Ofgem Cover Note

The recent Ofgem Call for Input on the Future of Distributed Flexibility has sparked widespread interest. This report is published as further background work, that has been undertaken since the release of the Call for Input, to ensure the information and analysis is openly available to all.

A standard interface model was identified as a fundamental enabler to any common digital energy infrastructure, as described in the Call for Input technical annex. This study was therefore commissioned by Ofgem to provide an initial high-level appraisal of candidate data standards potentially suitable for facilitating data exchange for market participants.

Ofgem extended the scope of the Long Term Development Statement (LTDS) reforms work to include this small piece of work on market standards. The LTDS reforms project aims to improve network planning data by implementing updated data standards using the Common Information Model (CIM). This technical work was tendered via Crown Commercial Services and the competitive tender won by Open Grid Systems (OGS). This ongoing work allowed Ofgem to leverage the OGS consortium's expertise on data standards, such as the CIM, and apply it to the emerging understanding of the need for a standard interface model.

The market standards study was a short, focused 6-week piece of work, combining desk-based research with a limited number of stakeholder interviews to investigate a range of international data standards. The report utilises a 'traffic-light system' to assess each candidate data standard based on objective criteria . This approach identifies and evaluates a small set of potentially applicable standards, selects the most suitable option, and outlines possible next steps for progressing that option.

However, we want to make clear that Ofgem is not proposing any specific standard in the Call for Input. Ofgem wants to actively use the Call for Input as an open opportunity for all views and information to be gathered to inform ongoing work. The findings of this report are published to facilitate wider debate and demonstrate the importance of open standards in realising the future vision outlined in the Call for Input.

The study and the associated conversations have been valuable in informing our ongoing thinking on the enabling work required for a standard interface model. We extend our thanks to the OGS consortium for their diligence and challenge.

Flexibility Markets:
Market Standards Study

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Executive Summary

Ofgem, in its Call for Input on The Future of Distributed Flexibility, discusses optimising the contribution of Distributed Energy Resources (DERs) and Consumer Energy Resources (CERs) for the dual goals of electric sector carbon reduction and safe, reliable and affordable electricity delivery. Given the current landscape in the United Kingdom – characterised by both market failures and the emergence of multiple flexibility markets with divergent, but overlapping, objectives and services, Ofgem suggested that there was a role for a common digital energy infrastructure. While Ofgem was neutral on the form such an infrastructure might take, the importance of quality interfaces - between the infrastructure and buyers, sellers, markets, and outside entities - as the enablers of any solution was emphasized.

In this report, candidate standards for enabling the interfaces of a common digital energy infrastructure were identified from the offerings of Standards Development Organisations (SDOs), like the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE), as well as from associations like the Organization for the Advancement of Structured Information Standards (OASIS) and the European Forum for Energy Business Information Exchange (ebIX). The authors validated the identified list of standards by reviewing a variety of existing market implementations, market platforms and market research initiatives for their use of standards-based data exchanges. Despite the real value standards will deliver to a common digital energy infrastructure, their existing use in business-level market data exchanges turns out to be quite rare, especially when compared with the more prevalent standards dedicated to communications with DER and CER devices.

Ultimately five potential viable candidate standards were identified:

- IEC Common Information Model (CIM)
- ebIX
- OpenADR
- IEC 61850-7-420
- IEEE 2030.5

A framework for evaluation was created that rated standards on four metrics:

- **The data domains covered by the standard.** In the context of this report a data domain is simply a category of data shared across the interfaces of a common digital energy infrastructure. Eight data domains were identified: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement, Grid Model. Standards with broader coverage were rated higher.
- **The type of information model used by the standard.** Standards implementing a message model (defining the structure of individual messages) were rated lower than standards leveraging a semantic model (defining an underlying information model used to structure content of all messages).
- **The development process.** Standards with a curated process supported by a Standards Development Organisation (SDO) were rated higher than standards supported by a community process provided by an industry membership organisation.
- **The richness of the message library.** The broader and deeper the coverage a standard provided for its supported data domains, the higher the rating.

The standards and their ratings are summarised in the table below:

	IEC CIM	ebIX	OpenADR	IEC 61850	IEEE 2030.5
Data Domains	8	4	5	3	3
Data Model	Semantic Model	Message Model	Message Model	Semantic Model	Semantic Model
Development Process	Curated	Curated	Community	Curated	Curated
Message Library	Rich	Developed	Developed	Developed	Developed

The IEC CIM has been recommended as the preferred standard. It is the only standard that has defined data exchanges supporting all eight identified data domains. It has a single, cohesive underlying semantic model supporting all of its data exchange profiles. Its development is supported by a well-respected SDO. And the depth and breadth of its coverage in many of the data domains is substantial.

While the CIM is the best choice as the data exchange standard for the interfaces of a common digital energy infrastructure, it also presents a broad and complex picture in its coverage of the various data domains. While no single CIM standard profile supports all of the identified data domains, their union does a thorough job of doing so, with some data domains supported two, three or even four times over.

This complex picture is the reason that a two-phase, and highly collaborative, approach to moving forward is recommended.

1. **Determine the approach to be taken, in each data domain, for leveraging the CIM standards.** There are many possible methods of defining the CIM-based standards to be used to support a given data domain: they range from selecting one standard as it exists, to modifying an existing standard, to merging two or three standards, to creating a new exchange profile and submitting it to the appropriate CIM standard Working Group.
2. **Define the sets of profiles to be used for the common digital energy infrastructure.** The definition of the profiles (subsets of CIM data) to support the various interfaces should be done in collaboration with the appropriate CIM Working Groups, user communities, and including the wide variety of other stakeholders with interest in a common digital energy infrastructure. The results of the work should be contributed back into the CIM for wider use from the industry at large.

Both phases should be done in parallel with the equivalent common digital energy infrastructure design activity, with the first phase run concurrently with the infrastructure's conceptual design and the second phase executed in concert with its detailed implementation design. The authors believe that the use and insightful enhancement of the CIM standard in the realisation of a common digital energy infrastructure, if done intentionally and collaboratively, has the potential to deliver significant value to both the UK and to the electric industry around the world.

1. Introduction

In its call for input on The Future of Distributed Flexibility[1], Ofgem identified data standards as a key enabler of a common digital energy infrastructure, regardless of the architectural form such a solution might take. While standards, both formal and de facto, for the exchange of market-related data and DER-related data have emerged over the last two decades, existing flexibility market solutions have typically leveraged only those standards supporting device level communications, rarely implementing standards-based data exchange among market parties.

The lack of standards adoption in business-level market data exchanges is due, in large part, to the fact that market interfaces have been viewed as enabling communication between various "clients" (buyers and sellers) and single market platform "server" which was solely responsible for defining its own interfaces. Market platforms were not concerned with sharing data with entities other than their clients, so interface design was driven largely by the data structure needed to support the functions and algorithms of a given market platform's software. And since the number of markets a given market client has historically needed to interact with has been relatively limited, there has not been significant impetus for client side calls for data standardisation either.

As emerging markets for flexibility (as well as clients for these markets) proliferate, the situation changes. A given seller or buyer may want to participate in multiple flexibility markets. Furthermore, it is becoming clear that optimising the value of Distributed Energy Resources (DER) will require markets themselves to coordinate. The Ofgem call for input contemplates a common digital energy infrastructure that depends on standardised data exchanges to facilitate effective communication, to enable rapid response to changing market needs, and to reduce barriers to client entry.

This report aims to inform this conversation by evaluating alternative data exchange standards for suitability as the foundation for the information exchanges of a common digital energy infrastructure, recommending an option based on objective criteria, and outlining a set of actions to move that option forward.

[1] Ofgem: Call for Input on The Future of Distributed Flexibility

2. Evaluation Approach

The purpose of the analysis presented in this report is to narrow the field of data exchange options to a small set of potentially applicable standards and, from that short list of candidates, select a preferred option and outline actions for moving that option forward. The approach used in the analysis relies on the notion of data domains. Data domains are groups of closely related information which are often exchanged in messages between parties collaborating to accomplish a purpose. There are several data domains that play a crucial role in realising the goal of flexibility optimisation. This report identifies a collection of these data domains and leverages them as a framework for exploring the interface requirements and standards necessary to support a common digital energy infrastructure.

2.1. Data Domains

2.1.1. Data Domains for Electricity Markets

As a first step, the data domains typically associated with a single, full-featured flexibility market are considered. These are shown as boxes superimposed on the process map described in Figure 1 of the Technical Annex to Ofgem's Call for Input on The Future of Distributed Flexibility. The process map illustrates the typical interactions Buyers and Sellers have with a market over the course of the end-to-end flexibility provision process. The picture is augmented with an additional, lower-level layer (in blue) representing processes related to the field devices - the DER themselves - which realise the grid optimisation behaviour called for by the market. The combined picture of flexibility-enabling data domains for a single, full-featured flexibility market is shown in Figure 1.

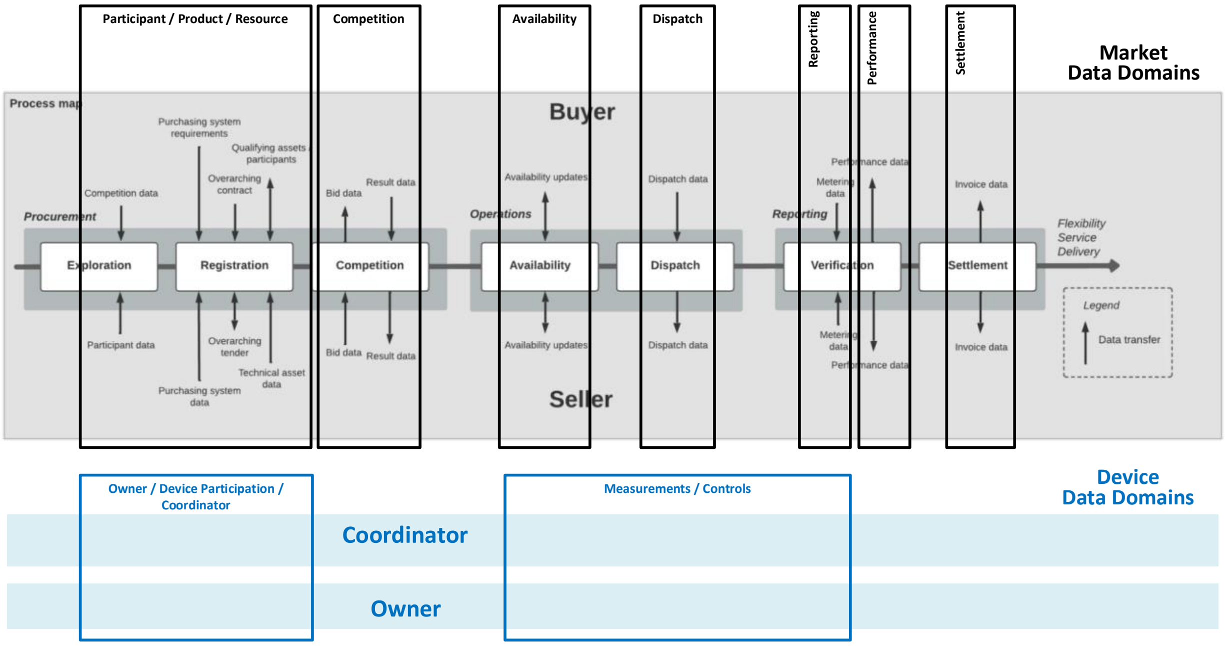

Figure 1: Data domains of exchanges supporting a full-featured flexibility market

The identified data domains for the market portion (which are represented in Figure 1 as black rectangles) are:

- Registration – identifies the main market actors and elements. Major types of data include:
    - Participant (a party acting in an electricity market business process, broadly classified as a Buyer or Seller). Includes contact, financial and qualification information for all Participants. Additionally, includes Seller/Resource and Buyer/Product mappings.
    - Product (a type of grid capability traded on a market, such as energy balancing, capacity, demand response, frequency response, etc.). Includes grid capability and grid location information. Sometimes the word Service is used interchangeably with Product.
    - Resource (a grid entity able to provide a capability). Includes resource type, physical capability, grid and geo location, and qualification information.
    - Product/Resource mapping

- **Competition** – includes information related to proposed trades. Major types of data include:
    - Offer (a proposal for a Resource to provide a Product at a specific grid location and price)
    - Bid (a proposal to purchase a Product which is desired at a specific grid location)
    - Matched/cleared Bids/Offers
    - Coordinated Bids/Offers (after processing by the market coordination function)
- **Availability** – encompasses information related to trades ready to execute. Major types of data include:
    - Resource availability (in advance of operation, which might be based on weather or other external factors including planned or unplanned outages)
    - Resource status (during operation, which may be derived from Device telemetry input)
    - Coordinated dispatch validation status (after processing by the market coordination function)
- **Dispatch** – provides information relating to the execution of trades. Major types of data include:
    - Directive (a specific instruction for the delivery of a grid capability including quantity and timing)
    - Directive response
- **Reporting** – supplies information about the effects of the execution of trades. Major types of data include:
    - Measurement (quantitative information reflecting resource execution of Directive), including items like energy, voltage, power values, measured over time, related to a Resource. Typically, a synthesis of information received from Devices.
- **Performance** – includes information related to evaluating the effectiveness of trade execution. Major types of data include:
    - Performance result (outcome of analysis of Resource response to Directive)
- **Settlement** – includes information related to the financial payments for trades. Major types of data include:
    - Market trade volume
    - Market delivered price
    - Invoice (amount payable in respect of delivered Product)

2.1.2. Device-Level Data Domains

In addition to the market data domains, additional data domains support lower, device-level communications. They are represented in Figure 1 as blue rectangles and they include:

- **Owner / Device / Participation / Coordinator** – identifies the main actors in device-related interactions. Major types of data include:
    - Owner (a party with ownership responsibility for a Device). Includes contact and financial information and Owner/Device and Owner/Participation mappings.

    - Participation (an agreement between Owner and Coordinator for grid capability provision by a Device).
    - Device (a physical component connected to the grid able to provide grid capability). Includes grid capability (nameplate) and grid location information.
    - Coordinator (an entity coordinating the behaviour of multiple Devices). Includes contact information and Coordinator/Participation mappings.

  (Note that often an entity acting as Coordinator at the device level will act as a Seller at the market level. Owner entities may also act as Sellers at the market level.)

- Measurements / Controls – encompasses information supplied by Devices and controls issued to Devices. Often referred to as telemetered or metered data. Major types of data include:
    - Monitored values and/or settings
    - Control instructions

The authors acknowledge that the identification and naming of data domains has a fair bit of art in its science and that data could have been divided into domains in multiple other ways. The domains outlined in Figure 1 were selected for the purpose of exploring data exchange standards and reflect divisions that were useful in that context.

