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How to Procure Flexibility Services within the Electricity Distribution System: Lessons from an International Review of Innovation Projects

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Abstract: The aim of this paper is to analyse and evaluate the deployment of smart platforms (operated by distribution system operators—DSOs—or by independent parties) in key jurisdictions that facilitate the trading of flexibility services—primarily by DSOs. We look at key innovation projects/initiatives from seven jurisdictions, including Australia, France, Germany, Great Britain, Japan, The Netherlands and Norway. We have deliberately selected 13 use cases that operate under different regulatory frameworks and market rules, and have been recently implemented (from 2017 onwards). With the selection of key use cases this study seeks to discuss the different smart architecture solutions and main capabilities across different demonstrators and their relationship to business as usual. It also analyses flexibility market designs, identifies main characteristics, and compares different price formation schemes and procurement methods. The value of flexibility for DSOs is also discussed.

Keywords: distribution system operators; flexibility services; regulation; procurement; distribution energy resources; innovation projects; lessons; international review

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1. Introduction

The decentralisation, decarbonisation and digitalisation of the energy system is creating new business opportunities for all the participants in the electricity value chain, such as suppliers, demand customers, traders, aggregators and network operators (e.g., distribution system operators—DSOs—and transmission system operators—TSOs). The democratisation of smart technologies (e.g., smart meters, artificial intelligence, active network management, blockchain) in the different components of the electricity supply chain is facilitating the management and trading of different flexibility services provided by distributed energy resources (DER) including demand customers. Flexibility is defined as "the modification of generation, injection and/or consumption patterns in reaction to an external signal (price signal of activation) in order to provide a service within the energy system" ([1], p. 5). There is not a unique definition of DER, but DER refer often to small-scale power generation (renewables and non-renewables), storage (including EV batteries), demand response and controllable loads connected to the distribution system.

Flexibility contributes to a more efficient and reliable operation of the electricity network and also to the decarbonisation of the electricity system if this comes from DER. In line with the theme of this special issue, these services are often being procured by leading electricity distribution utilities as part of innovation projects.

These services can be traded in two ways. The first one is between consumers and prosumers within the same local networks (i.e., within a single community) or at large scale (i.e., within a group of communities). These are commonly known as peer-to peer (P2P). Under this scheme, prosumers or flexibility providers may be part of an isolated network (i.e., microgrids) or be connected to the distribution network [2]. In the classic

P2P an interconnected platform allows sellers and buyers to trade renewable energy with no intermediaries at the agreed price. Some examples of P2P are: Brooklyn Microgrid in USA [3], sonnenCommunity in Germany [4], Vandebron in the Netherlands [5]. The second one is within conventional wholesale and retail markets (i.e., end-consumers and DER with the capability to interact with the grid, usually aggregated in order to meet grid requirements). In this case, DSOs can contract flexibility services using different approaches (see the next paragraph for details).

These two approaches refer to P2P platforms and grid services platforms, respectively [6]. This paper is focused on the second approach. Many of the different grid requirements can be in the form of congestion management and ancillary services. For instance, in the wholesale market, these requirements have been traditionally provided by the supply side (i.e., transmission- connected generators) and procured by electricity system operators using different mechanisms [7]. However, the deployment of decentralised generation and the transition from passive to active consumers, encourage the participation of new market players in the provision of flexibility services to the grid. Regulation and appropriate auction market designs can also increase the participation of decentralised flexibility such as DER, especially if aggregation of multiple small units is allowed and key roles in the electricity supply chain are extended [8,9].

DSOs are expanding their options for contracting flexibility services from DER and active consumers connected to their networks. This can take different forms: directly (i.e., single or aggregated units), via a common trading platform that involves several distribution utilities (e.g., Piclo Flex) or via a common platform for DSOs and TSOs who can receive bids for flexibility services simultaneously (e.g., GOPACS, Nodes). Regulation and policies that promote the trading of flexibility services from DER is still a work in progress in many jurisdictions [10]. Many of the current initiatives are still under development, with an important number of demonstrators that aim to evaluate their economic, technical and commercial viability.

In Europe, this deployment is supported by the European Commission in the latest Clean Energy Package that entitles DSOs to procure flexibility using a market-based approach in coordination with TSOs, especially for local congestion management and non-frequency ancillary services, see Directive (EU) 2019/944 [11]. The Council of European Energy Regulators (CEER) has adopted also a similar approach [12]. According to this Directive (Art. 32), member states shall provide incentives to DSOs for the use of flexibility, as an alternative to conventional solutions such as network upgrades, when flexibility is more economically efficient. DSOs shall be remunerated accordingly. They are also required to contract flexibility services from different market participants using a non-discriminatory approach. This Directive (Art. 15) also stresses the participation of active consumers in flexibility schemes, also suggesting fair treatment in terms of network charges, how they operate (directly or via aggregators), trade the services, etc. Something that is less explored is the role of energy communities (which encourages collective participation of active consumers) in the participation of local flexibility schemes to alleviate network constraints. Most of the current initiatives remained engaged with generation [13]. However the Clean Energy Package enables a supportive regulatory framework for the deployment of energy communities.

Competition in flexibility services can be also supported by unbundling rules that aim at the separation of the vertically integrated energy firm from activities not related to distribution, see Directive (EU) 2019/944 (Art. 35), with some exceptions depending on the type of asset, such as storage facilities (Art. 36). There is a risk of discrimination in the sense that DSOs may have preferences for their own assets rather than the ones owned by third parties when contracting flexibility services, which may preclude fair competition.

The current literature in local flexibility markets is diverse. Some of the studies look at market design for flexibility to solve network constraints (i.e., in the form of congestion management); both at distribution and transmission levels [14–18]. Here we observe a combination of country-level and regional analysis mainly limited to Europe, with pilots and business case initiatives, mainly concentrated on independent market platforms. A different group focuses on market design for flexibility from DER [19,20], and reviews the opportunities for DER across different electricity markets (ancillary services, system balancing and spot market) while others focus on the local market clearing methods used by distribution utilities [21] and stress the value of flexibility aggregation and optimal bidding [8,22,23]. Some others relate to P2P energy trading and blockchain [24–29]. These studies highlight the role of P2P energy trading in the integration of local electricity markets (more transactions between consumers and prosumers), however there are regulatory barriers that need to be addressed to expand the benefits that P2P can bring to local electricity markets. In comparison with the current literature, this paper is mainly focused on the distribution utilities' current practices (business as usual—BAU and trials) to contract flexibility services from DER, considering different energy regulatory frameworks and market structures, and extending the scope of the analysis beyond Europe and to a larger number of use cases.

The aim of this paper is to analyse and evaluate the deployment of smart platforms (operated by DSOs or by independent parties) in key jurisdictions that facilitate the trading of flexibility services—primarily by DSOs—in order to identify key lessons for innovation projects. We draw on the findings from the Modelling the Economic Reactions Linking Individual Networks (MERLIN) Project, which is being implemented by a distribution utility in Great Britain. This paper is based on the first two studies that the authors performed under the context of MERLIN, for further details see Anaya and Pollitt [30,31].

In its selection of key Use Cases this study seeks to discuss the different smart architecture solutions and main capabilities across different demonstrators and their relationship to business as usual (BAU). It also analyses flexibility market designs, identifies main characteristics, and compares different price formation schemes and procurement methods. The value of flexibility for DSOs is also discussed. The paper concentrates only on those cases where DSOs are the ones that procure flexibility services for their own use primarily (i.e., constraint management, ancillary services).

This paper looks for a diverse set of projects/initiatives from different jurisdictions including Australia, France, Germany, Great Britain (GB), Japan, The Netherlands and Norway. They have been chosen following a review of the different national publicly funded programmes and demonstration projects required by governments including those subject to regulatory sandbox, European Commission funded projects and academic and industry reports. A total of 13 use cases were selected. A questionnaire was designed and filled in per each use case in order to ensure coherence in the discussion and identification of lessons learned. Interviews were also arranged in some cases. Further details about the methodology are provided in Section 3.

