at more than two and a half times the auction rate in the 2023/24[86] and 2024/25[87] auctions.

EP Power Europe will receive £647 million between 2023 and 2035 for the provision of 330 MW of gas capacity. This equates to a capacity payment rate of over £178k per MW over 11 years. For comparison, the most recent GB Capacity Auction for 2024/25 settled at £18k per MW[88]. While the total cost will be spread across all SEM consumers, around a quarter (c. £160 million) will be borne solely by consumers in NI.

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[84] https://www.uregni.gov.uk/news-centre/reduction-power-nis-domestic-tariff-welcomed
[85] https://www.sem-o.com/documents/general-publications/BP_SO_09.2-Declaration-of-System-Alerts.pdf
[86] https://www.sem-o.com/documents/general-publications/T-4-2023-2024-Final-Capacity-Auction-Results-Report.pdf
[87] https://www.sem-o.com/documents/general-publications/T-4-2024-2025-Final-Capacity-Auction-Results-Report.pdf
[88] https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/Capacity%20Market%20Auction%20T4%20DY2024-25%20Final%20Report.pdf

These figures for simultaneously high levels of wasted energy and frequent incidence of system stress, with correspondingly inflated costs for fossil generation capacity are symptomatic of a highly inefficient system. The final section makes recommendations on how this inefficiency can be addressed.

Recommendations

As discussed, Smart Meters are (like any other technology) merely a tool and cannot deliver desired outcomes without the right policy and regulatory framework in place. While technology choices (network or DSL communications, for example) are important, they are less important than choosing the correct incentives and market structures. Different technologies have been deployed in different markets but have delivered similar benefits to consumers and the wider energy system.

Northern Ireland urgently needs to empower consumers and develop flexible demand. The following recommendations are made to address these challenges:

- **Establish flexible demand as an asset class**. Energy demand can have value, and energy demand at the right time and right place can have very significant value. Flexible demand should become an asset class, in the same way as renewable energy over a decade ago. Consumers, as the owners of this asset class, should be empowered to monetise the value of their resource by generating and owning data to make their assets investable, and by regulators and policy makers creating the conditions for a market with large numbers of participants and significant cash flow.
- **Design from the bottom up**. Smart Meter rollouts and the wider deployment of smart technologies have tended to follow the traditional 'top-down' approach to system design, focussing on system benefits and technology choices. The result has often been that consumers have been subjected to changes, rather than empowered by them. The first consideration in designing and deploying smart systems should therefore be to maximise the role of and benefits to the owners of flexible demand – business and domestic consumers.
- **Prioritise low-income households**. Tariffs and other incentives which rely on ownership of flexible technologies could become 'middle class subsidies', which create the risk of people who are not homeowners or have no access to capital being left behind. Initial markets should be designed to prioritise the social rented sector in

general and vulnerable households in particular. As the NI social housing sector accounts for more than 120, 000 homes, this could rapidly bring deployment at scale. See Appendix I on the joint UU and NI Housing Executive RULET project.

- **Monetise the capacity value of energy efficiency** by allowing energy efficiency to compete against traditional fossil generation assets in auctions designed to ensure that future energy needs will be met. This creates a new category of grid asset by co-opting consumers into becoming a merchant generator of demand reductions or 'negawatts', reducing the need for fossil capacity. Such markets have already been established in the US, for example in PJM[89].
- **Consider the circular economy**. Economic analysis should consider the wider benefits of flexible demand to the NI economy. For example, current capacity market arrangements prioritise fossil generation over demand reduction, and will lead to significant monetary benefits for international investors. Alternatively, money invested in demand response products like Critical Peak Reduction incentives could be paid to NI consumers and remain in the local economy. Similarly, rather than simply ascribing wholesale market costs to constrained and curtailed wind energy, it should be valued in terms of the benefits that it would bring to the NI economy (in energy savings, reduced carbon emissions and fuel poverty, displacement of and less reliance on imported fossil fuels) if it were consumed locally, rather than dumped.
- **Exploit synergies (1).** As discussed above, the NI system is unique in terms of its highly distributed and highly variable nature, creating a need for intelligent systems to manage variability where it arises, at the local level. The 2013 Matrix report identified the potential for NI's internationally recognised IT industry to develop products and systems that could have global impact in the transition to smart energy systems[90]. A recent report identified Belfast and Cambridge as the UK's most tech-centric cities[91]. Research organisations cite a range of values for the global smart energy market but figures between $250 billion[92] and $500 billion[93] by mid-decade are common. The