A note about Resources and Devices: A distinction is made between the physical DER itself (the PV and/or battery, for example) – which is referred to as a "Device" – and the entity providing the capability being made available to the market – which is called a "Resource". This distinction is important from a data modelling perspective (because the two are very different sorts of "things" that don't have a one-to-one relationship). The distinction is particularly important in evaluating data exchange standards for a common digital energy infrastructure, because it is those standards that "talk" in terms of Resources that are the critical enablers of business-level market interactions, not those supporting field exchanges with Devices.

2.1.3. Data Domains to Support a Common Digital Energy Infrastructure

Ofgem also noted that there was a wide spectrum of possible forms for a digital energy infrastructure from completely decentralised through various levels of coordinated to very centralised. Ofgem offered four archetypes representing different locations on the spectrum. The first reflected the least centralised position (the business-as-usual situation which would organically occur without strategic intervention), the second represented a "thin" solution with coordination limited to common registration, the third envisioned a "medium" level with individual markets coordinated under a known governance framework, and the fourth was a "thick" solution with a central platform supporting all market functions.

To function effectively, every archetype, "thin", "medium", or "thick", requires well-designed interfaces based on universally understood data structures to reduce friction in the communication of data among markets and with the common digital energy infrastructure. The data domains of those required interfaces include all the domains identified above for a full-featured standalone flexibility market, plus, the authors believe, an additional two data domains.

We have chosen to use the "medium" archetype as a backdrop for illustrating the common digital energy infrastructure data domains. Figure 2 shows the "medium" archetype with the full-featured standalone flexibility market data domains superimposed on it as black hollow boxes.

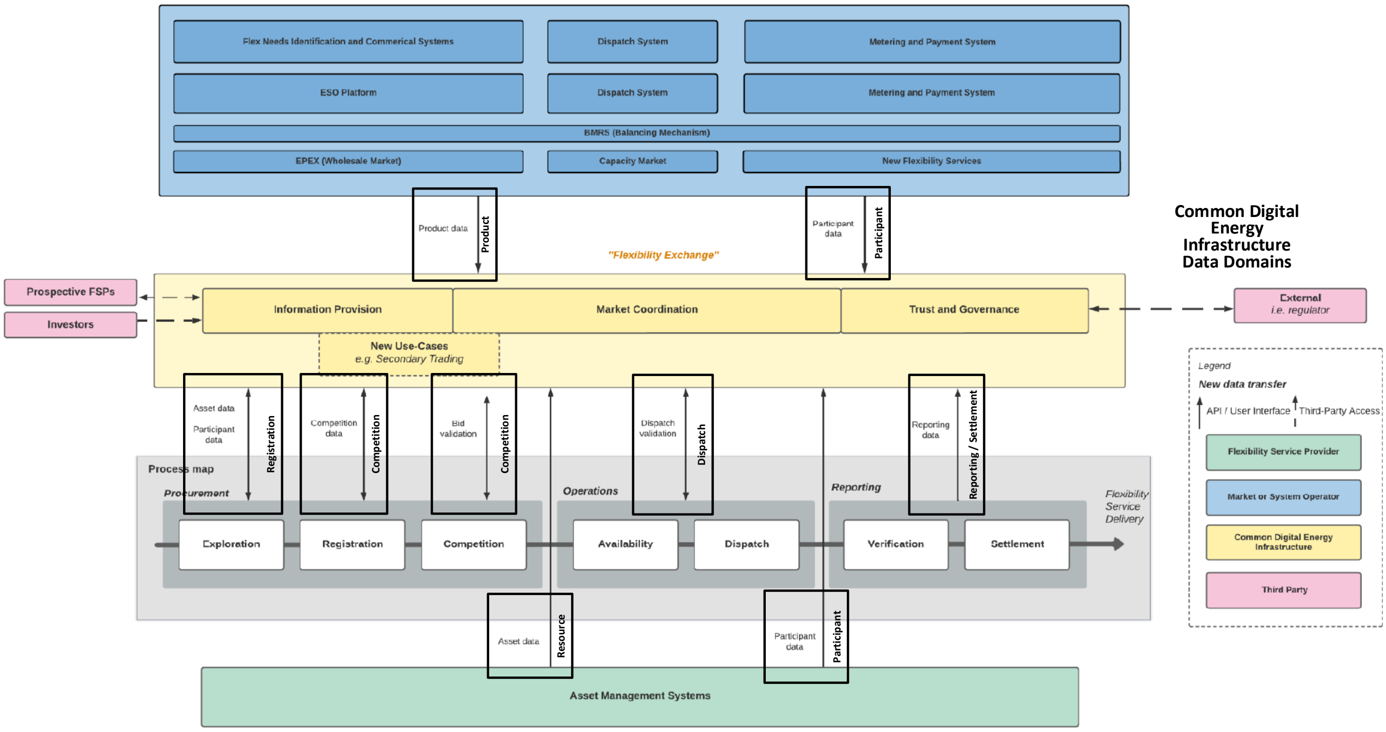

Figure 2: Data domains of the "medium" archetype

Figure 3 looks at the elements of Figure 2 from the "side", with individual Buyers - Market Operators (MOs) or System Operators (SOs) - in blue, individual Sellers - Flexibility Service Providers (FSPs) - in green, individual markets in grey, the "medium" archetype common digital energy infrastructure in yellow, and European data spaces in purple.

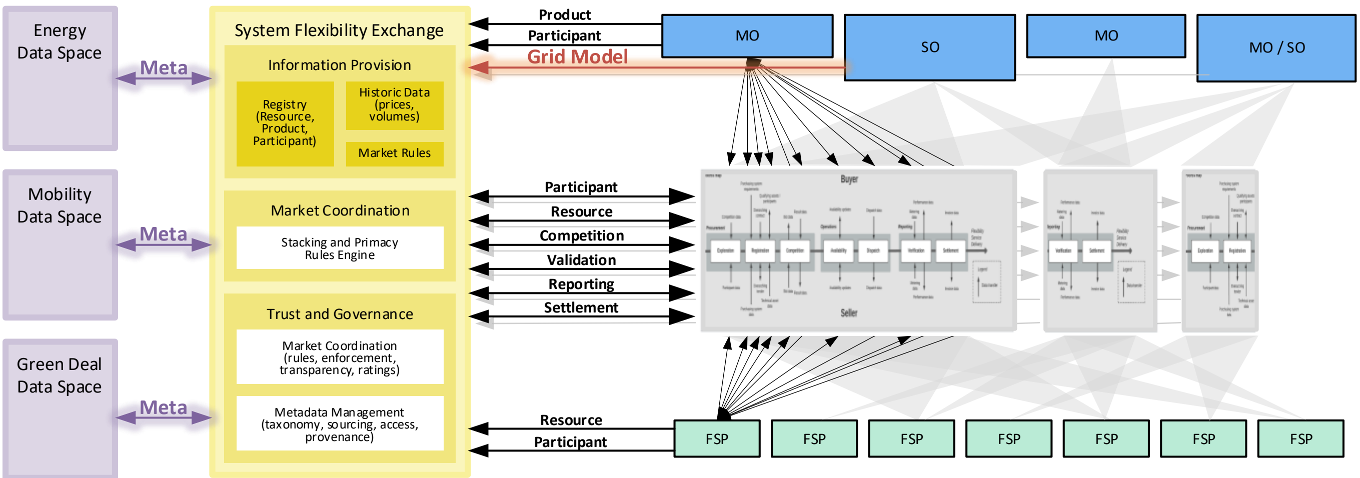

Figure 3: Two additional data domains: Grid Model and Meta

Figure 3 also identifies the two new data domains:

- **Grid Model** data (shown by the red arrow) which is sourced from grid operators and shared with the common digital energy infrastructure, though it would likely also be shared with markets and Sellers. The Grid Model data domain is a collection of data describing the equipment comprising the electrical power grid and information about how each piece of equipment is connected to one another. It is included in our data domain framework because of the central role it plays the system optimisation envisioned by the common digital energy infrastructure.
- **Meta** data (represented by purple arrows) which is shared between the common digital energy infrastructure and some of the industry data spaces proposed by the European Commission[2]. The Meta data domain contains information describing the structure and meaning of a collection of information and it is a vitally important enabling component of the vision of open data within the UK and Europe

The data domains required to support the common digital energy infrastructure vision consist, then, of the following:

- Registration
- Competition
- Availability
- Dispatch
- Reporting
- Performance
- Settlement
- Grid Model
- Meta

The first eight data domains are very different from the last one. The first eight relate to data that is specific to the electric utility sector. Meta, on the other hand, consists generically of “data that describes data” and applies across multiple industries. The **Industry Data Exchange Standards** section of this report uses the first eight data domains to form the framework for evaluating the strength of support for the common digital energy infrastructure vision offered by candidate utility industry data exchange standards. The **Meta Data Exchange** section separately considers the Meta data domain.

[2] Data.europa.eu and the European common data spaces

2.2. Standard Data Exchange Background

While it is tempting to think that the selection of a market data exchange standard would enable 'plug and play' capability among the applications interacting with (and within) a common digital energy infrastructure, such an expectation is overly simplistic. Two major characteristics of application-to-application data exchange standards contribute to this situation:

- **Data exchange standards focus on commonly exchanged industry data.** Applications store data internally in structures which reflect the way their software implements the functions they perform. As a consequence, different applications have different internal data storage structures. When deployed at a utility, an application has its data populated based on local philosophies and conventions and is used to support local business processes. Looking across the electric utility industry, this situation implies a significant diversity in data structure and meaning. Because of this, application-to-application data exchange standards typically seek to define elegant, generically-useful, extensible structures for data commonly used by the industry. Extension of data exchange definitions to fully satisfy local needs is nearly always a given when application integration solutions are designed. There is a common saying in application integration that standards can reduce the "distance to integrate", but almost never reduce that distance to zero.
- **Data exchange standards follow, as opposed to lead, industry and tool development.** Data exchange standards are usually developed to support existing, real-world use cases, not future, hypothetical ones. When a new sort of industry data emerges, it tends first to appear in use in software tools, then in implementations of those tools at utilities, then in proprietary interfaces between utility tools. When enough of these implementations (or at least designs for implementations) occur, two things essential to standards definition happen: 1) there is sufficient understanding of requirements to craft real-world use cases on which data exchange standards can be based and 2) there is sufficient industry pain to motivate the investment in creating data exchange standards.

These factors are at play for data exchange standards for both wholesale and flexibility markets. While there has been significant use of wholesale electricity market data in software tools deployed at utilities for nearly two decades, there have been very few interfaces implemented to share data between market tools, other than the "client" to "server" interactions mentioned in the Introduction section. As a consequence, the number of examples from which real-world data exchange use cases could be drawn is limited and so is the motivation for translating those use cases into data exchange standards. Additionally, the fact that wholesale markets come in two major flavours, zonal and nodal, has complicated the picture where standards development has been attempted.

The situation around flexibility market data is even less conducive to the process typically used in defining data exchange standards. While flexibility market software tools are appearing in abundance, the services they are designed to offer, the purposes those services are intended to serve, and the software representations of those services vary widely. Additionally, there is limited interaction among different flexibility markets - the same situation as among wholesale markets - leading to the same result of limited examples on which to base to real-world data exchange use cases and limited motivation for standards development.

This picture sets the backdrop against which the identified market data exchange standards are evaluated. Since no market data exchange standard could reasonably be expected to fully support flexibility market interoperability, the evaluation focuses on the potential each standard has to grow into complete support. The metrics used to measure that potential are describe in the following section.

2.3. Evaluation Methodology

This report evaluates the candidate industry data exchange standards using a "traffic signal" style rating for each of four metrics indicative of the potential of a standard to support the data exchanges of a common digital energy infrastructure. They are:

1. Data Domains
2. Data Model
3. Development Process
4. Message Library

These metrics reflect essential characteristics that the authors believe are indicators of the capability of a standard to be "grown" into complete and robust support of flexibility market interoperability.

2.3.1. Metric #1: Data Domains

The more market data domains a candidate data exchange standard already supports, the closer it is to being able to offer full support for flexibility market data exchanges. If 3 or fewer of the 8 data domains are supported, a "red" evaluation is given:

Data Domains	3 or Fewer Domains

Standards that provide support for some, but clearly not a majority, of the data domains are graded as "yellow":

Data Domains	4 to 7 Domains

And finally, if the data exchange standard appears to have messaging that supports some level of exchange in all the data domains called for by a common digital energy infrastructure, it would receive an assessment of "green":

Data Domains	All Domains

Note: A standard is counted as having support for a given data domain if it defines the foundational data constructs of that domain. For example, for the Competition data domain, the minimal constructs would be Bid, Offer and matched Bid/Offer and any standard defining those would be counted as supporting the Competition data domain.

2.3.2. Metric #2: Data Model

The common digital energy infrastructure picture, with multiple entities providing and consuming data via standardised data exchanges, is a classic example of a situation where semantic model-based integration is the right approach. Semantic model-based integration calls for the use of an underlying information model on which the content of all messages is based. This allows both the organisational structure and the meaning of the data being shared to be understood by all participating applications. The alternative approach, using messages that are simply collections of data elements, allows inconsistencies in content among message types and leads to differences in content interpretation among producing and consuming applications.

Data exchange standards that do not rely on a data model to structure either message format or content are flagged as:

Data Model	None

Standards whose message formats are described using a data model, but that do not rely on a common semantic model to structure data content across all message types are flagged as:

Data Model	Message Model

Standards whose messages all rely on a shared semantic model to structure their content are flagged as:

Data Model	Semantic Model

2.3.3. Metric #3: Development Process

The development process for establishing new messages or enhancing existing messages when improvements are necessary is a critical factor in the quality and long-term durability of a standard. For a standard known to need enhancement to fulfil a particular purpose (like all the standards under consideration in this report), this characteristic is particularly important.

Exchange standards whose development is done via a closed process under the control of a fixed entity are flagged as:

Development Process	Proprietary

Information exchange standards which open the process to interested parties, often through membership in a consortium, and which embrace collaborative decision-making to guide their development are flagged as:

Development Process	Community

And finally, those standards with a formal structure around how requests for changes can be made, how changes are then debated and applied, and then how the new message definitions are agreed upon, typically using a Standards Body to conduct voting, are flagged as:

Development Process	Curated

2.3.4. Metric #4: Message Library

If a particular data exchange standard provides messages for its supported data domains that have, in general, been driven by a limited set of use cases – as opposed to use cases drawn from across the industry – it is anticipated that more work will be required to grow the standard to fully support the exchanges of a common digital energy infrastructure. One indicator of the breadth of use cases considered by a given standard is the presence of messages (or of allowed data in messages) beyond what a given local implementation requires.