The structure of the paper is as follows. Section 2 provides a background on smart solutions used in the procurement of flexibility services from DER and a short discussion of flexibility markets. Section 3 discusses our use case methodology where we identify and analyse 13 Use Case examples of flexibility procurement from seven leading jurisdictions. We next go on to discuss the lessons from the use cases in different areas. Section 4 discusses briefly the smart architecture and solutions that have been developed in the use cases for the procurement of flexibility services. Section 5 discusses different options for market designs across the use cases for contracting flexibility services, with a focus on their procurement methods and pricing rules, remuneration schemes, products (services) to be procured, flexibility providers and penalties. Section 6 explains the new business models adopted across the use cases for contracting flexibility services with a focus on the cooperation with aggregators and independent platforms. Section 7 discusses the value of flexibility and identifies a set of factors to be taken into account when defining the cost of counterfactuals. Section 8 identifies the most and least common trends across the use cases and suggests a new auction mechanism approach. Section 9 identifies key regulatory issues that can help to unlock the value of flexibility. This section sets up the discussion that we develop in our companion paper in this special issue [32] which examines stakeholder views on how regulation might need to change to better promote the procurement of flexibility services in the seven jurisdictions we look at. Section 10 concludes by identifying the main lessons for innovation projects that support the use of flexibility services.

2. Background on Smart Platforms and Flexibility Markets

2.1. Smart Architecture Solutions for Planning and Energy Trading

DSOs are deploying new capabilities in order to deal with the increase of DER and to take advantage of the services that these can provide to alleviate grid constraints. Those capabilities can be in different forms, such as new platforms for planning and energy trading, in order to manage and operate more efficiently the networks in line with the increasing number of DER connected to the distribution grid. Active Network Management (ANM) and Distributed Energy Resources Management System (DERMS)) are among the BAU tools deployed by DSOs to manage and optimise DER. ANM is a core part of the smart grid concept and is used by utilities to manage network constraints, to monitor and respond to the state of the network in real time [33]. ANM has been an instrumental tool for several distribution utilities in GB to offer flexible (or interruptible) connections to DER, with around 4GW of total flexible capacity connected by 2020 with approximately 13 GWh of curtailed energy [34]. A DERMS solution helps utilities to manage, aggregate and dispatch DER more efficiently and to take advantage of them for several purposes including grid management and network reinforcement deferral, optimising their output [35]. Different market segments can benefit from DERMS deployment, including utilities, aggregators and energy markets.

The level of deployment of these smart solutions across utilities differs. In the evaluation of the role of flexibility in supporting the grids and the role in demand in 18 jurisdictions from Europe, Asia, Oceania, North and South America, only GB and New York are the ones that use ANM in BAU solutions [36]. In Europe for instance, few vendors can offer a full deployment of DERMS in the form of BAU and a common standard has not been reached yet [37]. Power flow analysis for planning has been used for a long time but if the utility manages DER the network has to be analysed in real time. Many of the DERMS solutions are developing new capabilities, but only in trial projects (i.e., Power Potential and MERLIN in GB). A comprehensive list of DERMS current and future capabilities can be found in [38]. In New York, one of the pioneers in the transitioning to a modern utility with a set of new functionalities known as Distribution System Platform (DSP) functions, DERMS development across investor-owned-utilities (IOUs) is diverse and its being implemented by following a phased approach.

DSP functions increase over time [29]. According to [39], Central Hudson Gas & Electric is among the most advanced in DERMS development (DERMS constitutes a key functionality of the DSP). DERMS is not a standalone tool and along with the adaptation of Supervisory Control and Data Acquisition (SCADA)-based Advanced Distribution Management System (ADMS), provides an advanced solution that will enable the utility to leverage DER for grid and local reliability benefits, realize value from DER and to benefit from potential distribution investment deferral [40]. ADMS and DERMS are different systems, which complement each other when they are integrated. This integration enables complete distribution grid visualisation, aggregation, forecasting and control from different perspectives [41]. The development of an ADMS-DERMS solution is still a work in progress with few products on the market [42].

2.2. Flexibility Markets

Smart solutions (e.g., ANM, DERMS, blockchain, smart meters) along with the deployment of cheaper DER have enabled the deployment of local flexibility markets. For instance, solar PV units in combination with advanced inverters allows DSOs to control their output (ramping up or down power) when it is required (such as in the Smart Grid Hub in the Avacon Use Case, see Section 4 for details). Non-wired solutions are an alternative to more expensive network investments. Regulation is playing an important role. Among the interesting initiatives are the adoption of totex regulation in GB that looks at the total expenditure rather than separate operational expenditure (opex) and capital expenditure (capex) allowances (which increases the freedom to select the optimal option). In Australia, the Regulatory Investment Test for Distribution (RIT-D) scheme aims to promote efficient investment in the distribution network and requires network projects valued at more than $6 MM to look for non-network options (i.e., flexibility services from DER) [43]. The threshold (initially set at $5 MM) is revised every three years. The scheme is also applicable to transmission operators (RIT-T). Several countries have established regulatory frameworks for virtual power plant (VPP) trading and demand response schemes [44]. Some countries have specific funds for VPP demonstrators such as in Australia for coordination between the system operator, energy regulator and others, and in Japan (vehicle to grid—V2G VPP) via the Minister for Economy, Transport and Infrastructure (METI)'s 2018 Sustainable open Innovation Initiative (SII). There are also initiatives such as the Universal Smart Energy Framework (USEF) that aims to standardise and trade flexibility by proposing an integrated framework for markets and products. USEF framework has been adopted in different projects across The Netherlands, Germany, Denmark, and most recently in GB (with project Fusion) [45].

Most of the current developments in local electricity markets are focused on P2P schemes and only few of them involve the participation of DSOs in the procurement of services from DER for congestion management and ancillary services. Congestion management is the most common application for flexibility services. There are three important developments in local congestion markets [46]. First, authorisation for all potential players to participate. Clearly in expanding participation to new players, it is important not to arbitrarily limit participation. Second, in order to include new players, conditions for participation may need to be redefined. Third, new markets and services will need to be established (which is the aim of Project MERLIN).

We can distinguish different approaches that DSOs are using for procuring flexibility services. First, some of them are integrated within the same network operator, which means that the DSO may have an agreement with its customers to directly manage their generation assets or flexible loads. In this case, depending on the regulatory framework, DER can be curtailed if the DSO mandates this (this happens in Germany).

Second, it can also be via an independent party or platform where aggregators (or VPP operators) or independent traders act as intermediators between the flexibility providers (FPs) and the utility. In this case a market-based approach is used instead in many cases (i.e., in GB for congestion management). However, the way in which these intermediaries compensate the FPs (i.e., DER owners) may vary (e.g., fixed rate per year, a fixed amount per activation etc.). Aggregators are increasing and expanding their participation in the procurement of flexibility services for both operators; TSOs and DSOs. Among those services are load shifting, balancing services and local flexibility [2].

A third category is when the procurement is via an independent platform (e.g., Piclo-Flex and Cornwall Local Energy Market—CLEM in GB, GOPACS in the Netherlands, Nodes in Norway, Enera in Germany). Often this involves a pay-as-bid pricing rule with different remuneration mechanisms (e.g., availability, utilisation, activation or service fee payments). In this category, the DSO may also procure flexibility (i.e., congestion management) through existing day-ahead and/or intra-day markets. According to [17] a platform for trading gives visibility, the opportunity to meet qualification criteria and allows competitive procurement.

The use cases that are part of this paper are within the three categories described above. A fourth category is also noted but will not be discussed in detail. This relates to the flexibility services offered to the TSOs instead, by aggregators/suppliers (e.g., Vandebron-Tennet project in The Netherlands) and by DSOs (e.g., the case of ENWL from GB and United Energy from Australia in the provision of specific services to NGESO and AEMO respectively).

3. Use Case Methodology

3.1. Methodology

For the selection of the use cases we have concentrated on those where flexibility services are procured by network operators (mainly DSOs) to solve congestion constraints (i.e., peak loads), voltage constraints etc.; and that make use of smart platforms for trading flexibility services.