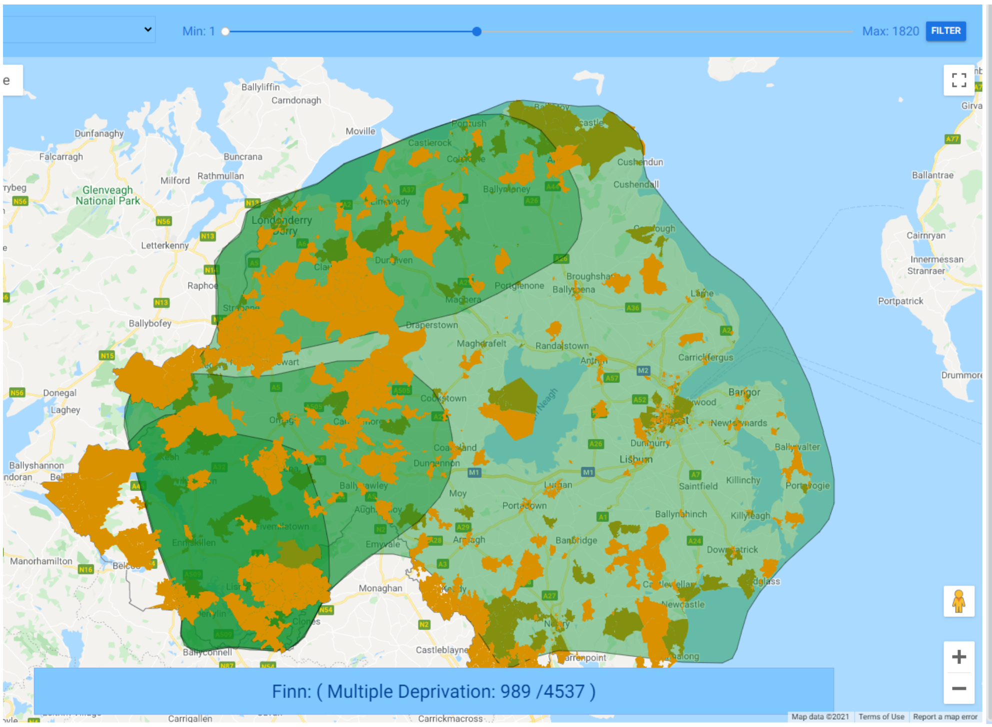
[89] https://learn.pjm.com/three-priorities/buying-and-selling-energy/capacity-markets.aspx
[90] https://technation.io/insights/report-2018/belfast/
[91] https://technation.io/news/uk-tech-jobs-growth-data/?utm_content=139723469&utm_medium=social&utm_source=twitter&hss_channel=tw-279144084
[92] https://www.alliedmarketresearch.com/smart-energy-market-A09434
[93] https://www.technavio.com/report/smart-energy-market-industry-analysis

characteristics of the NI power system provide the perfect test bed for the development of new products and market offerings to exploit this synergy.