If a standard supports its data domains with a limited number of messages which would require substantial work to extend to be useful, it is flagged as:

Message Library	Limited

If the information exchange standard supports a number of currently important use cases and contains messages able to support a range of local implementations, the standard is flagged as:

Message Library	Developed

And finally, data exchange standards which have both a rich library of messages for their supported data domains and a structure intended to be enhanced to support future requirements receive the highest score. These standards, which contain a wide selection of messages available for use by local implementations, are flagged as:

Message Library	Rich

Note that this metric reflects support for market-related messages not device-related messages.

2.3.5. Maturity Not a Metric

While the maturity of a data exchange standard is an important factor when its use is being considered in a specific implementation, maturity doesn't make this report's list of evaluation metrics. The evaluation here is focused on determining a candidate standard's potential to support the full range of flexibility market data exchanges. It is focused on the breadth of support for the data domains of interest and the general characteristics of a standard that position it well for being "grown" into complete support for full-featured flexibility market data exchanges. The evaluation is not as interested in the depth of a standard's support for specific data exchanges as it is in its breadth and suitability for future expansion.

With that said, descriptions of several of the standards include comments relating to vendor or utility implementations and/or to interoperability testing. These are included to round out the picture of the standard.

3. Industry Data Exchange Standards

3.1. IEC Common Information Model (CIM)

Data Domains	Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement, Grid Model
Data Model	Semantic Model
Development Process	Curated
Message Library	Rich

The Common Information Model (CIM) is a comprehensive, cohesive information model which structures a wide range of data representing the "things" of importance in electric utility operation. The CIM information model, which underlies all the IEC CIM standards, is documented in Unified Modelling Language (UML) and maintained by the CIM Users Group[3], a subset of the UCA International (UCAI)[4]. UCAI has more than 75 member companies, including grid operators, research organisations, testing facilities, hardware/software vendors, consultants, and universities. It provides extensive support for collaboration activities to hundreds of individuals who both benefit from the CIM and contribute to the extension and refinement of the CIM.

The CIM is a large data model and is logically partitioned into three different "packages" to facilitate management:

Grid	The Grid package is focused on modelling the electrical behaviour of elements of the power grid, such as conductors, transformers, generators, and breakers. The Grid package supports the modelling of grid topology using the concept of equipment terminals that connect via "connectivity nodes". In addition, the Grid package supports power flow-based network analysis, defining constructs which describe both power flow inputs (grid operating state) and outputs (grid solution).
Support	The Support package is focused on utility operations of the grid and includes a robust model for asset modelling to facilitate functions like asset maintenance and health monitoring, a switching order model to support control room operations, and a work model in support of field crew management. The Support package also houses the complex set of features to cover all aspects of metering.

[3] CIM Users Group (Home Page)

[4] UCA International Users Group (Home Page)

Markets	The Market package layers financial information on the modelling provided by the Grid package, aligning pricing information to "pricing nodes" which are the financial equivalent to the "connectivity nodes" of the Grid package. The Markets modelling is designed to support power markets in dispatching resources economically through the bid/offer submission and economics clearing based on grid locations, as well as to support mechanisms to economically optimise grid services for the grid operators to leverage during real-time.

Multiple families of International Electrotechnical Commission (IEC) data exchange standards leverage the CIM for their content. The IEC is a significant Standards Development Organisation (SDO) which publishes international standards for a wide variety of "electrical, electronic and related technologies". The IEC is a global, not-for-profit membership organisation that brings together more than 170 countries and coordinates the work of 20,000 experts globally.

All IEC standards, including the CIM-based standards, are created and maintained in adherence with a formal approval process based on National Committee balloting. There are three IEC Working Groups dedicated to the progression of the IEC CIM standards, each responsible for the data exchanges leveraging the content of one of the packages listed above:

- Working Group 13 is responsible for IEC standards using the Grid package
- Working Group 14 is responsible for IEC standards using the Support package
- Working Group 16 is responsible for IEC standards using the Markets package

Each Working Group meets face-to-face multiple times a year and typically hosts one or more web conferences weekly. Membership in the IEC Working Groups is controlled by National Committees who nominate experts to represent them. Working Groups 13 and 14 have about 130 nominated experts each and Working Group 16 has 80. There are approximately 25 countries with representatives on CIM Working Groups, along with one industry organisation: ENTSO-E.

The IEC CIM standards that describe data exchange content are known as profile standards. The families of IEC CIM profile standards relevant to this standards evaluation are:

- IEC 62325-351[5] and the IEC-62325-451 Series a set of well-established standards which describe market-related data exchanges for European markets. These standards are the basis for the European style market profile (ESMP) exchanges developed by the European Network of Transmission Operators for Electricity (ENTSO-E). Messages in this standard support exchange of transmission capacity allocation, settlement/reconciliation, balancing, HVDC scheduling, and energy consumption data ("My Energy Data").
- IEC 62325-452, a family of standards to support data exchanges for North American markets.
- IEC 62746-4, a recently developed profile currently midway through the IEC adoption process, which describes data exchanges related to market resources (including

[5] IEC 62325-351:2016

geographic and grid location data), scheduling information, bid/offer, dispatch, and commodity & pricing structures.
- IEC 61970, a mature set of standards which describes grid model data exchanges and which are the basis for the Common Grid Model Exchange Standard (CGMES) profile standard defined by ENTSO-E.

While a family of IEC CIM profile standards usually relies primarily on the modelling contained one CIM package, it is common to draw from several packages in developing profiles. This practice allows modelling developed by experts in other data domains to be leveraged and enables messages to be defined whose content "spans" data domains. For the first three IEC CIM standard families listed above, the Markets package is the primary package, with each family defining messages that support multiple of the data domains required by the common digital energy infrastructure vision. The families use the same underlying semantic model, differing largely in terms of the use cases they serve and the maturity of their development. The last family of IEC CIM standards listed above, IEC 61970, draws primarily from the Grid package, defining data exchanges which support the Grid Model data domain.

Each IEC CIM standard family is described individually below.

IEC 62325-451 (and ESMP)

Data Domains: Registration, Competition, Availability, Reporting, Settlement

***Message Library**:* Developed

Based on the Markets package, the IEC CIM 62325-451 family of standards supports primarily energy reporting activities. Its profile standards include the following:

- **IEC 62325-451-1:** Acknowledgement Business Process And Contextual Model[6]
- **IEC 62325-451-2:** Scheduling Business Process And Contextual Model[7]
- **IEC 62325-451-3:** Transmission Capacity Allocation Business Process (Explicit Or Implicit Auction) And Contextual Models[8]
- **IEC 62325-451-4:** Settlement And Reconciliation Business Process, Contextual And Assembly Models[9]
- **IEC 62325-451-5:** Problem Statement And Status Request Business Processes, Contextual And Assembly Models[10]
- **IEC 62325-451-6:** Publication Of Information On Market, Contextual And Assembly Models,[11]
- **IEC 62325-451-7:** Balancing Processes, Contextual And Assembly Models[12]

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[6] IEC 62325-451-1:2017

[7] IEC 62325-451-2:2014

[8] IEC 62325-451-3:2014+AMD1:2017

[9] IEC 62325-451-4:2017

[10] IEC 62325-451-5:2015

[11] IEC 62325-451-6:2018

[12] IEC 62325-451-7:2021

- **IEC 62325-451-8:** HVDC Scheduling Process, Contextual And Assembly Models[13]
- **IEC 62325-451-10:** Profiles for Energy Consumption Data ("My Energy Data") [14]

This family of profile standards is used by the European Network of Transmission System Operators for Electricity (ENTSO-E) as the basis for its European style market profile (ESMP). ESMP profiles define the data exchanges used in ENTSO-E's Transparency Platform implementation, which receives data from markets across Europe and allows access to information by all market participants and stakeholders.

ENTSO-E have invested significantly in the standardisation, refinement, interoperability testing, approval, and use of the IEC 62325-451-based ESMP standards[15]. They have formed an internal "Common Information Model Working Group" and actively participate in the UCAI Task Forces keeping both the IEC 62325-451 and IEC 61970 families of IEC CIM standards current and implementable.

IEC 62325-452

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Message Library: Developed

The planned IEC 62325-452 family of profile standards is focused on the North American style of markets, where resources are economically dispatched considering both transmission constraints and transmission losses within each solution. IEC 62325-452 is a standard-in-planning, comprising a set of solid, field-tested profiles which have not yet been formalised through the IEC standardisation process. The scope of IEC 62325-452 is wide and profiles are well developed, including all of the data domains of interest except Grid Model.

The California Independent System Operator (CAISO) is currently the only market to leverage the profiles, although it should be noted that the size of the market is larger than the whole of the UK, with over 50 GW of load at its peak. Furthermore, through the Western Energy Imbalance Market (EIM) that CAISO manages, parts of Arizona, Idaho, Montana, New Mexico, Nevada, Oregon, Texas, Utah, Washington, and Wyoming also participate in portions of the CAISO market. With its Flexible Ramping Product (FRP), the CAISO was also one of the first markets in the US to implement a flexibility service at the wholesale level.

IEC 62746-4

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Message Library: Limited

Quoting from the forthcoming standard:

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[13] IEC 62325-451-8:2022

[14] IEC 62325-451-10:2020

[15] ENTSO-E: Electronic Data Interchange (EDI) Library

Communications between electricity markets and grid operations are enabled by shared modelling among three series of standards: IEC 61968, IEC 61970, and IEC 62325. However, none of these standards extend into the domain of controllable resources deployed on the distribution grid, and specifically to those resources "behind" the customer electricity meter. IEC 62746 remedies this situation by providing a set of message profiles designed to convey grid instructions, grid conditions, pricing signals, and resources capabilities among multiple parties within the emerging Distributed Energy Resource (DER) space.

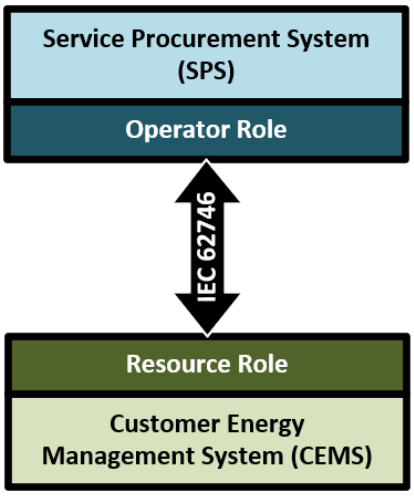

Figure 4: Endpoints of IEC 62746-4

IEC 62746-4 is unique in that it is exclusively focused on communications between the utility or market operator and the electricity consumers. Other CIM market-related standards support communication between a different set of potential users, either (a) between applications internal to the market operator or the utility, (b) between market operators and/or utilities, or (c) between a small set of direct participants with the market operator or utility, for example merchant generators. The model is illustrated in Figure 4.

With the understanding that many electricity customers may have DERs which are too small to warrant direct participation, the concept of DER aggregation has been extended in the CIM and hence is present in all new DER-related profiles, as shown in Figure 5.

This initial edition of IEC 62746-4 is limited, on purpose. The goal is to publish a relatively simple set of data exchanges which provide a standard that can be used for simple DERs, for example a stand-alone battery system or a collection of demand-response resources. As more use cases are brought to UCAI Task Force 21, this standard – like all CIM standards – will grow and evolve as use cases provide new modelling requirements. IEC 62746-4 supports five core data exchanges which can be assembled in a variety of different configurations to support different market designs. Those profiles are:

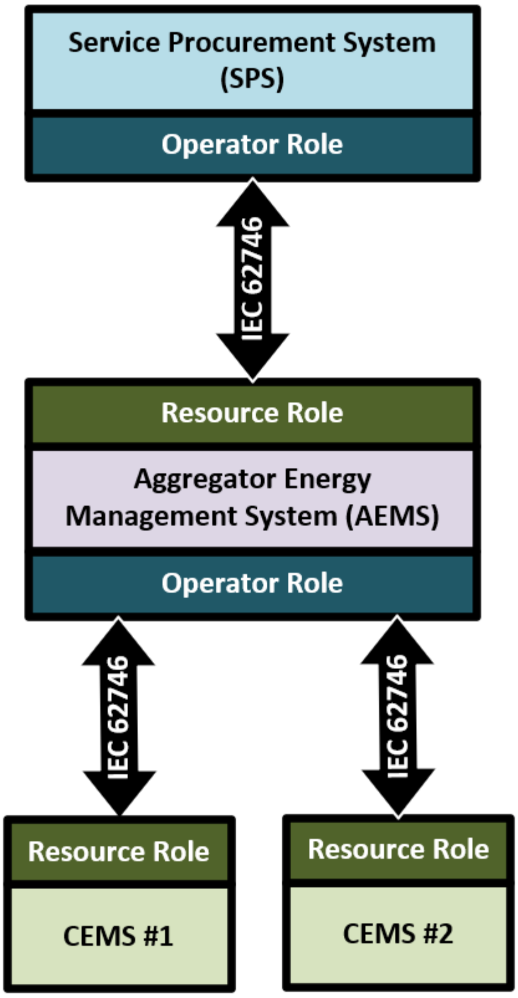

Figure 5: IEC 62736-4 with Aggregation

MarketDER: *Describes the market-level characteristics of a DER or an aggregation of DERs. Importantly, the MarketDER message homogenises different DER technologies to the point that each DER can be considered on its own merits for the provision of market services. If sent from the Resource Role, the message is generally understood to be a declaration of capability. If sent from the Operator Role, the message is generally understood to be a report of understood capability, or perhaps calculated capability based on historical performance*

ReferenceEnergyCurve: *Describes the consumption and/or production over time by a DER/customer/aggregator. It is used to exchange energy values as a function of time interval, including but not limited to energy forecasts, energy predictions, energy schedules, energy patterns, and energy usage.*

MarketDERBidOffer: *Describes desired price point at or above which a DER is willing to provide services (an offer) or at or below which a DER is willing to consume services. It is used to submit data to either a grid operator or to an aggregator in the form of a bid to purchase or an offer to sell services, or used to submit data without a price, also known as a self-schedule, of service consumption and/or production.*

MarketDERInstruction: *Describes the one or more setpoints for the DER. The instruction is sent from either the market and/or grid operator and may be adjusted through an aggregator. The number of setpoints can vary. The entity in the Operator Role may send periodic dispatches with individual setpoints or may send multiple setpoints in the form of a schedule.*

CommodityPriceExchange: *Describes price for a specific commodity (definition and market product and pricing location) for a specific time. Commodities are defined in advance, establishing a currency and unit-of-measure for the product being sold. Commodities may alternately be resource-specific, using the optional association to RegisteredResource, rather than pricing node.*

An important feature of IEC 62746-4 is that the grid representation (IEC 61970) is embedded into the communications. The MarketDER message contains not only typical registration information like nameplate information and geolocation, it also allows for the DER to be linked to a specific "node" in the grid representation. CommodityPriceExchange, which facilities the publication of prices for flexibility services also fixes those prices, which may change rapidly or slowly, to the same "nodes" in the grid representation. The ideas here is that collecting DER information and connecting the DER activities to the grid model will make the planning for and operation of the DERs easier for utilities.