To identify use cases we performed a review of the different national publicly funded programmes and demonstration projects required by governments including those subject to regulatory sandbox (e.g., Network Innovation Competition programme in GB; Smart energy showcases—Digital agenda for the energy transition in Germany; Australian Renewable Energy Agency (ARENA) DER projects in Australia; innovation projects from METI in Japan etc.). The review also included key independent initiatives by DSOs and those funded by the European Commission.

In order to be consistent in the discussion of use cases, a questionnaire was designed to capture and standardise key information for each one (see Appendix A). The questionnaire has been pre-filled and, in many cases, personal communication was required (i.e., via email, phone calls) in order to ask for clarifications.

3.2. Use Case Selection

We have deliberately selected use cases that cover diverse perspectives. First, we have covered 13 projects/initiatives implemented in different countries from Europe, Asia and Australasia. These operate under different regulatory frameworks and market rules. They include projects led not only by network operators (DSOs, TSOs) but also by independent parties (i.e., independent platforms and research institutions).

Second, this paper discusses the latest projects, primarily those recently implemented (from 2017 onwards). The energy sector is evolving rapidly, with new developments in the regulatory, technological and commercial arena. We have a combination of demonstrators (those that are using real data for solving congestion issues etc.), demonstrators under proof of concept (such as the case of Japan with a new V2G VPP proposal that is expected to be implemented in 2021 in the balancing market) and those that are already part of BAU (especially independent platforms and distribution utilities in GB). In Japan, an increase in the number of VPP resources from electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) is expected. METI's Energy Resource Aggregation Business Council states that by 2030 there will be around 9.7 m EVs/PHEVs in Japan which amounts to 44 GW (equivalent to 44 thermal power plants).

Third, there is also diversity in the type of service/product to be procured and in the type of FPs (from residential customers to large generators). In terms of the services, even though most of them deal with congestion issues (i.e., due to peak loads). However some of them also involve the procurement of reactive power to solve voltage issues, either now (e.g., power potential and SPEN in GB) or in the future, such as in the case of Ausgrid (who are currently in second phase of their project).

Fourth, different approaches to market auction design are observed, with a combination of competitive (i.e., pay-as-bid) and non-competitive mechanisms (i.e., regulated prices), remuneration schemes (advanced and/or utilisation payments) and procurement periods (from months ahead to day-ahead). Table 1 summarises the use cases.

Based on the analysis of use cases we want to explore the way in which network operators are currently using flexibility services to deal with grid management issues and how this can be translated into better operation and planning of their networks.

Table 1. Summary of Projects/Initiatives.

Country	Project/Initiative Name	Project Leader(S)	Type	Start Date	Status	Method to Contract Flexibility Services (*)
Australia	Battery Virtual Power Plant (VPP) [47]	Ausgrid (DSO)	demonstrator	June-18	ongoing (Phase 1 completed)	via aggregators
France	Nice Smart Valley [48]	Enedis (DSO)	demonstrator	January-17	end December 2019	via aggregators
Germany	Avacon [49]	Avacon (DSO)	demonstrator	January-17	end December 2019	directly
	The Altdorfer Flexmarkt (ALF) [50]	FfE e.V.	demonstrator (proof-of-concept)	2017	ongoing	via independent platform
GB	Power Potential [51]	NGESO (TSO)	demonstrator	2017	end March 2021	directly, aggregators
	Flexible Power [52]	WPD (DNO)	BAU	March-19	ongoing	via independent platforms
	Flexibility Hub [53]	UKPN (DNO)	BAU	March-19	ongoing	via independent platform (Piclo Flex)
	Piclo Flex [54]	Piclo	BAU	March-19	ongoing	via independent platform (involves several DNOs)
	Cornwall Local Energy Market [55]	Centrica	trial	May-19	ongoing (Phases 1 and 2 completed)	via independent platform
Japan	V2G Demonstrator Project Using EVs as Virtual Power Plant Resource [56]	Tepco (integrated utility: DSO/TSO)	demonstrator (proof of concept)	June-18	ongoing	via aggregators
The Nether-lands	Dynamo [57]	Liander (DSO)	BAU	Q4 2017	ongoing	via aggregators
	GOPACS [58]	TenneT (TSO) and 6 DSOs	BAU	January-19	ongoing	via national platform (involves TSO and DSOs)
Norway	Nodes [59]	Nodes	BAU	2018	ongoing (different European countries)	via independent platform

(*) Independent platforms allow the participation of aggregators via them.

3.3. Evaluation of Use Cases

We now go on to evaluate the use cases on a number of dimensions. We do this by considering what recent developments there are in the system architecture behind smart flexibility solutions; what market designs are being used to procure flexibility; how they are recognising the need to support new business models; how the value of flexibility is calculated by the DSO; what are the common and unusual trends in the development of flexibility procurement mechanisms and what is still missing; and finally, we discuss the role of the regulator in promoting flexibility markets. In each case we offer some general reflections on what this means for flexibility procurement by the DSO. Appendix B summarises the main characteristics of each use case, including interesting features and issues.

4. Smart Flexibility Solutions and New System Architecture

Most of the use cases acknowledge the development of smart architectures and solutions for the procurement of flexibility services in order to facilitate communication with, control of and access to different types of flexibility (flexible loads, generators, storage, others), data processing, activation of bids, optimal selection of bids, etc. Some of these developments are integrated within the DSO, others within independent platforms and others are developed by aggregators. For instance, in the Nice Smart Valley Use Case, Enedis has developed the E-FLEX tool that allows communication with aggregators via the Extensible Messaging and Presence Protocol (XMPP) channels, to receive bids and to call bids from them and to activate the most appropriate ones (as suggested by Enedis). Their respective aggregators (EdF, Engie) have also developed new tools to connect with E-FLEX. In the Avacon use case, the smart grid hub (SGH) was developed to access and control generators of any type directly at low voltage level via digital switching. SGH is considered a single use of DERMS. Power Potential has implemented a DERMS solution and also a new Platform for Ancillary Services (PAS)—a control and monitoring solution, which is the main interface between the system operator (NGESO) and DERMS. The Altdorfer Fleximart (ALF) platform proposes the development of the Smart Meter Gateway (SMGW) along with a control box for connecting, measuring and controlling different types of flexibilities. While in CLEM and Western Power Distribution (WPD) Phase 2 Use Cases a new optimal clearing solution with identification of constraints has been developed by N-SIDE.

5. Market Designs for Flexibility Services

5.1. Procurement Method and Pricing Rule

With some exceptions (e.g., Avacon), most of the network operators in the use cases use a market-based approach (i.e., tenders) for the procurement of flexibility services, including those procured via independent platforms and aggregators. Dynamo in The Netherlands pays a regulated price to the aggregator for flexibility services; however, the selection of the aggregator was via competition. In terms of pricing rules, we distinguish three types: pay-as-bid, regulated prices and pay-as-clear. The price formation of these three categories also varies across the use cases. Some of them use pay-as-bid or pay-as-clear with free prices, while others use pay-as-bid with some indication of regulated prices (i.e., in the form of maximum prices or ranges with lower/upper values per site), and still others pay regulated prices only, usually with fixed amounts or ceilings depending on the type of service to be procured. For instance, the use of free prices via pay-as-bid usually applies when flexibility services are contracted via platforms that are integrated within existing markets (i.e., Nodes, GOPACS with Energy Trading Platform Amsterdam—ETPA) or when services are contracted for balancing the system together with ancillary services (i.e., Power Potential in GB, V2G, VPP in Japan). Pay-as-clear with free prices is only used by WPD (Phase 2 project with CLEM).

In GB, most distribution network operators (DNOs) involved with the procurement of flexibility services are within the second category (i.e., pay-as-bid, with some indication of regulated prices). In GB we use the term DNO rather than DSO. Many of them provide an indication of maximum prices or lower and upper values at each substation. This is the case for the DNO UKPN in their procurement of flexibility services at HV sites. In France, even though the demonstrator project proposes a competitive mechanism using pay-as-bid to remunerate aggregators, the size of compensation appears to be limited to the value of flexibility that Enedis has estimated, up to 24 €/kW/year [60]. Results from this experiment suggest that the value is relatively low, which may discourage participation.