- **Exploit synergies (2).** NI has a relatively large public sector and associated estate. It also has a part-publicly owned water utility, which is by some distance the largest electricity consumer in NI, and which shares a regulator with the electricity network operator. Opportunities for the public sector (in particular water utilities and the health sector) to deploy flexibility at scale have improved system resilience, optimised joint investment and reduced costs for customers in California, Rhode Island and other US states[94]. NI should learn from successful implementation of cross-utility efficiency and flexibility elsewhere.
- **Invest in smart networks**. The electricity network is a crucial enabler for empowering consumers, with significant investment needed to accommodate increases in demand for low carbon technologies, such as electric vehicles and heat pumps, and to connect new sources of low-carbon generation. The changes required to the electricity distribution system means that the next distribution price control is of particular importance, particularly for the establishment of flexibility markets and for the deployment of smart systems to maximise the utility of network assets.
- **Establish new ways of collecting, analysing and sharing data**. Data will be required to make flexibility markets investable and to optimise the utility of networks in the future. Policy makers and regulators should recognise and implement the Energy Data Task Force recommendations on the adoption of network digitalisation strategies, and establish licence conditions that promote the openness and interoperability of network data.
- **Recognise locational value**. There are some areas of NI where the potential for the deployment of smart consumer-led technologies is very high. Rural western areas see the highest levels of constrained wind and typically have higher levels of social need, including fuel poverty. Ulster University's Interreg-funded SPIRE 2 project has developed a Demand Flexibility map, an interactive tool designed to help develop an effective flexibility strategy and implementation pathway for Northern Ireland. The tool provides a whole energy system model, linking socio-demographic, housing,

[94] https://www.jstor.org/stable/resrep17240?seq=1#metadata_info_tab_contents

heating and transport data with known congestion and constraints on the electrical transmission and distribution systems. The tool currently has 12 map layers with over 110 sub-layers and contains features to assist with filtering and visualisation. It has various map views such as satellite, terrain and street view for a more detailed picture and geography tour. The map is in active development and updated frequently with new features. For illustration, in Figure 19 below the map shows in brown the 1,820 (of 4,537) most socially deprived areas of NI by small area postcode. The green overlays represent constraint groups, areas which see high levels of wind turn down due to network bottlenecks. Note that three constraint groups and higher levels of social deprivation are concentrated in the west and north west, suggesting that these areas have the highest potential for using currently wasted wind energy to address social need. More details on the flexibility map can be found in Appendix II.



APPENDIX I

RULET (Rural-Led Energy Transition)

Electrification of heat and transport, along with the need for more renewable generation to meet the UK Net Zero 2050 target, requires a significant increase in flexibility to maximise system efficiency and to complement output from non-dispatchable renewables like wind and solar energy. Flexibility can be derived from a range of sources, including supply-side assets like investor-owned, grid-scale battery systems, fossil generators and interconnectors; or from demand-side resources such as dynamic domestic demand enabled by new business models and consumer-owned Low Carbon Technologies (LCTs – smart immersions heaters, domestic PV, heat pumps, thermal/battery storage, EVs).

Domestic electrical heating systems, combined with thermal storage and smart controls, and operated at scale, have the potential to create significant system value by managing high levels of wind penetration. Northern Ireland has world-leading levels of wind energy connected at network voltages (33kV and below) particularly in western counties. However, when wind generation exceeds electricity demand, the output from wind turbines is dispatched down through;

a) curtailment (global/system-level, to keep System Non-Synchronous Penetration [SNSP] below 70%) and;
b) constraint (local, due to network capacity limits).

In 2020, 465 TWh of wind energy, representing 15% of available wind with a retail value of over £80M, was dispatched down – effectively dumped. This level of turn down indicates an inefficient system with high levels of connection but poor integration of renewables.

The declining costs of domestic-scale LCTs means that with new market arrangements for demand response and Time of Use tariffs, even moderately affluent households will be able to own assets which will allow them to shift their consumption of grid electricity to off-peak/low-price periods. This creates a risk that those who are unable to flex demand because they are not homeowners, and/or have limited access to capital (including homes at risk of fuel poverty – so-called 'left-behind households') are disadvantaged.

RULET PROJECT AIM AND DESCRIPTION

AIM - The RULET project aims to reduce or eliminate the risk of low-income households being left behind in the transition to smart, integrated energy systems by demonstrating the system value of smart, flexible heating systems in social homes.