IEC 61970 (and CGMES)

Data Domains: Dispatch, Reporting, Grid Model

Message Library*:* Rich

Based on the Grid package, this IEC CIM standard family of data exchanges describes information used and produced by power flow-based network analysis functions. Its primary focus is on the Grid Model data domain, with support for Dispatch and Reporting as they serve the utility control centre functions. But because of the complexity of this domain (it is the most complex of all domains under consideration), messages are necessarily very complex. Profile standards include the following:

- **IEC 61970-452:** physical equipment and connectivity descriptions[16]
- **IEC 61970-453**: diagram layout profile[17]
- **IEC 61970-456:** system operating state description (used as input to power flows, including short circuit studies) and power flow outputs[18]
- **IEC 61970-457:** dynamic (sub-cycle) behaviour models which can optionally be used to augment the -452 information[19]
- **IEC 61968-13:** common distribution power system model profiles[20]

IEC 61970-600-1[21] and IEC 61970-600-2[22]: collectively referred to as the Common Grid Model Exchange Standard (CGMES), these standards describe a set of profiles consistent with those of the IEC 61970-45x profile standards and augment them with a few extensions that are normative for Europe and one additional profile of relevance to flexibility markets: the Geographical Location profile. Note that ENTSO-E is also developing new profiles, called Network Codes profiles, which are complimentary to CGMES profiles and will serve data exchanges related to business processes such as Coordinated Security Analysis (CSA), Coordinated Capacity Calculation (CCC) and Outage Planning Coordination (OPC) that require

[16] IEC 61970-452:2021

[17] IEC 61970-453:2014+AMD1:2018

[18] IEC 61970-456:2021

[19] IEC 61970-457:2021

[20] IEC 61968-13:2021

[21] IEC 61970-600-1:2021

[22] IEC 61970-600-2:2021

usage of Common Grid Model (CGM). Scheduling information, dispatch, costs and cost sharing information will be exchanged with these new profiles.

Data exchanges based on the IEC 61970-45x and/or 61970-600-1/-2 profile standards have been interoperability tested nearly 20 times in the last two decades. Interfaces compliant with the standards are implemented on dozens of vendor tools. And multiple utility implementations rely on the 61970 standards. Two of the largest are the platform supporting ENTSO-E's Ten-Year Development Plan (TYNDP) process[23] and the Network Model Management System (NMMS) implemented at ERCOT[24] as part of its nodal market implementation.

[23] ENTSO-E: Ten Year Network Development Plan Document Library

[24] ERCOT Experiences Implementing and Using Network Modeling Tools

3.2. Energy Business Information eXchange (ebIX)

Data Domains	Registration, ~~Competition~~, ~~Availability~~, ~~Dispatch~~, Reporting, Performance, Settlement, ~~Grid Model~~
Data Model	Message Model
Development Process	Curated
Message Library	Developed

ebIX is the name applied to the collection of data exchange standardisation artefacts curated by the European Forum for Energy Business Information Exchange (ebIX Forum), whose purpose is to advance, develop and standardise the use of electronic information exchange in the energy industry.

ebIX members include a large number of grid operators, including APG (Austria), Fingrid (Finland), Statnett (Norway), Svenska Kraftnät (Sweden), and TenneT (Netherlands and Germany). Its membership also includes several consortiums for counties with multiple grid operators, including Atrias (on behalf of four grid operators in Belgium) and PTPiREE (on behalf of nine grid operators in Poland). It also has organisations which are not grid operators including BDEW (Germany), ESZ (Slovenia), and Westnetz (Germany). The ebIX Forum has a clear business structure and a formalised standard approval process.

The ebIX data exchange definition process is "top down" - it starts with a standardised model of market roles against which specific use cases are defined which then drive the definition of specific data exchanges:

1. The Harmonized Electricity Market Role Model (HEMRM) – see below for more details - describes a model identifying all the roles that can be played for given domains within the electricity market.
2. Use cases are defined which result in Business Requirement Specifications (BRSs) for the different intercompany market processes and associated information exchanges
3. Business information models (roughly parallel to the CIM's profiles) are created to define required data exchanges.

More on the HEMRM

The Harmonized Electricity Market Role Model (HEMRM) [25,26] describes a model identifying all the roles that can be played for given domains within the electricity market. It has been developed to facilitate the dialogue between market participants from different countries

[25] Harmonized Electricity Market Role Model

[26] ebIX: Role Model

through the designation of a common name for each role and related object that are prevalent within European electricity market information exchange. The model covers both wholesale and retail markets and is seen as naturally growing and evolving. The HEMRM is maintained jointly by ENTSO-E, European Federation of Energy Traders (EFET), and the ebIX Forum. It is referenced as a resource in market data and research initiatives, like the Nordic Market Expert Group's (NMEG's) effort to harmonize market message exchanges in the Nordic countries[27] and the European Commission-funded Horizon 2020/Horizon Europe BRIDGE project[28], which proposes the addition of new roles and data classes to the HEMRM.

ebIX was designed for used for both electricity and gas markets, but only in "downstream" markets, i.e., distribution or retail markets selling energy to end-use customers. This distinction is important, as the flexibility services under consideration are focused on grid needs, rather than energy sales and purchases. Downstream customers are not the buyer (although they may be sellers in the future) of these grid services, so ebIX in its current implementation is a model limited to energy – and not ancillary services – and is purely financial and not directly related to transactions related to grid conditions. Many of the ebIX messages are focused on enabling customer choice and are grouped into "Structure" messages[29] which define the business relationships among the many entities in the downstream electricity markets, such as:

- Align Customer Characteristics
- Align Metering Configuration
- Manage / Change / Align / Re-Arrange Accounting Point
- Customer Move
- Change / End of Supplier
- Change / End of Balance Responsible Party
- Change / End of Meter Data Responsible

There are also several variations of exchanging metering information:

- Measure Collected Data
- Validate & Exchange Measured Data
- Measure for Billing
- Measure for Reconciliation
- Measure for Imbalance Settlement
- Measure for Renewable Energy Certifications

And a single message which exchanges settlement results:

- Settle Reconciliation

ebIX BRSs have served as the foundation (or inspiration) for data exchange definitions in retail market implementations across Europe for over a decade, including the Nordic data hubs and solutions in Switzerland, Belgium, Poland, Slovenia, and the Netherlands. Implementations in a given country typically tailor the ebIX message foundation to their local needs, some

[27] Nordic Energy Market Domain Model

[28] Bridge European Energy Data Exchange Reference Architecture

[29] ebIX: Document Downloads

following the standard very closely, some more loosely, and many sampling the standard at implementation time with no need or intention of upgrading.

ebIX is continuing to be developed as the industry evolves. A ebIX Distributed Energy Flexibility project to define standardised processes and data exchange for energy flexibility products, building on the Harmonised European Role Model was initiated in 2017 and a second phase launched in 2020[30]. As a result, in the past few weeks, new ebIX messages have been published around flexibility services:

- Flexibility Register Administration
- Prepare / Aggregate Resources for Flexibility Services
- Quantification & Settlement of Flexibility Services

[30] ebIX: Distributed Flexibility Project

3.3. OpenADR

Data Domains	Registration, ~~Competition~~, Availability, Dispatch, Reporting, Performance, ~~Settlement~~, ~~Grid Model~~
Data Model	Message Model
Development Process	Community
Message Library	Developed

The OpenADR Alliance[31] publishes and promotes the OpenADR specification[32], which is based on work originally developed by Lawrence Berkeley National Laboratory. The OpenADR Alliance was created to enable utilities and aggregators to cost-effectively manage growing energy demand and decentralised energy production, and customers to control their energy future. The OpenADR specification reflects the purpose of its parent organisation and focuses largely on data exchanges between consumers and aggregators although use of OpenADR data exchanges is also envisioned to support aggregator to SO interactions using virtual resources with aggregated sets of capabilities.

The development of the OpenADR specification is managed for OpenADR Alliance by the Organization for the Advancement of Structured Information Standards (OASIS), an organisation advancing the fair, transparent development of open-source software and standards across multiple industries, through its Energy Interoperation Technical Committee (TC)[33] and its Energy Market Information Exchange (eMIX) TC[34]. OASIS TCs are geared more toward initial standard creation activity than ongoing standard development. While there are formal rules governing the approval of standards by OASIS TCs, they reflect the project-oriented nature of TCs and are based on voting by committee members, not by standing national committees. The OpenADR Alliance was able to attain IEC approval to distribute OpenADR 2.0 as a IEC Publicly Available Specification numbered IEC/PAS 62746-10-1. It is unclear how the development process of OpenADR is coordinated among the OpenADR Alliance, OASIS and the IEC.

The OpenADR Specification is built on messages defined by the two OASIS TCs: the Energy Interoperation (EI) Version 1.0[35] and Energy Market Information Exchange v1.0 (EMIX)[36]. The

[31] OpenADR Alliance (Home Page)

[32] OpenADR: OpenADR 2.0 Specifications

[33] OASIS: Energy Interoperation TC

[34] OASIS: Energy Market Information Exchange (eMIX) TC

[35] OASIS: Energy Interoperation Version 1.0

[36] OASIS: Energy Market Information Exchange (EMIX) Version 1.0

result of this message architecture is that OpenADR messages themselves are highly structured and modelled, but their content is not.

OpenADR 2.0 provides a number of services:

- EiRegisterParty (Entity enrolment)
- EiEnroll (Resource enrolment)
- EiMarketContext (used to query program rules)
- EiEvent (core function for both price-responsive and command-and-control DR)
- EiQuote (Complex price structure query)
- EiReport (for measurements and feedback)
- EiAvail (to document Resource availability)
- EiOpt (to provide simple Op-In/Opt-Out control)

The standard was developed when command-and-control was the primary method of demand response communications and extensions to the economic domain are somewhat constrained. While the EiQuote and EiEvent do allow for some price communications, concepts like price-quantity bidding and schedules are limited.

OpenADR version 2.0 was completed in 2011. While over a decade old now, many manufacturers have incorporated OpenADR 2.0 into devices and many utilities have developed OpenADR control interfaces. This demonstrates a maturing unparalleled in this space, with a reach beyond the international standards at the IEC or any individual vendor proprietary interface.

3.4. IEC 61850

Data Domains	Registration (partial), ~~Competition~~, Availability (partial), Dispatch, Reporting, ~~Performance~~, ~~Settlement~~, ~~Grid Model~~
Data Model	Semantic (but structured around device modelling)
Development Process	Curated
Message Library	Developed

IEC 61850 is a well-established international standard defining communication protocols for Intelligent Electronic Devices (IEDs) at electrical substations. Like the CIM, IEC 61850 benefits from the global reach and rigorous standards development processes of the IEC and the advocacy and adoption support offered by UCAI.

IEC 61850 is known for its use of a highly structured information to describe device monitoring and control capabilities, to support real-time data exchange, and to execute controls. IEC 61850 includes support for substation communications design and device configuration processes. As a very mature communication standard, its core capabilities have been used to create standards supporting specific electric system equipment (like hydro power plants, power converters, synchrophasors, and meters) and specific processes (like condition monitoring or protection). It is a logical layer protocol with mappings defined to multiple transport protocols to support a range of communication speed and reliability requirements.

The IEC 61850 information model is focused on describing device capabilities and characteristics, viewing IEDs as servers and the entities interacting with them as clients. This device orientation underlies all IEC 61850 data exchange standards, including the IEC 61850-7-420[37] standard, edition 2 of which was released in 2021. IEC 61850-7-420 focuses specifically on communication with distributed energy resources (DERs) and Distribution Automation (DA) systems. It is rich and full-featured in its support of communications with DER and includes data models for a wide variety of functions reflecting the capabilities of distributed generation systems, energy storage systems, controllable loads, and facility DER management systems or microgrids. There are models supporting the DER device communication requirements of a very large number of grid codes (European Requirements for Generators (RfG), Demand and Connection Code (DCC), and System Operation Guideline (SOGL) as well as IEEE-based functions). As an example, IEC 61850-7-420 enables communication with DER related to following types of capabilities required by RfG and DCC:

- Disconnect / Connect Function
- Automatic Connect / Reconnect
- Cease to Energize / Return to Service Function

[37] IEC 61850-7-420:2021

- Reduce Active Power Output / Set Active Power Output
- High/Low Voltage Ride-Through (Fault Ride-Through) Mode
- Dynamic Reactive Current Support Mode
- Fast Load Shedding
- Tap-change-Blocking
- Low Voltage-Watt Emergency Mode for demand side management

As the inclusion of communication with DER facility management systems and microgrids would suggest, IEC 61850-7-420 provides a way of describing aggregated DER. Its design even includes support for aggregates of DER that do not all have the same grid location. This capability of communicating with collections of DER causes IEC 61850-7-420 to be included in the list of candidate standards (otherwise it would be classified strictly as supporting the device level data domains).

Though IEC 61850-7-420 appears to offer a solid DER device level communication option[38], adoption seems to be fairly limited to-date, with more research articles[39],[40] than vendor tools[41] identifiable online.

[38] PACWorld: Semantic Interoperability of DERs Obtained by Standardized Designs and Mappings to DER Protocols, thanks to IEC 61850-7-420 Ed 2.0

[39] MDPI: Implementation of Resilient Self-Healing Microgrids with IEC 61850-Based Communications

[40] OSMOSE: IEC 61850 Standard: What for, which benefits, what pending challenges?

[41] Matrikon: OPC Server for DER – Distributed Energy Resources IEC 61850-7-420

3.5. IEEE 2030.5

Data Domains	Registration (Partial), ~~Competition~~, Availability (Partial), Dispatch, Reporting, ~~Performance~~, ~~Settlement~~, ~~Grid Model~~
Data Model	Semantic Model
Development Process	Curated
Message Library	Developed

Institute of Electrical and Electronics Engineers (IEEE) 2030.5 is an application protocol for smart metering and automation of demand/response and load control in local or home area networks. According to the IEEE[42]:

> *The purpose … is to define the application protocol to enable utility management of the end user energy environment, including demand response, load control, time of day pricing, management of distributed generation, electric vehicles, etc. The defined application profile sources elements from many existing standards, including IEC 61968 and IEC 61850, and follows a RESTful architecture … using IETF protocols such as HTTP.*

The IEEE is the world's largest technical professional organisation dedicated to advancing technology for the benefit of humanity. IEEE has over 427,000 members from more than 190 countries. It engages in a wide range of activities including publishing, sponsoring conferences, developing technology standards, and supplying professional education.