Regulated prices (e.g., fixed amounts such as yearly lump-sum payments, vouchers, fixed prices per activation, prices in line with the loss of production, or in the form of a discount on grid charges regardless of utilisation) are mainly paid to small-scale DER such as residential customers (with flexible loads and small generating/storage units). An exception to this rule is Dynamo, where a regulated price is paid by the DSO to the aggregator, due to the limited number of aggregators that can provide flexibility services to the medium voltage (MV) substation when it is required. These payments are in many cases made by aggregators (which are compensated by network operators for flexibility services), with some exceptions (such as the case of Avacon where the DSO is the one that compensates the residential customers). The size of this remuneration is sometimes agreed via a non-disclosure agreement (NDA) (e.g., Dynamo). This means that figures are not in the public domain or are only provided in the form of a range of values (e.g., in Australia). The applicability of regulated prices to small-scale customers shows that in contrast to medium or large-scale customers (i.e., industrial, commercial, generators), residential customers are offered longer term contracts and then are exposed to lower levels of uncertainty. This may also imply lower levels of remuneration in comparison with the industrial/commercial customers—see for example the ALF use case in Germany.

5.2. Remuneration Scheme

Depending on the type of service, network operators compensate flexibility providers using different types of payments: utilisation (or dispatch, or in the form of spread payment), reserve (e.g., availability, arming) or other types (e.g., activations, service fee, etc.). We observe that the type of payment set in many of the use cases is in line with the way similar services are already being compensated in related national markets for constraint management, reserves, reactive power (e.g., flexibility services procured by DNOs in GB, Dynamo, V2G VPP in Japan, Power Potential, ALF for short-term products and the services procured via GOPACS and Nodes). There would therefore appear to be some standardisation (at least within the same jurisdiction) in the remuneration schemes for flexibility services. However, there is less agreement in terms of the value that network operators provide to each payment component, especially for schemes where prices are not set "free" but have regulated elements. For instance, while WPD allocates a percentage value to each component (i.e., utilisation, availability) regardless of the site with an average value of £300/MWh (excluding their Restore service), UKPN indicates lower and upper values related to the total payment to be made at each high voltage (HV) site. Other use cases such as Nice Smart Valley in France are exposed to a lower value of flexibility due to the fixed amount estimated by Enedis, while in Dynamo, Liander values utilisation and availability similarly. Section 7 discusses further how network operators value flexibility.

5.3. Products/Services

Most of the services identified in the use cases are for managing network constraints (via increase/reduction in demand, generation, storage) and in a few cases for balancing the system by contracting ancillary services (i.e., reactive power, voltage management). In contrast with conventional energy services in the wholesale market, these services are usually required in specific local areas, mainly to solve local grid issues (the closer an asset is to the place where the flexibility is required, the higher its effectiveness to solve it). Thus the location of the asset matters. Most of them are procured by DSOs (DNOs in GB), some of them can be procured by both distribution and transmission network operators simultaneously (Nodes, GOPACS, CLEM with WPD Phase 2 project), and only one by the system operator in GB (Power Potential). The name of the services varies across use cases with some level of standardisation noticed in those under BAU operation such as in Japan (RR-FIT) and in GB (flexibility services offered by DNOs). DNOs in GB have recently standardised the naming of flexibility services based on Energy Networks Association (ENA) recommendations. There are four proposed branding names: sustain, secure, dynamic and restore, see [61]. Depending on the type of service, we observe two kinds of trading period: short term (i.e., day-ahead, intra-day) or medium/long term (e.g., weeks/months/years ahead). Most of our distribution utilities are offering a short-term trading period (except for flexibility services procured by UKPN and WPD but including the case of CLEM with WPD phase 2).

For some use cases, the trading period is in line with the current rules for the procurement of similar services in other markets (i.e., V2G VPP in Japan, Dynamo, Nice Smart Valley, ALF).

5.4. Flexibility Providers

We identify a large range of flexibility providers using diverse technologies including flexible loads (e.g., heat pumps, hybrid systems, cooling systems), generation and storage units (including EV batteries) and conventional cogeneration/combined heat and power (CHP). Depending on the future CHP regulatory framework, innovative developments in cogeneration, such as Micro-Collective-Flexible-SmartHigh-Efficiency MCFlexSHE CHP and cogeneration cooperatives/communities, could become important flexibility resources. For a discussion about the possible future regulatory framework of CHP in Europe, addressing these and other developments, see [62].

Flexibility providers can benefit from revenue stacking only if it does not compromise the contracted capacity (i.e., avoidance of double activation) and in some cases their participation is subject to a minimum capacity on an aggregated or individual basis (i.e., Power Potential, UKPN and other DNOs in GB). In contrast with the typical flexibility providers represented by larger customers (e.g., business, commercial) and medium-large sized generators/storage systems (which usually participate in the provision of balancing services procured by system operators), the participation of residential customers in the provision of flexibility is permitted in many of the use cases. The participation of residential customers in flexibility markets is expected to grow in importance. However due to the limited size of their flexibility, a third party (i.e., aggregator or supplier) is required to facilitate residential trading, making the whole flexibility package more attractive for network operators. In addition, smart meters can also help to understand and better forecast the flexibility performance of residential customers, which can be translated into a more cost-reflective compensation scheme. This opens an interesting debate about the management of and access to customers' data. Are independent aggregators or DSOs allowed to get this data? Is the access restricted to retailers? Rules vary across jurisdictions with some of them already offering "one stop shop" for data (e.g., in Norway with Elhub which began operation in November 2019).

5.5. Penalites

Penalties seem superficially attractive, but in practice they appear to be expensive to impose because of flexibility providers' risk aversion. Non-payment for utilisation can be a large penalty in itself. However, there is an issue over availability payments needing some punishment to encourage actual availability. from the use cases, we observe how penalties are currently applied. Penalties for non-delivery are in the form of loss of revenues (sometimes with specific rules per type of payment and service). Some of them are supported by DSO and Feed-in Tariff (FIT) regulation such as Avacon in Germany, with loss of the network charge discount (Section 14a Energy Industry Act–EnWG–) for flexible loads and loss of compensation (FIT) for DER. Others have specific methodologies that reflect BAU operation rules (e.g., WPD and UKPN from GB in the procurement of flexibility services via demand response, V2G VPP Japan in line with balancing services, in GOPACS based on ETPA terms and conditions, etc.). For instance, WPD proposes a more sophisticated methodology in comparison with UKPN. Both define a threshold (of delivery performance: DP) where flexibility providers can be compensated fully if DP $\geq$ 90% or 95% respectively, however for lower values UKPN applies a linear relationship between the ratio of payment and DP, if DP < 60% no payment is made [63]. On the other hand, WPD applies a non-linear approach. According to WPD and based on its previous experience a linear relationship between utilisation payments and delivery does not incentivise the accurate declaration of capacity by flexibility providers [64]. There are also a group of use cases where penalty schemes have not been defined yet or are not imposed.

6. The Need for New Business Models

Network operators are using different ways to procure flexibility services. Some of them are testing more than one channel, such as WPD (via its own platform, Piclo Flex and CLEM), Liander (with Dynamo and via GOPACS too), Ausgrid with Battery VPP and additional demand response programmes (part of the Power2U Program). Except for Avacon, the participation of aggregators (which can be compulsory or optional) is permitted across all the use cases. According to [2], aggregators can provide: local flexibility (to DSOs subject to the existence of a local market), load shifting (in the form of demand side response to grid operators) and balancing services (such as ancillary services). Some network operators allow the procurement of flexibility services via a single aggregator (i.e., Battery VPP in Australia, Dynamo). Sometimes the decision to have one aggregator is due to a lack of participation in congested areas at specific sites (i.e., HV/MV substations). This is the case of Dynamo for instance. For this reason, the remuneration scheme agreed between the network operator and the aggregator is via regulated prices. Others require the participation of at least two aggregators to incentivise competition (i.e., Nice Smart Valley). The advantage of contracting with aggregators is that it mitigates the risks of non-delivery (aggregators compile and manage bulky capacity from a portfolio of smaller flexibility providers). Aggregators also facilitate the participation of residential customers in the provision of flexibility services to network operators (by aggregating small-scale flexible loads, generation and storage). However, the rules regarding the role of "independent aggregators" (which do not act as electricity suppliers) are not clear across the jurisdictions. For instance, France and Belgium are among the few European countries with specific rules for independent aggregators [65]. Independent aggregators may be discouraged from participating in specific markets (e.g., wholesale, ancillary services). For further discussion about independent aggregators and their participation in flexibility markets (i.e., demand response) see [66].