The project will quantify the value which could be created by significant uptake of flexible, low-carbon electric heating in NI social housing, and integrating cheap, wind-dominated electricity. Smart energy demand in NIHE-owned homes, equipped with both standalone and hybrid heat pumps with thermal storage, could provide flexible load to make use of low- or zero-cost wind energy (which might otherwise be dumped), alleviating fuel poverty and creating value for wind farm operators, electricity retailers, network and system operators and social housing landlords and tenants alike. At present no business model exists to monetise this value.

In this context, UU and NIHE are carrying out a joint research project to assess how electrical heating, energy storage and smart control technologies could create new business and ownership models for flexible heat demand in up to 100 NIHE-owned homes. The project involves a field trial of a range of domestic energy systems provided by project partners Climote, Grant Boilers and Sunamp. In parallel with the field trial, UU will work with NIE Networks and SONI to model the impacts of extensive uptake of flexible electrical heating systems in NIHE's c.80k dwellings; in particular, off-gas grid homes in areas of high wind penetration. Energia/Power NI has received regulatory approval to trial a new dynamic Day Ahead Market-based tariff, the first of its kind in Northern Ireland, which will allow NIHE tenants to take advantage of cheap wind energy to heat their homes.

PROJECT PARTNERS

UU SPIRE 2 Project	NI Housing Executive	Climote	Energia	UREGNI
Grant Boilers	NIE Networks	SONI/SEMO	Sunamp	NI DfC

APPENDIX II

Northern Ireland Demand Flexibility Map

In the past, output from fossil generators was flexed in order to match energy supply and demand. However, the move to clean energy from renewable sources and the challenges posed by decarbonisation of heat and transport have created the need for flexible demand. These challenges include managing system frequency and voltage variation, overloading of network equipment due to the uptake of heat pumps and electric vehicles, the problem of excess generation at times of low demand and the costs of conventional network infrastructure to transport wind energy from remote locations to load centres. Demand Flexibility is the capacity to shift the time when energy is drawn from or exported to the grid by behind-the-meter (ie, consumer-owned) resources in response to an external signal (such as electricity price). This is achieved either by using energy storage or changing the activity time.

For policy makers and regulators to effectively plan decarbonisation for NI, they must understand the geospatial relationship of various energy assets and consumer groups. For example, what areas have excess wind energy available? How do flexibility needs and opportunities differ from location to location? How can we estimate the amount of flexibility or response available at local level? Is there enough local flexibility available to solve a congestion or power quality problem? Where would activating demand flexibility create most value? How do we prioritise flexibility activation in the event of competing resources? Only with a clear picture of the location and nature of demand flexibility can policy makers, regulators, system and network operators have a chance of developing an energy system that is both fair and economically efficient.

Ulster University's Interreg-funded SPIRE 2 project has developed a Demand Flexibility map, an interactive tool designed to help develop an effective flexibility strategy and implementation pathway for Northern Ireland. The tool provides a whole energy system model, linking socio-demographic, housing, heating and transport data with known congestion and constraints on the electrical transmission and distribution systems. The tool currently has 12 map layers with over 110 sub-layers and contains features to assist with filtering and visualisation. It has various map views such as satellite, terrain and street view for a more detailed picture and geography tour. The tool is in active development and updated frequently with new features.

How has the tool been used?

- We have used the tool to perform a geospatial assessment of flexibility needs and opportunities at neighbourhood level
- We have used it to identify neighbourhoods at risk of being left behind in the energy transition

- We have developed a flexibility distribution and prioritisation model that gives precedence to vulnerable consumer groups to ensure that there is increased justice in the energy system.

How could it be used in the future?

- Forecasting uptake of low carbon technologies at neighbourhood level
- Mitigating against fuel poverty
- Understanding the impact of clean technologies on the grid
- Understanding the opportunities for investments
- Help in siting of district heating schemes or large energy storage or renewable generation.

The map is available at https://niflexmap.web.app/