Initially created by the ZigBee Alliance, the IEEE 2030.5 protocol has been under IEEE Standards Association (IEEE-SA) stewardship since 2013. The IEEE-SA is a well-recognised SDO and has an established, rigorous process under which its standards are developed and maintained.

The design of IEEE 2030.5 draws on the data models of IEC standards, including the CIM for metering and IEC 61850 for functions. Its underlying data model is more flexible than that of IEC 61850 and more tailored to DER communication. It provides definitions for data exchanges related to the following:

- Billing
- Demand Response/Load Control (DRLC)
- Distributed Energy Resources
- Messaging
- Metering
- Energy Flow Reservation
- Prepayment

[42] IEEE Standard for Smart Energy Profile Application Protocol 2030.5-2018

- Pricing

It also supports device self-discovery and aggregating of DER into virtual or mixed DER groups.

While differing in origin and emphasizing different services, IEEE 2030.5 and IEC 61850-7-420 occupy much the same place in the landscape of DER-related data exchange standards[43]. The focus of both is clearly on communications with individual devices. Like IEC 61850-7-420, the support provided by IEEE 2030.5 to communicate with groups of DER causes IEEE 2030.5 to be included in the list of candidate enabling standards (otherwise it would be classified strictly as supporting the device level data domains).

The selection by California Rule 2[44] of IEEE 2030.5 as the default protocol for communications with smart inverter-based interconnected devices has led to a significant amount of IEEE 2030.5 implementation activity on the part of both vendors and utilities.

[43] QualityLogic: IEC 61850 and 2030.5: A Comparison of 2 Key Standards for DER Integration

[44] California Public Utilities Commission: Rule 21 Interconnection

4. Meta Data Exchange

The envisioned common digital energy infrastructure will have multiple interfaces and complex workflows which rely on interactions both with elements directly related to the common digital energy infrastructure (Buyers, Sellers, individual markets) and with elements of other platforms which support sharing of market data with the outside world. Current conversations regarding the energy transition and digitalization of the electric industry paint a vision of effective and nearly seamless cross-platform data federation. This vision is articulated in documents such as "A Strategy for a Modern Digitalised Energy System"[45] and the EU action plan "Digitalising the Energy System"[46]. It is also reflected in the multiple Horizon Europe research and innovation projects which are looking into energy data spaces and best practices for data sharing.

The objective is to allow data across multiple platforms to be leveraged so that better insight can be gained from a holistic, comprehensive view of collections of energy data. The notion of metadata – data about data – is key to achieving the objective. Metadata provides information about a wide variety of data characteristics, including its organisation, structure, meaning, vocabulary, and history. The importance of metadata is illustrated by Ofgem's Data Best Practice Guidance ("DBP Guidance") report[47], which highlights the following best practices related to metadata:

- Use common terms within Data Assets, Metadata and supporting information.
- Describe data accurately using industry standard Metadata.
- Licensees must enable Data Users to search for and link Data Assets and associated Metadata to Data Assets and Metadata provided by other organisations.
- Licensees must label and describe Data Assets and Metadata using a taxonomy that is commonly recognised by practitioners who use the Metadata across the relevant subject matter domain.
- The Licensees must make it easy for Data Users to be able to use and understand information that describes each Data Asset.
- The Licensees must therefore provide Metadata associated with Data Assets and this Metadata must be made available to Data Users independent of the Data Asset.
- The Licensees must treat the Metadata as a Data Asset.
- When providing Metadata, the Licensees must format and structure this in a widely recognised and accepted format that is machine readable.
- When it updates or extends a Data Asset, the Licensees must ensure that the Metadata reflects any such changes so that Data Users can identify additions or changes.

The authors of this report concur with the importance placed on metadata and reference data by the work cited above and believe that leveraging a forward-looking approach to the definition and management of metadata is essential to maximising the long-term value delivered by a common digital energy infrastructure solution. While the common digital energy infrastructure will have the luxury of leveraging profiles based on a common semantic model for most of its internal data exchanges, there will undoubtedly be a growing need in the future

[45] Catapult: A Strategy for a Modern Digitalised Energy System

[46] Digitalising The Energy System - EU Action Plan

[47] Ofgem: Data Best Practice Guidance v1

for interfacing with platforms and systems which conform to different standards. And that's where a common, standards-based approach to metadata becomes important.

Ofgem recently published a "Consultation on updates to Data Best Practice Guidance and Digitalisation Strategy and Action Plan Guidance"[48], in which a decision for the use of Dublin Core as the metadata standard was proposed. We believe this direction has great merit. Dublin Core provides a vocabulary – the definition of a set of terms - called DCMI Metadata Terms[49] which can be used to describe metadata characteristics. These terms are extensively used by various metadata models which describe constructs (like Catalog, Resource, Thing, Dataset, Distribution, DataDownload, etc.) that enable generic data management, data interpretation and data access. There are two major metadata models currently in use and development.

The first major metadata model is DCAT (Data Catalog Vocabulary)[50] from the World-Wide Web Consortium (W3C)[51], the public-interest non-profit organisation which builds consensus for global standards for web technologies. It is a robust metadata model in general use which facilitates interoperability between data catalogues published on the Web. It can be used combination with the W3C PROV (Provenance)[52] standard which describes the chronology of the ownership, custody and location of a data object.

- DCAT enables a publisher to describe datasets and data services in a catalogue using a standard model and vocabulary that facilitates the consumption and aggregation of metadata from multiple catalogues. This can increase the discoverability of datasets and data services. It also makes it possible a decentralised approach to publishing data catalogues and enables federated searching for datasets across catalogues in multiple sites using the same query mechanism and structure. Aggregated DCAT metadata can serve as a manifest file as part of the digital preservation process.
- PROV is an ontology providing the foundation to implement provenance applications in different domains. Provenance applications have the ability to represent, exchange, and integrate provenance information generated in different systems and under different contexts.

The second major metadata model is from Schema.org[53], an organisation formed by Google, Microsoft, Yahoo and Yandex. It is a rich metadata model similar to DCAT, which has been used to build out 'types' of metadata models for a wide range of concepts useful in web searches. Schema.org provides a collection of shared vocabularies webmasters can use to mark up their pages in ways that can be understood by the major search engines: Google, Microsoft Bing, Yandex and Yahoo!. Schema.org appears to be a much more loosely organised entity than the W3C, stating on its website, " Schema.org is not a formal standards body. Schema.org is simply a site where we document the schemas that several major search engines will support."

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[48] Ofgem: Consultation on updates to Data Best Practice Guidance and Digitalization Strategy and Action Plan Guidance

[49] DCMI: DCMI Metadata Terms

[50] W3C: Data Catalog Vocabulary (DCAT) - Version 3

[51] World Wide Web Consortium (W3C) (Home Page)

[52] W3C: PROV-O: The PROV Ontology

[53] Schema.org (Home Page)

There appears to be significant cross-pollination and coordination between W3C and Schema.org. The DCAT and Schema models seem each to be aware of and leverage content from the other. The W3C organisation hosts the Schema.org Community Group[54], where Schema.org development occurs.

Interestingly, both the European Commission (EC) and the UK government appear to utilize and/or promote both of the metadata models. At the European Commission:

- An extension to Schema.org has been proposed to describe EC legislation documents[55]
- Extensive collaboration was sponsored in the development of DCAT-AP (DCAT Application Profile for Data Portals in Europe)[56], a specification based on DCAT, whose focus is public sector datasets in Europe. The result of a multi-year effort, the specification of the DCAT-AP was a joint initiative of DG CONNECT, the EU Publications Office and the Interoperable Europe Programme. The specification was elaborated in 2019 by a multi-disciplinary Working Group with representatives from 16 European Member States (including the UK), the US, and several European institutions. The basic use case supported by DCAT-AP is cross-data portal searching for datasets with the purpose of making public sector data available across borders and sectors.

On the UK government website:

- Schema.org is referenced in gov.uk's developer docs[57], though details on the type of data being described is non-existent.
- DCAT is used in support of data posted on data.gov.uk[58], which helps people find and use open government data.

In the European data spaces world, a recent data.europa.eu report entitled "data.europa.eu and the European common data spaces: A report on challenges and opportunities"[59] states "Metadata schema for data spaces are still underspecified, although DCAT-AP is generally considered a good option as it has shown its value in the federation of open data portals." It goes on to note that extensions will be needed to meet data spaces requirements. The report also mentions the development of the IDSA Reference Architecture Model (IDS-RAM)[60] by the data spaces community, but draws the conclusion that, "Open data holders have extensive experience in data publishing, metadata management, data quality, dataset discovery, data federation, as well as tried-and-tested standards (e.g. DCAT) and technologies. There seems to be very little knowledge/technology transfer from the open data community to the data spaces community, which is a missed opportunity."

[54] W3C: Schema.org Community Group

[55] EC: About ELI legislation extension for schema.org

[56] Europa.eu: DCAT Application Profile (DCAT-AP)

[57] publishing.service.gov.uk: What data we expose as schema.org structured data

[58] data.gov.uk: Accepted DCAT and Data.JSON Fields

[59] data.europa.eu: Role of data.europa.eu in the context of European common data spaces

[60] International Data Spaces: IDS Ram (Home Page)

5. Implementations & Tools

This section provides brief descriptions of a range of market implementations and a selection of the software tools used to support them. The majority of entries relate to flexibility markets, but a few wholesale market implementations/tools relevant to the UK market or to the standards evaluated in this report are also included.

The initial intent in exploring market implementations and tools was to ensure that the full range of candidate market data exchange standards was identified. As the investigation progressed, it became clear that the use of standards in business-level market data exchanges, particularly in flexibility market implementations and tools, is very rare. As was mentioned previously, this situation is a logical outgrowth of the fact that markets typically communicate only with their own "clients" and not with other markets. A market implementation or tool typically provides a set of Application Programming Interfaces (APIs) tailored to supporting interaction with its specific market functions. These APIs are published and available for use by all of the market implementation's "clients".

For convenience, each tool/implementation overviewed in this section is characterised with the following:

> ***Data Domains:*** *<which of the eight identified data domains are required by the functions of the tool/implementation>*
>
> ***Interfaces:*** *<identified standard>* or Proprietary

A couple quick notes about the characterisations:

- Regarding ***Data Domains***: The relevant data domains have been inferred from descriptions of implementation/tool functionality which were available to the authors (primarily online information) and consequently may not be completely accurate.
- Regarding ***Interfaces***: In alignment with the language of the Metric #3: Development Process section, an interface developed "via a closed process under the control of a fixed entity", is classified as "Proprietary", even if it is made publicly available.

In the end, the information presented in this section regarding market implementations and tools is relevant to the discussion of the use of standards in a common digital energy infrastructure: not necessarily because it illustrates the use of standards, but because it provides insight into flexibility market maturity and variety, into the data domains required by different implementations, and into market implementation challenges and solution approaches. All of these provide useful context, and help identify potential collaborators, for the future work of creating a common digital energy infrastructure.

5.1. Wholesale/Upstream Implementations

5.1.1. ENTSO-E Transparency Platform

Data Domains: Registration, Competition, Availability, Reporting, Settlement

Interfaces: IEC 62325-451 (and ESMP)

The goal of ENTSO-E's Transparency Platform[61] is to facilitate access to information by all European market participants and stakeholders in promoting the transparency goals of the European Union's (EU's) Internal Energy Market vision[62]. The Transparency Platform collects market, load generation, transmission, outage, and balancing information from data providers such as TSOs, power exchanges or other qualified third parties and makes it available online.

5.1.2. North American Wholesale Electricity Markets

There are nine wholesale markets for electricity in North America:

- Alberta ESO
- California ISO
- ERCOT
- ISO New England
- Midcontinent ISO
- New York ISO
- Ontario IESO
- PJM Interconnection
- Southwest Power Pool

While the market designs are different, they all support day-ahead and real-time energy markets, most using nodal pricing. Also, most have grid support service markets for reserve and regulation, and some have forward capacity markets as well. Unfortunately, despite similar market implementations, the technical interfaces for data collection and dissemination were developed independently and are not, with the exception of California ISO, based on standards.

5.1.3. California ISO Market

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: profiles are based on the classes of the CIM Markets package

The California ISO market[63] supports a substantial set of market processes including congestion revenue rights, interchange scheduling, outage management, metering and telemetry, settlements, reporting and market monitoring. California ISO is the only North American

[61] ENTSO-E: Transparency Platform

[62] European Parliament: Internal Energy Market Fact Sheet

[63] California ISO: Market Processes & Products

market operator to implement CIM-based messaging for sharing market data with its buyers and sellers. Its interface implementation is intended to be leveraged in the creation of the planned IEC 62325-452 profile standards.

5.1.4. EPEX SPOT

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

EPEX SPOT[64] is a major European financial wholesale electric power exchange operating in Austria, Belgium, Denmark, Finland, France, Germany, Great Britain, Luxembourg, the Netherlands, Norway, Poland, Sweden and Switzerland. It hosts continuous, day-ahead and intraday energy trading along with a capacity auction.

The bespoke APIs offered by EPEX SPOT can be used by market participants to send and receive specially formatted and standardised messages to and from its trading systems. APIs are available for the M7 continuous trading system and for ETS auction trading.

EPEX SPOT is primarily a financial market whose purpose is to lower system-wide generation costs via competition. It does not have electric system optimisation as a goal, so grid-related data (grid models, grid location of assets, pricing nodes, etc.) is not exchanged.

In November of 2021, EPEX SPOT acquired the Local Energy Market (LEM) platform developed during the **Error! Reference source not found.** project from Centrica. EPEX SPOT is marketing L EM as a flexibility market solution which will allow Transmission System Operators as well as Distribution System Operators to manage grid congestions by using flexible assets.[65]

5.1.5. Nord Pool

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

Nord Pool[66] is a major European financial wholesale power market offering trading, clearing, settlement and associated services in both day-ahead and intraday markets across sixteen European countries in the Nordic and Baltic regions, the UK, and Central Western Europe. It is licenced in Norway by the Norwegian Water Resources and Energy Directorate to organise and operate a market place for trading power, and by the Norwegian Ministry of Petroleum and Energy to facilitate the power market with foreign countries. It is a Nominated Electricity Market Operator (NEMO) in the fifteen countries it serves other than Norway.

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[64] EPEX SPOT (Home Page)

[65] EPEX SPOT: New trading platform boosts EPEX SPOT's Localflex offer

[66] Nord Pool (Home Page)

Nord Pool's published, bespoke APIs support buyer and seller interaction with multiple market functions:

- Intraday market activities, including order submission
- Day Ahead market activities, including order submission and request of results to/from internal trading systems
- Compliance (supported by Nord Pool's REMIT Transaction Service), including reporting
- Clearing, including trade capture reporting
- Market data reporting, which supports access to anonymized market data
- Required near real-time notification of unexpected changes to generation, consumption or transmission (supported by Nord Pool's REMIT Urgent Market Messaging (UMM) Service.