Independent platforms are also evolving and bringing new options for procuring flexibility services. Procuring flexibility services via independent platforms, especially those integrated within existing markets (e.g., GOPACS, Nodes), increases the chance of matching supply and demand. These platforms allow the participation of DSOs and the TSO and are examples of coordination platforms (i.e., DSO-TSO), preventing any conflicts as a result of congestion-related action by the DSOs or TSO. ALF is the other independent platform operated by Forschungsstelle für Energiewirtschaft e. V. (FfE), that in common with GOPACS and Nodes allows the matching of supply and demand orders; however, it is still under proof of concept. According to FfE, and at the time of writing, it was not clear whether ALF will continue as an independent platform or will be integrated into the DSO.

7. The Value of Flexibility

The value of flexibility depends on where, when and for what it is needed. From the use cases, only a few of them provide some indication about how the value of flexibility has been estimated (i.e., in the form of maximum/minimum payments). The decision to provide an indication of the value of flexibility depends also on the maturity of the flexibility market and whether this is integrated into an existing energy market (e.g., intra-day, day-ahead wholesale). It also may depend on the type of auction mechanism that is used. For instance, reverse auctions require a starting reference price provided by the buyer (i.e., it could be the costs of the conventional solution to solve the problem: network reinforcement, diesel generation costs etc.). The procurement of flexibility services by DNOs in GB is relatively new (starting in 2019 as BAU). This means that potential flexibility providers may still need an indication of the size of their payments. However, in the case of GOPACS, Nodes and also V2G VPP in Japan (all these are integrated or are due to be integrated into existing markets), a pay-as-bid approach is used with free prices and without any indication of potential gains. This makes sense because the number of flexibility providers is potentially larger, increasing participation and liquidity.

From the use cases we observe WPD uses a maximum value irrespective of the site (set at £300/MWh), UKPN provides a range of minimum and maximum values associated with each HV site as a result of cost benefit analysis and Enedis proposes a maximum value irrespective of the site. For Avacon however, the value is established via regulation (i.e., network grid discounts offered by the DSO). None of these projects provide details of the methodology used. A brief explanation is provided by Enedis [60]. However, this is a general value that is not associated with the problem to be solved in Nice Smart Valley use case. In the case of WPD the value is just an indication from a previous project. WPD has suggested that it may use of a pay-as-clear approach (with free prices) when there is enough competition. However, results from the experiment (CLEM with WPD Phase 2), suggest that flexibility providers have continued bidding at prices close to the original value.

The value of flexibility can be estimated based on the cost of counterfactual solutions to solve the problem. For instance, if there is a need to reinforce the network, the value of flexibility is related to the cost of deferred capital. This can be estimated as an annual value in order to set the maximum amount the distribution utility could spend in flexibility per year at a specific point of the network. Flexibility can be an alternative to network reinforcement, however, in practice different potential options need to be evaluated by distribution utilities. These include reconfiguration of the existing network with appropriate switching in and out of equipment and the use of utility only assets (i.e., a voltage tap changer), or the use of assets that can be run hotter for longer with better maintenance etc.

The value of flexible services should also consider regulatory incentives and total costs (totex). In GB, the RIIO-ED1 totex allowance provides financial incentives to DNOs to optimally trade off capital and operating costs in order to minimise total costs. Financial incentives (or penalties) also apply to (1) quality of service measures such as customer minute lost—CML and customer interruptions—CI; (2) connections (time to connect incentive); (3) customer services (related to social obligations output); and (4) losses (a discretionary reward scheme). The largest incentives come from the interruptions incentive scheme—IIS (composed of CML and CI). For instance, for the period 2017–2018 IIS incentives represented around 70% of the total incentives [67].

The case for the inclusion of option value is less clear. This requires a probabilistic view of the future. It is quite difficult to provide a comprehensive and passably accurate set of all the relevant future scenarios in which the participation of an asset or DER solution might appear. As [68] makes clear in Chapter 5 (on Real Option Valuation), the problem with real options is that they are a qualitative and somewhat subjective way of departing from normal investment appraisal. They are particularly popular and useful in natural resource sectors, or sectors with exclusive rights (e.g., investment in a patent protected technology). They should be treated with caution under the following circumstances: first, when the initial investment is not a pre-requisite to subsequent investments; second, when the firm does not have the exclusive right to make subsequent investments; and third, when, the advantage the option investment gives does not lead to sustained advantage. These criticisms apply in a world of uncertainty about the future path of technology for flexibility within the electricity sector. Another problem, as [67] notes, with non-tradeable options is that they will inevitably not be fully reflected in the valuation of a private firm. For a regulated firm this translates to the risk that the regulator might not fully recognise the cost of a real option in its regulatory asset base.

If option value is to be recognised at all in a regulatory setting, there has to be a cap on willingness to pay for option value. There is in every other sphere of economic activity. This is because if there is not a cap one can end up justifying large amounts to be spent on contingencies most of which will never be realised and which will therefore be difficult to justify ex post. For a good discussion of the role of option value in investments more generally, see [69] and for option value in transmission planning [70].

Some jurisdictions such as New York have suggested a common methodology for valuing flexibility with a focus on those provided by DER. Each of the six distribution utilities in New York State (known as Investor-owned utilities—IOUs) has produced its own document on how to do cost benefit analysis of DER, see for instance [71]. These documents point out the dangers of double counting and the need to carefully work out whether a category of benefit is additional to others already included. The methodology identifies four pots of benefits (e.g., bulk system, distribution system, reliability/resiliency and external) and costs (including incentives to participate). An interesting approach is the credit given to community generation (at 2.25 c/kWh) [72]. This raises the issue of an additional value to be put on community DER, not captured elsewhere.

After selecting and estimating the respective values for each factor, the next step is to estimate the total costs of the counterfactual which reflects the willingness to pay for flexibility. Depending on the type of service and estimations of its use, the total value can then be expressed in single components (i.e., maximum annual availability and utilisation prices).

8. Most and Least Common Trends and What Is Still Missing

8.1. Most Common Trends

Many of the use cases involve the procurement of a set of flexibility services (i.e., multiple products provided by a diverse range of technologies) which aim to solve different types of grid constraints, with a focus on congestion at the distribution level. Among the most common technologies are solar PV, storage systems (including domestic batteries), wind turbines, flexible loads (such as heat pumps) and CHP. There is also a combination of different remuneration schemes, with utilisation and availability payments, with pay-as-bid (including those with regulated components) being the most common approach. The participation of third parties such as aggregators is also allowed in most of the use cases. In some cases, their participation can be compulsory (e.g., Battery VPP, V2G VPP Japan, Nice Smart Valley, Dynamo), in others it can be optional (e.g., ALF, WPD with Flexible Power, UKPN, Power Potential). Independent platforms are also evolving, and many DSOs are using them (or planning to) as an alternative way to procure flexibility services.

8.2. Least Common Trends

Only a few of the use cases specify the procurement of ancillary services, especially in the form of reactive power/voltage management. In terms of flexibility services, Nice Smart Valley is the only one where flexibility is also provided by customers with hybrid systems (i.e., by switching from gas and electricity to only gas in case of network constraints). A hybrid system produces both heating and domestic hot water using gas or electricity. The selection of the most efficient generator is managed by an intelligent control system. This is the first time in France that a remote control was built in order to manage gas appliances [73]. The matching of supply and demand orders are only observed in platforms that are integrated within existing markets, with the exception of ALF which also offers this matching (still in "proof of concept"). GOPACS is the only one where the "intraday congestion spread (IDCONS)" is paid instead by the network operator (TSO or DSO) that requires the flexibility service (estimated by the price difference between the seller and buy orders). According to Stedin (a DSO), the probability of having no matching orders is very low, due to the interaction of GOPACS with the existing market which has sufficient liquidity. However, if matching does not happen the market model changes to the mandatory regime, where bidding is required.