It is worth noting that Nord Pool, like EPEX SPOT, is primarily a financial market focused on generation, not grid, optimisation and, as a consequence, grid-related data is not exchanged.

Nord Pool has recently announced a partnership with Equigy (creators of the Opus One DERMS by Opus One

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement, Grid Model

Interfaces: Proprietary

Opus One DERMS is a configurable platform designed to suit multiple levels of utility management of customer DER from simply controlling direct dispatch to a more complex approach such as market energy trading. It provides a wide range of capabilities:

- DER utility interconnection workflow
- DER modelling, including asset capability, asset grouping and grid modelling
- DER program management including contract management, flexibility markets, transactive energy management, demand programs, local service exchange, and settlements

Opus One DERMS appears to be a comprehensive set of capabilities which addresses utility optimisation of DER and demand response and includes utility planning functionalities like power flow studies and hosting capacity analysis along with utility operations and market functions like monitoring and control of DERs and microgrids.

Opus One contributed software solutions to both the **FUSION project at SP Energy Network (SPEN)** and the **TRANSITION project with Scottish and Southern Electricity Networks (SSEN) and Electricity North West Limited (ENWL)**.

Crowd Balancing Platform by Equigy) on a project call FlexiSwitch to reduce barriers to market entry for small scale providers.[67]

[67] Nord Pool: Nord Pool and Equigy Partner for Power Flexibility

5.1.6. National Grid ESO

Data Domains: Registration, Availability, Dispatch, Performance

Interfaces: Proprietary

National Grid ESO's **Single Market Platform (SMP)** is constructed to synchronize information between the asset owners in the UK and the ESO. It was first available to participants of the wholesale markets in February 2022. Core messages[68] include:

- Create/Manage Unit (Generation or Demand Type)
- Create/Manage Asset (as a constituent of a Unit)

The **Platform for Ancillary Services (PAS)** leverages the SMP for Registration, and adds more complex transactions[69], including:

- Bid/Offers (although, it is important to note that these are via EPEX Spot, with the National Grid ESO platform using the EPEX SPOT APIs)
- Availability/Outage Information
- Disarming/Rearming Instructions
- Performance Metering

Moving into the realm of smaller resource providers, the **Demand Flexibility Services (DFS)** was "developed to allow the ESO to access additional flexibility when national demand is at its highest – during peak winter days – which is not currently accessible to the ESO in real time."[70] The DFS is aimed at aggregators (resource size from 1 to 100 MW) and facilitates only day-ahead, half-hour increment energy balancing. Metering and baselining data is required to support demonstration of demand reduction delivery.

Another future platform will be implemented to support the **Enduring Auction Capability (EAC).** "The Enduring Auction Capability (EAC) is being designed to deliver co-optimised procurement for our day-ahead Frequency Response and Reserve products. It is envisioned that this method of procurement will allow us to meet our needs in the most efficient way, while enabling providers to participate in multiple markets."[71]

It will be important to monitor how National Grid ESO extends its interfaces into the future, as there may be important overlaps between its platforms and the common digital energy infrastructure.

[68] National Grid ESO: Single Market Platform API Detailed Specification

[69] National Grid ESO: ASDP (PAS): ASR Frequency Response Changes

[70] National Grid ESO: Demand Flexibility Service (Industry Information)

[71] National Grid ESO: Enduring Auction Capability (Industry Information)

5.2. Flexibility Platforms

This section overviews a number of flexibility platform implementations, some of which are vendor offerings (both software solutions and market implementations) and several of which are UK DNO innovation initiatives.

Numerous flexibility platforms have emerged in Europe and Australia in recent years. This section provides a brief overview of several of relevance in the UK flexibility landscape:

- Flex by Piclo
- deX by GreenSync
- ElectronConnect by Electron
- NODES by Agder Energi
- Opus One DERMS by Opus One
- Crowd Balancing Platform by Equigy
- Flexible Power, a joint DNO-created solution
- FlexR by ElectraLink

For additional information on these platforms and the European flexibility landscape in general, ENTSO-E's 2021 "Review of Flexibility Platforms"[72] is a valuable resource. While none of the identified platforms appear to implement any of the market data exchange standards identified in the Industry Data Exchange Standards section, a general understanding of their existence and capabilities provides context to the standards selection discussion. It is highly likely that a number of these platforms will continue to compete in offering innovative user experiences and bespoke market services when underpinned by a future common digital energy infrastructure solution implemented in the UK.

All six UK DNOs currently operate flexible power programs by which they procure flexibility services. The programs vary in their sophistication and the degree to which their functions require exchange of data from the full set of data domains identified in this report. The DNO programs currently in production rely largely on one or more of the software platforms listed above. Innovation initiatives, aimed at more active management of flexibility, are going on at nearly all of the UK DNOs. Four of those initiatives are highlighted in this section:

- Cornwall LEM in a National Grid Electricity Distribution (NGED) service territory
- The flexibility services platform project at UK Power Networks (UKPN)
- The FUSION project at SP Energy Network (SPEN)
- The TRANSITION project with Scottish and Southern Electricity Networks (SSEN) and Electricity North West Limited (ENWL)

5.2.1. Flex by Piclo

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

[72] ENTSO-E: Review of Flexibility Platforms

Piclo Flex[73] is an independently operated marketplace that supports SOs in the end-to-end process of procuring and operating flexibility. It implements an auction-based market with discrete competitions and pre-defined bidding deadlines.

The Piclo Flex platform supports the full range of flexibility market functions including:

- Procurement (including Market Visibility, Qualification, and Bidding)
- Operations (including Availability and Dispatch)
- Settlement (including Performance and Invoices)

It also supports a secondary trading marketplace that allows users to buy and sell existing flexibility contracts.

Piclo Flex has APIs that support the exchange of information related to procurement, operations and settlement and is engineered for integration with ADMS, DERMS and other back-office systems of FSPs and SOs. The Piclo website indicates that richer API capabilities are currently being developed.

In the UK, Piclo Flex appears to be in production use at UKPN, SPEN, ENW, NGED (previously Western Power Distribution), SSEN, and Northern Ireland Electric (NIE). According to its website, Piclo has also deployed Flex in Lithuania, Portugal and the United States. Piclo provided a satellite platform to allow visibility of the market platform of Project LEO[74], a 4-year collaborative initiative focused on flexibility management at the grid edge. Piclo Flex has recently been selected by National Grid for its first Local Constraint Market (LCM) in Scotland[75,76].

5.2.2. deX by GreenSync

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

GreenSync's Decentralised Energy Exchange (deX) [77] is a market-enabling digital platform that aims to provide electricity networks with better coordination and control of the increasing volume of distributed energy resources (DER) in the electricity grid. deX also aims to enable consumers to get more value from their energy assets (such as solar, batteries and electric vehicles), by being rewarded for participating in grid services.

deX was the result of a two and a half year Australian Renewable Energy Agency program that culminated in the realisation of deX as a commercially viable, digital DER integration and management platform.

deX appears to provide:

[73] Piclo Flex (Home Page)

[74] Project LEO Final Report

[75] Piclo to support National Grid ESO's new Local Constraint Market in Scotland

[76] NGESO: Local Constraint Market

[77] GreenSync deX (Home Page)

- a rich set of functions enabling a market role (including digital contracting, bid evaluation, settlement and support for both energy and ancillary services)
- a rich set of functions enabling an aggregator role (including registration, coordination, monitoring and dispatch of devices for energy and ancillary services, tools for monitoring and analysing performance and support for multi-technology aggregations)
- a collection of interface APIs to support communication among the market role, the aggregator role, individual DER (and their owners) and SOs.

In its "Navigating standards and frameworks for distributed energy resources" white paper[78], GreenSync states, "deX is young and the field of DER management is still evolving quickly. GreenSync does not think it is helpful to attempt standardisation of the deX API today;", going on to explain its awareness of a variety of standard exchange standards and protocols and its openness to future opportunities.

5.2.3. ElectronConnect by Electron

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

Electron's ElectronConnect[79] provides a marketplace infrastructure, in the form of a multi-market launch and hosting facility, that enables network operators, distributed energy resource operators and others to interact and unlock market-based efficiencies. Based on a series of modular components, the platform maximises a market operator's ability to launch services, access registered energy assets and solve an energy system's most immediate needs.

Electron was founded in 2015 and engaged in network optimisation projects before creating ElectronConnect. The ElectronConnect platform has been selected to support marketplaces for SSEN, National Grid ESO, and London Hydro (Canada). Its technology is also deployed in a real-time local marketplace in Orkney, implemented in project TraDER[80].

Electron's website refers to the 'Electron API' which enables "communication with existing IT systems, incl. DERMS, ANM, and SCADA, allowing users to maximise integration opportunities." There is no reference to the use of data exchange standards.

5.2.4. NODES

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

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[78] GreenSync: Navigating standards and frameworks for DER

[79] ElectronConnect (Home Page)

[80] Energy Systems Catapult: Project TraDER

NODES is the independent marketplace for a sustainable energy future where grid owners, producers and consumers of energy can trade decentralised flexibility and energy. NODES offers a continuously clearing platform allowing FSPs to place offers when suited to their operating conditions.

NODES[81] has embarked on a series of projects, which seek to determine how their market design can be applied to resolve different challenges faced by the system operators and the Flexibility Service Providers as they look to buy and sell flexibility. At the same time NODES will integrate other elements of the market, such as the wholesale market to avoid any imbalance costs or, where unused flexibility can be offered up to the TSOs.

According to its website, NODES operates across 10 countries in Europe and Canada where its service portfolio enables system operators to test a variety of use cases by reserving flexibility (availability) and procuring flexibility close to real-time (activation)[82]. The activation market has been trialed independently or in combination with the availability market in the UK (IntraFlex), Sweden (e.g., sthlmflex in Stockholm), Norway (e.g. NorFlex) and Ontario (e.g. PowerShare). NODES-Intraflex was launched by Western Power Distribution (now NGED) in 2020 and is testing the use of a continuously clearing market operating from a few days ahead to close to real-time for the procurement of flexible generation and consumption. It is independent of NGED's primary flexibility procurement system from Flexible Power. Among research projects, NODES is co-developing the Universal Market Enabling Interface (UMEI), allowing distributed communication without the need for a central hub[83].

The NODES Platform (API and GUI) supports the full range of flexibility market functions including:

- Pre-trading (including onboarding, grid modelling, and asset registration)
- Trading (including market visibility, availability contracts, activation, dispatch notification, and secondary trading)
- Post-trading (metering hub, validation, settlement and invoicing)

NODES has recently been selected by Göteborg Energi Nät AB (Sweden) to extend the operation of Effekthandel Väst, a regional flexibility market, in Gothenburg and neighbouring areas.

5.2.5. Opus One DERMS by Opus One

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement, Grid Model

Interfaces: Proprietary

[81] NODES white paper: Paving the way for flexibility https://nodesmarket.com/publications/

[82] https://nodesmarket.com/projects/

[83] https://euniversal.eu/euniversal-the-umei-api/

Opus One DERMS[84] is a configurable platform designed to suit multiple levels of utility management of customer DER from simply controlling direct dispatch to a more complex approach such as market energy trading. It provides a wide range of capabilities:

- DER utility interconnection workflow
- DER modelling, including asset capability, asset grouping and grid modelling
- DER program management including contract management, flexibility markets, transactive energy management, demand programs, local service exchange, and settlements

Opus One DERMS appears to be a comprehensive set of capabilities which addresses utility optimisation of DER and demand response and includes utility planning functionalities like power flow studies and hosting capacity analysis along with utility operations and market functions like monitoring and control of DERs and microgrids.

Opus One contributed software solutions to both the FUSION project at SP Energy Network (SPEN) and the TRANSITION project with Scottish and Southern Electricity Networks (SSEN) and Electricity North West Limited (ENWL).

5.2.6. Crowd Balancing Platform by Equigy

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance

Interfaces: Proprietary

The Crowd Balancing Platform (CBP)[85] enables aggregators to participate with smaller flexibility devices, such as home batteries and electric vehicles, in electricity balancing markets. As a market-intermediary platform, it shares relevant information between the participating parties in a transaction – such as TSOs, DSOs, aggregators and data providers. It enables the proof of delivery of flexibility transactions, while allowing the market to operate within grid limits.

Developed by Equigy, an international consortium of TSOs (SwissGrid, TenneT, Terna, APG), the CBP facilitates the standardised registration, bidding and activation of flexibility transactions from aggregators of DERs. Equigy works together with national TSOs to implement the CBP in each country according to the needs of their market.

According to the Equigy website, the CPB is deployed in Germany, Italy, Switzerland, and the Netherlands. The CPB has recently announced a new partnership with Nord Pool to trade energy flexibility in the Dutch market[86].

5.2.7. Flexible Power

Data Domains: Registration, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

[84] Opus One DERMS

[85] Crowd Balancing Platform (Home Page)

[86] Equigy: Nord Pool and Equigy Partner for Power Flexibility

Created by four DNOs (NGED, Northern Power Grid, SSEN, and SPEN), Flexible Power[87] offers a single point of information in respect of DNO flexibility service requirements. Flexibility providers are able to view flexibility locations, requirement data, procurement notices and documentation published by all DNOs on the joint website. Once contracted, providers are given access to the joint Flexible Power Portal where they can declare their assets' availability, receive dispatch signals and view performance and settlement reports.

5.2.8. FlexR by ElectraLink

Note: Flexr is not a flexibility platform, but is included here because of its focus on shared data.

Flexr[88] is a DNO data provision and standardisation service that will connect to the data held by all six DNOs and their DER customers. It is being developed by ElectraLink, the regulated central body responsible for operating the data hub that underpins the UK energy market. ElectraLink also provides expertise to the development of market-related industry codes and analyses energy market data to provide data insight and transparency.

Flexr is a data uncovering and sharing service that does not compete with existing flexibility market services, but is intended to support the further development of these market services and level the playing field to allow for even greater levels of innovation in the market.

ElectraLink's response report to its consultation on FlexR[89] provides insight into industry perceptions of the value of a shared flexibility market data service. ElectraLink delivered a minimum viable product (MVP) for FlexR in 2021[90].

The role that FlexR seems to play in hosting DNO flexibility data makes it a system of interest in the development of a common digital energy infrastructure. It could offer early collaboration opportunities for exploring standards-based - and metadata-driven - data sharing.

5.2.9. Cornwall Local Energy Market (LEM) Platform

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

The Cornwall LEM Flexibility Market Platform[91,92] was a proof-of-concept project sponsored by European Regional Development Fund and Centrica and implemented in Cornwall, an area of National Grid Electricity Distribution (NGED)[93] service territory with a significant penetration of renewables (and consequent grid management issues). It ran from 2017 through 2020 and was

[87] Flexible Power (Home Page)

[88] Flexr (Home Page)

[89] ElectraLink: Flexr consultation response

[90] ElectraLink: Flexr prototype complete with thousands of electricity assets logged

[91] Centrica: Cornwall Local Energy Market

[92] Centrica: The future of flexibility - How local energy markets can support the UK's net zero energy challenge

[93] Formerly Western Power Distribution (WPD).

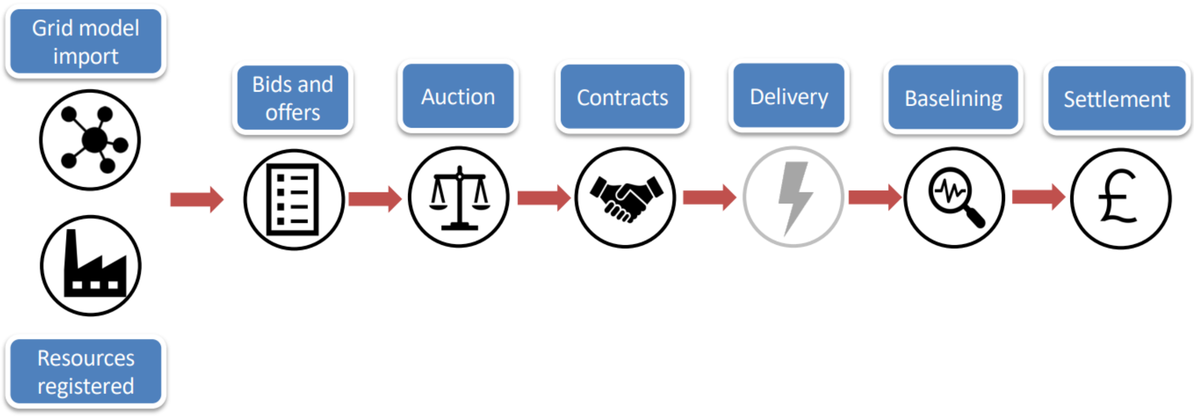
the UK's largest-ever trial of energy flexibility, enabling households and business owners in Cornwall to generate, store, and trade renewable electricity.

The LEM project enabled local electricity network operator NGED and the NGESO to simultaneously buy flexibility via a third-party platform - a smart auction-based marketplace designed by Centrica that traded energy capacity automatically. The auction model implemented in the LEM project:

- Allows complex bids and ensures a better execution/matching of blocks
- Enables transmission/distribution co-ordination, resulting in more optimal allocation of network capacity

The Complex energy auction and power matching algorithms (which consider a variety of order, grid and economic constraints) were provided by N-SIDE[94].

The LEM project identifies the foundational role of a grid model in the end-to-end market process, as shown in Figure 6, which is an excerpt from the "Cornwall LEM Flexibility Market Platform" presentation given by Centrica at the Cornwall Local Energy Market Event on 19 November 2020[95]. (The presentation also identified several required improvements to grid model data - all of which happen to be supported by IEC 61970).



From the "Cornwall LEM Flexibility Market Platform" presentation given by Centrica at the Cornwall Local Energy Market Event on 19 November 2020

Figure 6: The LEM platform's end-to-end market process

The LEM project spawned a raft of research reports and papers which are available from Centrica[96], including a set describing the metadata of information[97] available from the project.

The authors have not been able to confirm if the LEM project levered data exchange standards for its market-related communications.

The Cornwall LEM project is of relevance to future common digital energy infrastructure efforts for several reasons:

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[94] N-SIDE Case Study: Cornwall LEM project - TSO/DSO Coordination

[95] Centrica: Cornwall LEM Flexibility Market Platform presentation 2020

[96] Centrica: Cornwall LEM research reports and papers

[97] Trilemma: LEM Residential MetaData Summary Report

- It implements complex algorithms considering both the transmission and distribution grid conditions
- It utilises grid models
- It recognises the importance of metadata support for data sharing

In September 2021, EPEX SPOT acquired the LEM platform from Centrica[98].

5.2.10. Flexibility services platform project at UK Power Networks (UKPN)

Data Domains: Registration, Competition, Availability, Dispatch, Reporting

Interfaces: Proprietary

UK Power Networks (UKPN) organised the flexibility services platform project which was delivered by a market-leading consortium of GreenSync, Smarter Grid Solutions (SGS) and Nexant. The project utilises GreenSync's Decentralised Energy Exchange (deX) as the market platform to connect and contract distributed energy resources, Smarter Grid Solutions' ANM Strata as the core platform and Nexant's iEnergy product as the customer interface.

5.2.11. FUSION project at SP Energy Network (SPEN)

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement

Interfaces: Proprietary

SPEN's FUSION project[99] is an Energy Network Association (ENA) Network Innovation Competition (NIC) project trialling commoditised local demand-side flexibility in East Fife, St. Andrews through a structured and competitive market. It is aligned with the Open Network programme of the Energy Network Association (ENA). Running from 2018 through 2023, FUSION recently completed its first phase[100] and has launched it second phase.

The project seeks to demonstrate how the introduction of a local demand-side flexibility market can help a DSO better manage its network. The project trials an online interactive platform that allows a DSO to signpost local network requirements to the market and then purchase customer flexibility to alleviate localise network congestion.

The market design is based on the Universal Smart Energy Framework (USEF)[101], an "internationally recognised standard for trading flexibility" which outlines a comprehensive set of rules and processes for ensuring the smooth operation of DSO markets. USEF both defines a role-based market design and defines data exchanges to specifically to support interactions between the aggregator and DSO roles[102]. While publicly available, the data exchange definitions are not based on any international standard.

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[98] EPEX SPOT: New trading platform boosts EPEX SPOT's Localflex offer

[99] SP Energy Networks: Fusion project

[100] SP Energy Networks: FUSION Interim Trial Learnings Report

[101] Universal Smart Energy Framework (Home Page)

[102] USEF: Flexibility Trading Protocol Specification

The FUSION flexibility trading platform is being provided by Opus One Solutions[103]. Opus One software has historically supported standard CIM grid model exchanges, but it is not clear that grid model data is part of the FUSION project scope.

ENA Open Network programme[104]

The comprehensive Open Networks programme of the Energy Network Association (ENA), is a wide-ranging collection of initiatives focused on distributed system operation and flexibility markets. It has brought together the nine electricity grid operators in the UK and Ireland to work together to standardise customer experiences and align processes to make connecting to the networks as easy as possible and bring record amounts of renewable distributed energy resources, like wind and solar panels, to the local electricity grid. It has sponsored a wide range of innovative flexibility projects and trials, including both FUSION and TRANSITION.

5.2.12. TRANSITION project with Scottish and Southern Electricity Networks (SSEN) and Electricity North West Limited (ENWL)

Data Domains: Registration, Competition, Availability, Dispatch, Reporting, Performance, Settlement, Grid Model

Interfaces: Proprietary with the exception of grid model exchanges which are CIM-based

The joint SSEN and ENWL TRANSITION project[105,106] is an Energy Network Association (ENA) Network Innovation Competition (NIC) project that is designing, developing and demonstrating market solutions informed by the ENA's Open Network programme. It is trialling local energy flexibility, facilitating new markets, and testing market models with the objective of developing a platform that will enable neutral market access for all customer groups. Physical trials have been hosted in Oxfordshire in SSEN's service territory and simulation trials run in ENWL. Results are allowing market rules and conflict avoidance rules to be tested.

Solution tools enabling the testing of different flexibility market models were provided by Opus One[107]:

- Neutral Market Facilitator (NMF) platform for buyers and sellers of flexible electricity sources supports registering of requirements and capabilities;
- Whole System Coordination (WSC) tool integrates data from a variety of different sources to quantify the requirements for network flexibility across different timeframes.

From project documents, it appears that Piclo and DIgSILENT tools are also a part of the integrated solution.

The project activities have included the identification of data requirements and data exchanges for DSO functions, making this project of special interest to future common digital energy

[103] SPEN: contract awarded to help develop electricity flexibility project
[104] ENA: Open Networks programme: developing the smart grid
[105] SSEN: Transition
[106] EWNL: Transition
[107] SSEN: SSEN awards Opus One contract to develop market flexibility and coordination solutions

infrastructure efforts. The project also focused efforts on the use of CIM-based grid model data exchange: it is tackling the challenges of using the CIM to describe lower voltage networks and DER and to merge modelling from multiple internal utility sources. No references to the use of data exchange standards apart from the CIM for grid models were found.

5.3. Flexibility Market Activities in Australia

5.3.1. Australian Dynamic Operating Envelopes (DOE)[108]

The Australian Distributed Energy Integration Program (DEIP) is a forum of Australian government agencies, market bodies, industry associations and consumer associations aimed at maximising the value of customers' distributed energy resources (DER) for all energy users. The DOE workstream of DEIP explores the use of DOEs for customer-to-grid export management. The concept of DOEs has developed in Australia as a result of issues related to the grid's capacity to accept energy from DERs. The following explanation is provided in the Dynamic Operating Envelope Working Group's Outcomes Report[109]:

> "Dynamic operating envelopes vary import and export limits over time and location based on the available capacity of the local network or power system as a whole."

One of the reports published as part of the Workstream was the Smarter Homes Study[110], which assessed how residential energy customers can coordinate their distributed energy resources (DERs) through a Home Energy Management System (HEMS). The study considers the readiness of available HEMS products and services to respond to dynamic operating envelopes (DOEs). It identified both energy market participation and provision of network service to Distribution Network System Providers (DNSPs) as value streams that HEMS can unlock. The report identified several facets of DNSP-to-customer connection point interaction as challenging including the manner in which DOEs could be supported by device-focused standards like IEEE 2030.5 and or communication standards like DNP.

5.3.2. Post-2025 Market Design

Australia's Energy Security Board (ESB), a government forum comprised of the heads of the Australian Energy Market Commission, Australian Energy Regulator and Australian Energy Market Operator, has been tasked with developing a fit-for-purpose market framework to support reliability that could apply from the mid-2020s. In its Post-2025 Market Design[111], ESB's advice included four reform pathways related to:

- Resource adequacy mechanisms and ageing thermal retirement
- Essential system services and scheduling and ahead mechanisms
- Effective integration of distributed energy resources (DER) and flexible demand
- Transmission and access reform pathway

In relation to the second bullet, ESB has identified a number of services (fast frequency response, system strength management, primary frequency response, operating reserves and ramping services, synchronous services, and capacity commitment mechanisms) whose

[108] ARENA: Dynamic Operating Envelopes Workstream

[109] ARENA: Dynamic operating envelope working group outcomes report

[110] ARENA: Smarter homes for distributed energy

[111] ESB: Post-2025 market design

provision via market mechanisms will be critical to keep Australia's electricity grid in a safe, stable and secure operating state[112].

In relation to the third bullet, ESB have outlined two Post-2025 DER Implementation Plans to be created, one relating to design and implementation process and the other to an interoperability policy framework. With respect to the latter, ESB published "Interoperability Policy for Consultation, Stage 1: Inverter based resources"[113]. It solicits input on how the "CSIP-Aus"[114] interoperability standard whose development was facilitated by ARENA should be applied in the NEM.

CSIP-Aus is focused on the visibility (both static and near-real-time) of DER and their active management through the provision of dynamic (real power) import and export limits. It heavily leverages the IEEE 2030.5 standard, along with California's Common Smart Inverter Profile (CSIP), adding extensions where necessary to meet Australian needs. Like IEEE 2030.5 and CSIP, CSIP-Aus primarily supports communication directly with DER devices themselves, though it can also be used to communicate regarding aggregations of devices via a third party such as an aggregator, generating facility or microgrid.

[112] ESB: Essential system services and scheduling and ahead mechanisms

[113] ESB: Interoperability Policy Stage 1: Inverter based resources - final for consultation

[114] ARENA: Common Smart Inverter Profile - Australia

6. Conclusions

6.1. Recommended Standard

6.1.1. Industry data exchange standard

Five candidate industry data exchange standards were included in this evaluation. They are listed in Figure 7.

	IEC CIM	ebIX	OpenADR	IEC 61850	IEEE 2030.5
Data Domains	8	4	5	3	3
Data Model	Semantic Model	Message Model	Message Model	Semantic Model	Semantic Model
Development Process	Curated	Curated	Community	Curated	Curated
Message Library	Rich	Developed	Developed	Developed	Developed

Figure 7: Summary of Industry Data Exchange ratings

Of the five, only IEC CIM, ebIX and OpenADR are viable candidates. The central focus on device communication that characterises both IEC 61850 and IEEE 2030.5 results in a Data Domains rating of "red" and takes them out of contention. There is a clear winner among the remaining three: the IEC CIM. It is the only standard that has defined data exchanges supporting all eight identified data domains. It has a single, cohesive underlying semantic model supporting all of its data exchange profiles. Its development is supported by a well-respected SDO. And the depth and breadth of its coverage in many of the data domains is large. Much of the CIM's success in meeting the data domain requirements comes from the expansiveness of its central semantic model and from the decades of collaborative development work that have gone into its creation.

The authors believe there are a number of fundamental of characteristics that make CIM the obvious choice as the enabling interface standard for a common digital energy infrastructure. They include:

- Comprehensive semantic model. All CIM data exchange profiles rely on the same semantic information model – this provides the ability to easily define messages that contain information that "connects" different data domains.
- Global development process. The CIM's semantic model and profile development processes are world-class and underpinned by an industry consortium that encourages broad participation (UCAI) and a Standards Development Organisation (IEC) that formalises approval of changes.
- Broad European adoption. There is both an appreciation of the value of semantic models and familiarity with the CIM in Europe. Examples include:
    - The European Network Codes' requirement of structured exchange of data in both the market and grid model domains.

    - ENTSO-E's CIM-based implementations (Transparency platform and bi-annual TYNDP development) and ongoing CIM development support (CGMES and market profiles).
    - The emerging use of CIM in the UK for structuring required data exchanges in projects like Ofgem's Long-Term Development Statement (LTDS) initiative[115] and ENA's Grid Code 0139 revision.
- **Solid foundation for future development.** The underlying CIM information model is the result of decades of work by industry experts. This has resulted in a quality information model that accurately represents the major data constructs relevant to the electric industry.
    - Throughout the CIM, the basic classes in market and grid packages provide a solid, well-designed framework which can be (and continually are) extended to meet future requirements.
    - An example of this is the CIM information model's support for full-featured nodal markets, including the grid models central to the pricing algorithms. Despite the fact that standard profiles are not yet defined for nodal market data exchanges, the underlying model will support their development as the California ISO market implementation illustrates. (This particular example of the CIM's robust information model is of particular relevance in the UK as the move toward a nodal market is contemplated by NGESO[116], an action which is aligned with the Ofgem-issued a call for input on Location Pricing Assessment[117].)
- **Existing support for metadata**. The CIM's carefully-defined, well-managed semantic model and its use of W3C XML standards in its profile definitions put CIM-based implementations in a good position to participate in future metadata-driven cross-platform data exchange environments.