In comparison with other distribution utilities, several DNOs from GB are already procuring flexibility services via Piclo Flex as BAU. GOPACS has been adopted by a few DSOs and by a TSO (TenneT) as BAU. In terms of the pricing rule, CLEM with WPD (Phase 2) is the only use case with a pay-as-clear proposal. WPD performs a N-2 test to determine whether to proceed with the pay-as-clear approach. The test provides information about the zones with enough participation to allow market clearing, otherwise the maximum price approach (i.e., £300/MWh) applies instead [74]. This approach is in line with the new pricing strategy proposed by WPD composed of three phases: Phase 1 fixed (current situation with a maximum value of £300/MWh), Phase 2 Pay-as-clear (when there is enough competition) and Phase 3 Full Market (a progression toward close to real-time market operation) [75].

8.3. What Is Still Missing

In general, most of the use cases propose standard procurement methods to contract for flexibility services. To some extent many of the services procured are already being contracted by system operators (TSOs); the difference here is the application of these services (i.e., for distribution grid management). Given that flexibility services are contracted by the DSOs (with operations subject to regulatory oversight), what is missing is a clear and standard methodology (at the country-level) that supports the selection of the most cost-efficient approach (i.e., baseline versus flexibility options). This is an important step that will help to define the maximum and minimum values that DSOs are willing to accept at each site (i.e., each substation). Other auction mechanisms need to be tested in the light of the increase of DER. There should also be a move towards uniform (pay-as-clear) pricing rather than discriminatory (pay-as-bid) settlement rules. For a clear discussion of the need for both capacity-based bid selection and uniform pricing see [76]. This is because pay-as-bid rules encourage inefficient bidding and are out of line with wholesale energy market pricing.

In the context of a new flexibility procurement auction, such as MERLIN, a reverse auction for DER response might make sense, rather than a fixed price. A reverse auction is a common method to auction diamonds, radio spectrum, electricity, gas, and other products [77]. The starting price cap could be the cost of the conventional solution (i.e., baseline costs). This reverse auction could specify a minimum benefit for customers to be achieved in the auction before it would be completed. This minimum benefit would cover the costs of the auction, plus some target revenue benefit for the customers. This benefit would arise as a combination of the price and quantity of flexibility; hence the auction would trade off lower prices and lower quantities of flexibility. The reverse auction should be a descending clock with an activity rule and deferred acceptance to make sure that all bidders participate fully and bid truthfully. An activity rule ensures that each bidder remains active and only reveals its hand at the end of the auction (which is what happens in an eBay auction). It means that bidders need to participate in each round of the auction, indicating their willingness to accept the current price, in order to stay in the auction. Deferred acceptance means that if bidders reject an offer price this is irreversible (i.e., bidders cannot re-enter at a lower price in the reverse auction) and no bid is firmly accepted until the final reconciliation. Bids could be made competitive across multiple constrained locations with some sort of bid scoring mechanism to handle the value of different locations. There may be rough and ready ways to clear a multi-locational auction, which provide a reasonable degree of efficiency, in line with [78]. Deferred acceptance allows the DNO to check whether there are any network reconfigurations, in the light of all bid quantities and prices, which add consumer value, and this could be specifically made part of the auction. There would be room for experimentation as to the bid increments, the number of constraints to be included and the target revenue benefit from the auction to be set etc.

We suggest there is value in experimenting with a reverse clock auction and a revenue benefit target. This would involve starting the bidding at the willingness to pay for flexibility and reducing the price to increase the benefit to customers. The auction would be concluded when the target benefit had been achieved. The payment rule would be pay as clear—i.e., at the closing price all remaining offers in the market would be accepted and paid the closing price. The existence of a large number of potential flexibility providers reinforces our preference for pay-as-clear rather than pay-as-bid.

9. The Role of Regulation

From the use cases, we observe different ways in which regulation can help to integrate flexibility solutions (and all the advantages that this can provide) within BAU network operation. These can be through funding innovation projects, adapting the price control schemes to promote more flexible networks and cost reflective tariffs, enabling and democratising digitalisation, and setting clear roles among the different parties (DSOs, aggregators etc.).

Regulation encourages network operators to experiment (via innovation funds or regulatory sandboxes) in order to gain knowledge that supports future regulation. Many of the use cases analysed in this paper have been partially funded by governments under specific competitive schemes such as Network Innovation Competition in GB, Schaufenster intelligente Energie (Sinteg) in Germany, METI in Japan, Australian Energy Regulator (AER), some of which focus on VPP and demand response programmes. The aim of the demonstrator projects is not limited to testing the role of distribution utilities as neutral market facilitators for DER, encouraging new market participants and testing new business models for trading flexibility services. It also aims to identify current limitations and future developments in the regulatory arena that promote flexibility.

Regulation can help to provide the right incentives for network operators to opt for flexibility and hence more efficient operation, however finding a balanced approach—not over scaling the regulatory approach—is always a challenge. One way is via Totex regulation. Totex regulation is adopted in GB, Germany, The Netherlands and Norway [79]. Due to its sophistication, the pace of its development (in time and specification) differs across countries. GB implemented the first Totex regulation in DPCR5 (period 2010–2015). Totex regulation goes beyond the energy sector with applications in the water sector (e.g., Ofwat in GB). A different approach is found in Australia, where the Regulatory Investment Test for Distribution (RIT-D) scheme promotes efficient investment in the distribution network by requiring higher value network projects to look for non-network options (i.e., flexibility services from DER) [43].

Setting more cost-reflective tariffs is something that can also help, for instance through the introduction of dynamic pricing facilitated via smart meters subject to minimum requirements [80]. Looking forward, some studies acknowledge the benefits of distribution local marginal pricing (DLMP) to manage congestion using DER [81]. Even through nodal prices for transmission pricing (estimated as a result of an economic optimisation) have been applied by many system operators (e.g., USA, Australia, New Zealand, Singapore), their implementation at the distribution level is arguable and will depend on the level of granularity required. Full DLMP based on economic optimisation at distribution level is still impractical due to lack of reliable optimisation methods [82].

Regulation also encourages digitalisation, especially in the adoption of smart meters and associated data management. The efficient management and integration of small-scale flexibilities needs to be supported by smart meters, especially in the residential sector. This is important, considering that in most of the use cases the participation of the residential sector is supported. All the jurisdictions of the use cases evaluated in this paper are committed to supporting smart meter implementation (partially or nationwide). However, implementation varies. Norway completed their nationwide smart meter rollout in early 2019, followed by The Netherlands in 2020, while Germany will require until 2032. In Germany the rollout is mandatory only for customers with a consumption over 6 MWh (however those with lower consumption can voluntarily opt for it).

Regulation can also help set the rules for accessing and managing behind the meter flexibility assets. Flexibility assets behind the meter need to be visible and tradable. In the case of Germany, we observed that there are limitations on the participation of domestic battery systems. The current rules encourage behind-the-meter applications only, ignoring the potential to provide flexibility services in-front-of the meter.

Regulation can help to define the role of independent aggregators (also known as VPP operators) in the flexibility value chain. Aggregators are instrumental for explicit demand-side flexibility (which involves a financial reward from network operators to flexibility providers). Regulation regarding the role of independent aggregators varies across jurisdictions, especially in relation to their participation in retail, wholesale and ancillary markets. For instance, in the European market the participation of independent aggregators is mainly associated with industrial and commercial customers [83]. France is among the first movers—since 2003—in opening its different markets to the participation of independent aggregators (focusing on demand side response—see [84]). In GB, their participation in the provision of balancing services to NGESO in the form of a "Virtual Lead Party" has been approved [85].

Regulators, along with industry stakeholders, will help to shape the future of the DSO by defining clear functions and new roles for distribution utilities (e.g., as a neutral market facilitator), including the extent of their interactions with other parties (e.g., TSOs, aggregators). Most of the use cases that are part of this study are testing new DSO capabilities to manage the grid using flexibility services provided by third parties. No jurisdictions have yet decided on a framework that reaffirms distribution utilities as neutral market facilitators for DER or the creation of an independent party to manage this. The interaction between DSO-TSO is being evaluated in some jurisdictions of the use cases such as Australia, GB and The Netherlands.

10. Concluding Remarks

This paper explores the development of innovation projects and independent market platforms where the use of flexibility services from third parties is proposed to solve grid issues, especially at distribution. Thirteen use cases from seven jurisdictions were evaluated covering different dimensions including the smart architectures, market design, new business models, value of flexibility, identification of most and least common trends. The role of regulation in the integration of more flexibility solutions was also discussed briefly. Key lessons from innovation projects can be identified per each dimension. These are summarised in the next paragraphs.

First, the key thing for a successful smart architecture is that it is easy for participants to understand and access. Making it as easy as possible to participate in a local flexibility market is key. A proof-of- concept exercise is recommended to test the capabilities of both the platforms themselves and their interoperability with existing systems. Simulation of flexibility markets is necessary to test optimisation algorithms, market rules etc. We would also recommend extensive stakeholder engagement to encourage market participation and feedback on the design of the smart interface.

Second, clear rules regarding the market design to be adopted with specifications according to the type of service to be procured are required. For more established services we would recommend similar rules to the current ones applied by the GB DNOs (with respect to names, type of compensation, and penalty schemes) in order to ensure consistency, standardisation and stakeholder buy-in. In terms of penalties, non-payment for non-delivery is a significant penalty. It is a good idea to have some penalty in the case of non-delivery during a specific event where flexibility was requested but not delivered by a contracted party. This penalty would vary from non-payment of utilisation payments if the contract was 100% on utilisation payment only, to some fraction of the availability payment if the payment were 100% on availability only. For the UK capacity market non-delivery penalties for an individual unit are capped at 200% of monthly capacity payments [86].

Third, new business models that work depend on there being underlying sources of value to society that can be monetised. It is the role of the DSO in innovation projects to identify what those sources of value are and to market test them. It may be that new business models can be facilitated by actively encouraging DER and aggregator participation and, potentially, by signing exclusive contracts with a single aggregator, to whom encouraging participation is then delegated.

Fourth, DSOs seeking to procure flexibility need to publish the principles on which they will evaluate the value of flexibility at a given network node and hence their willingness to pay for flexibility (in line with the different services to be procured). This would involve building on the benefit-cost of DER methodologies outlined by the New York utilities (IOUs), suitably adapted for the local context. For example, in the UK this would involve making use of values in line with HM Treasury guidance on social cost benefit analysis. This recommendation is in line with the recent proposal of the ENA Open Networks Project (Workstream 1A—Flexibility Services) regarding the need to account for a common methodology across DNOs for Active Network Management (ANM) vs. Flexibility vs. Reinforcement vs. other options [87].

Fifth, in the identification of the least common trends in the procurement of flexibility services, one area where more experimentation is needed is auction design. We suggest there is value in experimenting with a reverse clock auction and a revenue benefit target. This would involve starting the bidding at the willingness to pay for flexibility and reducing the price to increase the benefit to customers. The auction would be concluded when the target benefit had been achieved. The payment rule would be pay as clear—i.e., at the closing price all remaining offers in the market would be accepted and paid the closing price. The larger the number of potential flexibility providers the more the preference for pay-as-clear (rather than pay-as-bid).

Finally, having a supportive regulatory environment around flexibility is crucial. An important task of innovation projects is to identify the limitations of the current regulatory regime in supporting socially desirable innovation. Unlocking the value of flexibility depends on allowing the benefits to society to be monetised via the regulatory regime. We discuss the role of regulation more fully in our other paper in this special issue [32].

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Abbreviations

ADMS	Advanced Distribution Management System
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ARENA	Australian Renewable Energy Agency
BAU	Business as Usual
CEER	Council of European Energy Regulators
DER	Distributed Energy Resources
DERMS	Distributed Energy Resources Management System
DNO	Distribution Network Operator
DSO	Distribution System Operator
ENA	Energy Networks Association
ENWL	Electricity North West
ETPA	Energy Trading Platform Amsterdam
FP	Flexibility Provider

GOPACS	Grid Operators Platform for Congestion Solutions
IDCONS	Intra-day Congestion Spread
IOU	Investor-Owned-Utility
LEO	Local Energy Oxford
MERLIN	Modelling the Economic Reactions Linking Individual Networks
METI	Minister for Economy, Transport and Infrastructure—Japan
NGESO	National Grid Electricity System Operator
OFGEM	Office of Gas and Electricity Markets
RIT-D	Regulatory Investment Test for Distribution
RIT-T	Regulatory Investment Test for Transmission
SCADA	Supervisory Control and Data Acquisition
SGH	Smart Grid Hub
SPEN	Scottish Power Energy Networks
SSEN	Scottish and Southern Electricity Networks
TSO	Transmission System Operator
UKPN	UK Power Networks
USEF	Universal Smart Energy Framework
SINTEG	Schaufenster intelligente Energie—Digitale Agenda für die Energiewende (Smart energy showcases— digital agenda for the energy transition)
V2G	Vehicle to Grid
VPP	Virtual Power Plant
WPD	Western Power Distribution

Appendix A

Table A1. Use Case Template.

About the project	Name
	Location
	Description
	Project/initiative lead (any DSO, TSO, others?)
	Project/initiative partners
	Type of project/initiative (trial, business as usual)
	Start date
	End date (leave blank if this is BAU)
	Government/local authority/EU funded (Yes/No)
	Name of the programme/scheme (e.g., SINTEG in Germany, NIC in UK)
	Problem(s) to solve (e.g., congestion management, voltage or thermal constraints, other)
	Flexibility providers (solar PV, batteries, heat pumps, etc.)
Auction design and trading mechanism	Name/type of product
	Problem to be solved
	Price rule (e.g., pay as bid, pay as clear, other)
	Remuneration scheme (e.g., availability, utilisation, both, number of activations, other)
	Price formation for availability (e.g., regulated, free, other)
	Price formation for utilisation (e.g., regulated, free, other, na)
	Maximum price for utilisation (€/MWh)
	Minimum bid (MW)
	Maximum bid (MW)
	Length of contract

Table A1. *Cont.*

Auction design and trading mechanism	Maximum price for availability (€/kW)
	Procurement period (the time when the service is provided)
	Trading period (e.g., day-ahead until 4 pm, or between 10 am–12 pm)
	Number of tenders per year or periodicity (monthly, quarterly, anytime, other)
	Define the party that trades (e.g., direct trading, via aggregators, both)
Others	DER connection point (LV, other)
	Are residential customers involved in the provision of flexibility services? (yes, no)
	Use of DERMS for the project (yes, no, na)
	DSO-DSO coordination (yes, no)
	DSO-TSO coordination (yes, no)
	Grid management need (DSO, TSO, both)
	Penalties for non-delivery (yes, no). Specify trigger for non-delivery (e.g., if availability is less than 60% then zero payment)

Appendix B

Table A2. Use Case Comparison Table.

Part 1				
Country	**Use Case**	**Product/Service to Be Traded/Tested**	**Flexibility Providers**	**Quantity Traded or to Be Traded**
Australia	Battery Virtual Power Plant (VPP)	constraint management and voltage constraints (phase 2)	residential battery systems	up to 1 MW (VPP)
France	Nice Smart Valley	distribution grid constraint (congestion)	hybrid systems (residential hybrid boilers, CHP commercial building, hybrid rooftop), flexible customers (residential, industrial)	not available
Germany	Avacon	distribution grid constraint (congestion)	residential flexible loads (heat pumps, storage heaters) and generation assets (solar PV)	not available
	The Altdorfer Flexmarkt (ALF)	constraint management (with short- and long-term products)	PV systems, heat pumps, electric vehicles, and storage systems, such as night storage heaters, home batteries	not applicable
GB	Power Potential (NGESO)	reactive and active power	PV systems, wind turbines, CHP, biogas plants, etc.	approx. 11,700 MVarh (wave 2)
	Flexible Power (WPD)	flexibility services (several)	PV systems, wind turbines, CHP, biogas plants, storage systems, flexible loads	880 MW contracted for 2020
	Flexibility Services—Hub (UKPN)	flexibility services (several)	PV systems, wind turbines, CHP, biogas plants, storage systems, flexible loads	105 MW contracted for 2020
	Piclo Flex	flexibility services (several)	PV systems, wind turbines, CHP, biogas plants, storage systems, flexible loads	depends on the capacity to be procured by DNOs

Table A2. *Cont.*

Part 1				
Country	**Use Case**	**Product/Service to Be Traded/Tested**	**Flexibility Providers**	**Quantity Traded or to Be Traded**
GB	Cornwall Local Energy Market	flexibility services (several)	diesel generators, gas turbine, flow battery, domestic battery clusters, ice manufacturer	11 MVA (phase 1)
Japan	V2G Demonstrator Project Using EVs as VPP Resource	Replacement Reserve—for FIT (“RR-FIT”) due to network congestion, voltage constraints	EV batteries (V2G-VPP)	not applicable
The Netherlands	Dynamo	constraint management (congestion)	Lidl (with cold store and battery at the distribution centre), Van del Valk (heat pump)	not available
	GOPACS	constraint management (congestion), TSO-DSO coordination	PV systems, wind turbines, CHP, biogas plants, storage systems, etc	TenneT (36,000 MWh) intraday market
Norway	Nodes	congestion, grid management, balancing services	PV systems, wind turbines, CHP, biogas plants, storage systems, etc	not available

Part 2					
Country	**Use Case**	**Price Rule**	**Use of Maximum Prices, Ranges (Market-Based Only)**	**Remuneration Scheme**	**Aggregators**
Australia	Battery Virtual Power Plant (VPP)	regulated prices (customers)	not applicable	only dispatch (10 kW battery with 10–15 dispatch events can get paid between $90-$135 per year)	required (Reposit Power)
France	Nice Smart Valley	pay-as-bid (aggregator), regulated prices (customers)	not directly but subject to the value of flexibility set by Enedis	(1) availability/others: for aggregators depending on the Use Case; for customers: fixed/variable amounts to participate in the trial; (2) utilisation: for aggregators free	required (EDF, Engie)
Germany	Avacon	regulated prices (non market-based)	not applicable	(1) availability/others: Flex loads (a discount of around 57% of grid charge), (2) utilisation: DER compensated in line with loss of production	no

Table A2. *Cont.*

Part 2					
Country	**Use Case**	**Price Rule**	**Use of Maximum Prices, Ranges (Market-Based Only)**	**Remuneration Scheme**	**Aggregators**
Germany	The Altdorfer Flexmarkt (ALF)	short term: pay-as-bid, long term: regulated prices (customers)	not defined yet	(1) short term: utilisation according to contracted power and offered price, (2) long term: lump-sum payment (i.e., yearly)	optional (short term), no (long term)
GB	Power Potential (NGESO)	pay-as-bid (wave 2)	no	utilisation (active and reactive power) and availability (reactive power)	optional
	Flexible Power (WPD)	pay-as-bid (with regulated prices)	yes	availability (secure, dynamic), utilisation (secure, dynamic, restore); with maximum prices (£300/MWh secure, dynamic; £600/MWh restore)	optional
	Flexibility Services—Hub (UKPN)	HV: pay-as-bid, LV: regulated price	yes (range per site)	availability (secure), utilisation (secure, dynamic), service fee (sustain: £47.58/kW/year). Range (with lower and upper values) regarding total price for HV (secure)	optional
	Piclo Flex	pay-as-bid	yes (based on each DNO's requirements)	utilisation and/or availability depending on the service	optional
	Cornwall Local Energy Market	phase 1: pay-as-bid (with regulated prices), phase 2: pay-as-clear	yes (Phase 1)	phase 1: utilisation, phase 2: utilisation, availability (reservation). Regulated price up to £300/MWh (combined) in phase 1	optional, phase 1 (Kiwi Power)
Japan	V2G Demonstrator Project Using EVs as VPP Resource	pay-as-bid	no	RR-FIT: (1) paid for both delta-kW (availability) (2) and kWh (utilisation).	required (Hitachi Solutions, Shizuoka Gas)

Table A2. *Cont.*

Part 2

Country	Use Case	Price Rule	Use of Maximum Prices, Ranges (Market-Based Only)	Remuneration Scheme	Aggregators
The Netherlands	Dynamo	regulated price (aggregator)	not applicable	availability and utilisation. High ratio availability/utilisation (0.9)	required (Scholt Energy)
	GOPACS	pay-as-bid (trading parties), TSO/DSO pay a spread (difference between buy and sell order)	no	dispatch (utilisation)	optional
Norway	Nodes	pay-as-bid	no	utilisation (dispatch), availability	optional

Part 3

Country	Use Case	Smart Solutions/Others	Interesting Features/Findings	Issues
Australia	Battery Virtual Power Plant (VPP)	control algorithms (learn and forecast household consumption and generation)	significant increase in average customer dispatch power due to VPP dispatch	(1) need of accurate short-term forecasting of customer demand to ensure optimisation of battery dispatch, (2) need to investigate no matching between accepted energy&requested energy dispatch
France	Nice Smart Valley	E-FLEX platform, forecasting tool (developed by GE&Enedis)	(1) the best way to reward residential customers via a reduction in energy bill, (2) among the first DSOs in testing flexibility from gas customers	(1) flexibility price set by Enedis for flexibility (€ 24/kW/year) is too low to encourage FP participation, (2) need to combine flexibility with other services (energy efficiency) to attract more participants
Germany	Avacon	Smart Grid Hub (a single use of DERMS)	(1) overall curtailments can be reduced up to 4% due to higher precision and finer granularity, (2) use of smart flex-control mechanism	(1) no clear rules regarding activation of interruptible loads and the provision of flexibility services via in front of the meter applications, (2) lack/poor mobile network coverage
	The Altdorfer Flexmarkt (ALF)	ALF platform, smart meter gateway (SMGW)	(1) identification of two products: short term, long term, (2) smart meters as an enabler to small-scale flexibility integration	legal and regulatory boundary conditions have been essential to create the platform concept

Table A2. *Cont.*

Part 3				
Country	**Use Case**	**Smart Solutions/Others**	**Interesting Features/Findings**	**Issues**
GB	Power Potential (NGESO)	DERMS (DSO), PAS (NGESO)	(1) procurement of RP from DER by NGESO, (2) coordination TSO-DSO	long delay implementation due to integration issues, securing participants
	Flexible Power (WPD)	DERMS	three different channels to procure flexibility	(1) there is still lack of competition in many CMZs: in the latest tender all contracts (94.8 MW) were awarded on a fixed price basis)
	Flexibility Services—Hub (UKPN)	DERMS	(1) first DNO in procuring flexibility in LV sites, (2) long-term certainty of delivery	
	Piclo Flex	online energy trading marketplace	(1) national platform (involves several DSOs), (2) neutral and independent marketplace	Viability of Piclo's current business model in the long term is not clear
	Cornwall Local Energy Market	N-SIDE: optimal clearing solution with identification of constraints	simultaneous procurement of flexibility services by WPD and NGESO using the same pool of resources	(1) Phase 1: large variation in delivering between providers (2) Phase 2 prices were still close to £300/MWh even though the use of pay-as-clear
Japan	V2G Demonstrator Project Using EVs as Virtual Power Plant Resource	DERMS	(1) VPP (V2G) to support grid management including reactive power, (2) demonstrated viability (technical, V2G business model)	(1) in the current solution EVs are controlled site by site with no possibility of switching capacity (use of unused EV due to disconnection of other EV), however this will be tested in the next year, (2) EV battery aging analysis is required due to frequent charging/discharging
The Netherlands	Dynamo	USEF	testing different ways to procure flexibility, GOPACS is the next step	(1) securing participants and aggregators, (2) issues for controlling whole capacity, (3) flexibility from cooling less practical than batteries
	GOPACS	active management cooperation (TSO-DSO)	(1) national platform (involves several DSOs and TSO), (2) interaction with intraday market, (3) use of IDCONS	Only Tennet and 2 DSOs are currently operating
Norway	Nodes	active management cooperation (TSO-DSO)	(1) integrated within existing markets, (2) flexibility is available for all the parties	to ensure transparency the platform should be operated by an independent neutral party

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