6.1.2. Meta data exchange standard

The vision of open data, and all the societal benefits it can bring, means that the common digital energy infrastructure will be called on to share data with entities not just in its own market domain and but also in external domains where data structures are different from its own. A universally understood metadata model is an essential enabler of this cross-domain data exchange.

The authors recommend the use of W3C metadata model standards – DCAT, DCAT-AP, and PROV – to enable the common digital energy infrastructure to more easily exchange information – both incoming and outgoing - with external platforms. As the narrative of the **Meta Data Exchange** section would suggest, of the two major metadata models implementing the Dublin Core terms, the W3C standards appear to have greater European support and development investment, better alignment with the energy sector's requirements, and the backing of a more solid organisation. Equally, one might understand from the narrative that the world of metadata models is fairly nascent and rapidly changing, with significant

[115] Ofgem: The Common Information Model (CIM) regulatory approach and the Long Term Development Statement
[116] National Grid ESO: Net Zero Market Reform
[117] Ofgem: Locational Pricing Assessment

development work occurring across Europe. Leveraging that progress will be an important part of the success of the common digital energy infrastructure.

6.2. Recommended Actions

Ofgem are seeking feedback, via a call for input, on a common digital energy infrastructure, whose purpose is the coordination and optimisation of DER and CER with the aim of increasing the electric industry's ability to serve society in its pursuit of a zero-carbon future. In their call for input, Ofgem identified standards-based interfaces as an enabler of the common digital energy infrastructure, an insight which the authors of this report believe makes the common digital energy infrastructure both more achievable and of broader industry benefit.

6.2.1. Background

We have recommended the CIM as the standard of choice to support the full suite of data domains for the interfaces required by a common digital energy infrastructure. While CIM is absolutely the right answer, simply stating "use the CIM" implies a standards situation far simpler than what currently exists. The CIM consists of an underlying, foundational information model and myriad profiles that define subsets to be used in individual data exchanges. The CIM information model varies from one part to another in its completeness and sophistication. And different families of profile standards support different use cases which may or may not address a given implementation's requirements.

In the case of a common digital energy infrastructure, a set of required data domains has been outlined and a set of CIM profile standard families supporting those data domains has been identified. Figure 8 provides a high-level summary of the intersection of the CIM standard families and data domains using the metrics of Coverage and Maturity.

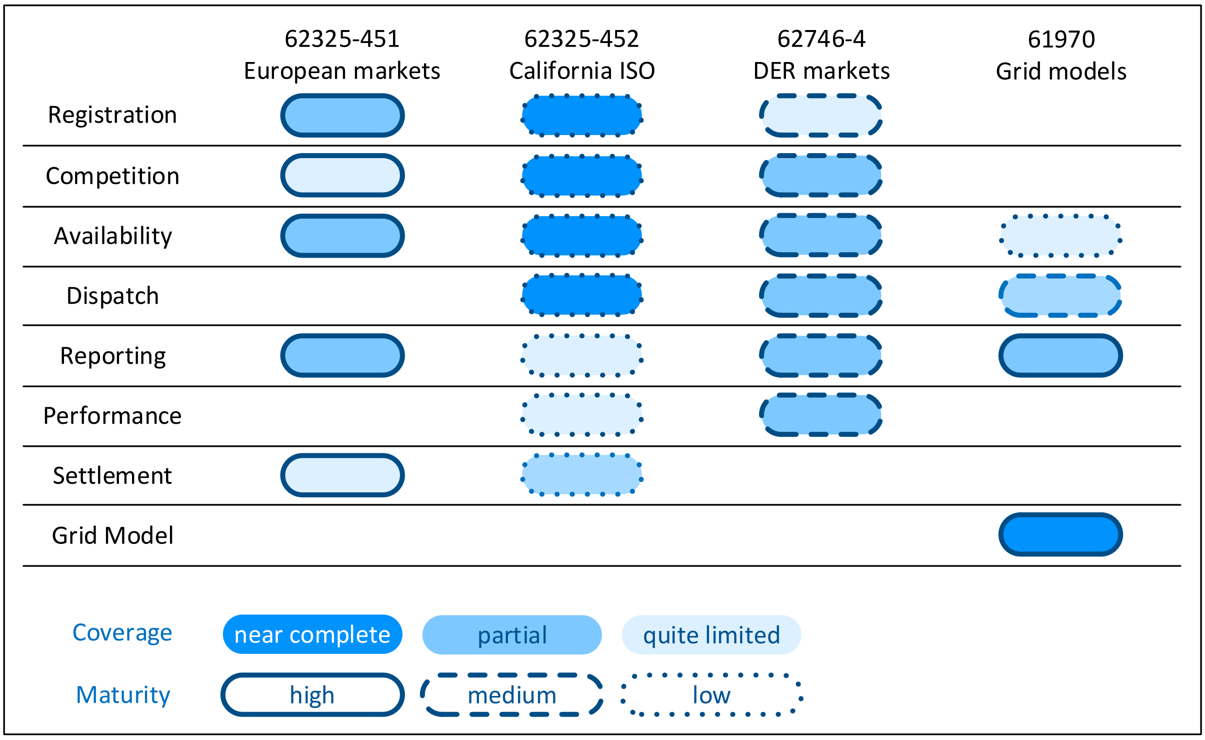

Figure 8: Data domains and their support by different CIM profile standard families

The Coverage metric reflects how thoroughly the standard supports the data domain with respect to the requirements of a common digital energy infrastructure (as they are currently understood). The Maturity metric reflects the degree to which the existing standard has progressed toward an becoming an approved, significantly implemented standard. Both metrics impact the value and usefulness of a standard in its support for a common digital energy infrastructure solution.

One of the observations that comes out of Figure 8 is the overlapping nature of the IEC 62325-451, IEC 62325-452 and IEC 62746-4 CIM profile standard families. Each family profiles the Markets information model in its own unique way. Each covers different data domains. Each is at a different level of standardisation and adoption. At a high level, they can be characterised as follows:

- The existing IEC 62325-451 is limited in data domain coverage and defines messages that leverage the power of the Markets classes to only a limited degree, but IEC 62325-451 is well-documented, well-supported, and is implemented in the ENTSO-E Transparency platform.
- The yet-to-be-standardised IEC 62325-452, which is implemented at the California ISO, has significant potential value because it extensively leverages the power of the Markets classes in support of a full-featured, nodal wholesale market, but it is not yet on the road to standardisation.
- The new IEC 62746-4 reflects a sound approach to retail (flexibility) markets leveraging the appropriate CIM classes, but is still in the IEC review process (approval anticipated in late 2023) and has not yet been implemented in the real world.

This synopsis is presented not to suggest that one family is better than the other nor that one should be chosen over the others at this point, but rather to illustrate that there is both (a) a wealth of CIM profile development work that has gone on in support of markets and (b) a need for additional investigation to formulate a practical strategy for using CIM in support of a common digital energy infrastructure.

6.2.2. Recommended Action 1: Solidify the Approach

Because of the complex nature of CIM support for the required data domains, the initial step suggested by this report is to determine the approach to profile definition that should be taken for each required data domain. This activity will recommend the profile family (or families) to be used as the basis for the development of profiles supporting the common digital energy infrastructure solution. While driven by local requirements, the work should consider the impact on the wider industry of the decision to use one or more of the existing profile families for any given data domain and/or across all data domains. This activity is an essential first step as it will guide all subsequent work, providing an indication of where future efforts should be focused and which organisations should be engaged with.

This activity should occur in concert with initial efforts related to solution architecture refinement and the conceptual design of the common digital energy infrastructure functions.

Suggested tasks include:

1. Validating the picture of CIM support for the requirements of a common digital energy infrastructure that this report has painted.
2. Synthesizing a high-level description of the types of data included in each of the data domains outlined in this report using input from the team doing conceptual solution design.

3. Analysing the gaps (at a high level) between existing support provided by each of the CIM profile standard families and the data types identified for each required data domain.
4. Developing the profile approach to be taken for each data domain. There are multiple options including:
    - Using a specific existing CIM profile standard
    - Enhancing a specific existing CIM profile standard
    - Extensively modifying an existing CIM profile standard
    - Synthesizing one or more existing CIM profile standards into one profile
    - Creating a new profile.

6.2.3. Recommended Action 2: Define Profiles

As the common digital energy infrastructure transitions from archetype selection and conceptual design into more detailed design activities, a team to undertake initial profile definitions should be constituted. There is an important interplay between the requirements coming out of the design of the common digital energy infrastructure solution and the data organisation insight offered by the semantic model underpinning the data exchanges. That interplay should be recognised and leveraged. As a consequence, the profile definition team needs to be put in place concurrently with the common digital energy infrastructure solution design team so it can both contribute to and pull from the design conversation.

The profile definition team should represent a variety of perspectives and skillsets. Because a local interface solution with industry-wide impact is being designed, optimal results will require a collaborative, inclusive approach and an awareness of the context surrounding the effort.

The major outputs include:

- The initial definition of profiles for the data exchanges of the common digital energy infrastructure solution
- An articulation of the relationship between the CIM as used for the common digital energy infrastructure and the CIM as maintained by standards entities:
    - How the local profiles relate to IEC, European and UK CIM-based profiles and the strategy for their concurrent management
    - How the underlying local CIM-based information model relates to the IEC CIM model and the strategy for concurrent management.

6.2.4. General Recommendation: Establish Relationships

The value to the industry of the long-term results of the common digital energy infrastructure work outlined above should not be underestimated. Nor should its complexity nor its potential for creating controversy. There is a varied landscape of CIM market-supporting profile standards and implementations each with its own set of stakeholders. While this variety has served to satisfy multiple local implementation needs, it has also masked the significant value and power of the underlying CIM information model for supporting future-looking market data exchange and management and thereby limited its use. The challenge and opportunity for the interface standards work of the common digital energy infrastructure is to create a solution that both serves local requirements effectively and simultaneously improves CIM standards' clarity and industry usefulness. (It is worth noting that the common digital energy infrastructure will itself benefit as the CIM becomes more widely used.)

There are many organisations in this space, such as IEC TC 57 Working Groups 16 and 21, UCAI Task Forces 16 and 21, ENTSO-E, and California ISO, which are all in the process of developing and maintaining the various CIM standards. Relationships with them should be established and nurtured during this work. Doing so will allow those involved in the common digital energy infrastructure effort to understand the unique focus and perspective of each organisation. Formally joining some of them will both help educate the common digital energy infrastructure team about the CIM and its processes and make the other organisations aware of the new requirements anticipated to be coming from the common digital energy infrastructure effort in the future.

Outside the CIM world, there are also relationships that should be built. There are multiple UK markets and a plethora of UK market participants, all of whom have much at stake in the outcome of the common digital energy infrastructure work. They are both invaluable sources of knowledge and organisations who will need to invest, some significantly, in interfaces that allow them to interact with the common digital energy infrastructure. Additionally, it will be important to stay abreast of activities going on internationally - across Europe and Australia in particular – which relate to both market implementations and the utilisation of metadata-driven cross-platform data exchange. The Implementations & Tools section provides a good starting point for identifying potential organisations with which to establish contact.

It is vitally important that the common digital energy infrastructure solution avoids becoming just "one more local CIM market implementation". Moving forward intentionally and collaboratively, keeping the bigger picture in sight as detailed decisions are made, is the surest way for the investment in a common digital energy infrastructure to produce the most benefit for both UK and the electric utility industry at large.

Appendix: Device Communication Protocols

While none of the protocols listed below support the business-level market data exchanges which are the focus of this report, they are candidates for implementing the device data exchanges essential to the achievement of the overall common digital energy infrastructure vision.

They are divided into two categories: Behavioural and Interface.

Behavioural

BSI PAS 1878[118]

"Publicly Available Specification (PAS) 1878 specifies requirements and criteria that an electrical appliance needs to meet in order to perform and be classified as an energy smart appliance (ESA). It defines the attributes, functionalities and performance criteria for an ESA, and specifies how compliance with these can be verified." PAS 1878 has a companion interface specification, PAS 1879 (see below).

California Rule 21/CSIP[119]

California Rule 21 is tariff that describes the interconnection, operating and metering requirements for generation facilities to be connected to a utility's distribution system. Each California investor-owned utility is responsible for the administration of Rule 21 in its operating territory. Rule 21 outlines inverter autonomous functions and identifies IEEE 2030.5 as its default communications protocol.

IEEE 1547-2018: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces[120]

"Standard 1547-2018 went into effect as of August 2018. The revised standard leverages the capabilities of inverter-based DERs and allows them to operate like conventional generators. By providing requirements relevant to performance, safety considerations, and the maintenance of interconnection, the standard determines how DER devices are designed and tested. It will also define how DER will be integrated into the power system going forward."

AS/NZS 4777.2:2020: *Grid connection of energy systems via inverters*[121]

"The objective of this Standard is to specify minimum performance and safety requirements for the design, construction and operation of inverters intended for grid connection of energy systems."

[118] BSI PAS 1878

[119] QualityLogic: Introduction to IEEE 2030.5 and CA Rule 21/CSIP

[120] IEEE: What is IEEE Standard 1547?

[121] AS/NZS 4777.2:2020

IEC 61724-1: *Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis*[122]

IEC 61724-1:2021 outlines terminology, equipment, and methods for performance monitoring and analysis of photovoltaic (PV) systems. It also serves as a basis for other standards which rely upon the data collected. This document defines classes of photovoltaic (PV) performance monitoring systems and serves as guidance for monitoring system choices.

Interface

BSI PAS 1879[123]

"PAS 1879 sets out a common definition of demand side response (DSR) services for actors operating within the consumer energy supply chain and provides recommendations to support the operation of energy smart appliances (ESAs)." PAS 18798 has a companion behaviour specification, PAS 1878 (see above).

AS/NZS 4755 (2017): *Demand response capabilities and supporting technologies for electrical products*[124]

This standard specifies the framework for demand response capabilities and supporting technologies, demand response enabled devices (DRED). The framework and DRED technology specified by this standard allows DER to alter, in eight different ways, from their normal mode of operation based on an initiating signal originating from a remote agent e.g., distribution network, market operator, retailer. This change in behaviour may be in response to a price or grid security signal.

IEEE 1815-2014 (DNP): *IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3)* [125]

DNP3 enables "open, standards-based Interoperability between substation computers, RTUs, IEDs (Intelligent Electronic Devices) and master stations (except inter-master station communications) for the electric utility industry."

Modbus[126]

"Modbus Protocol is a messaging structure developed by Modicon in 1979. It is used to establish client-server communication between intelligent devices. It is a de facto standard, truly open and the most widely used network protocol in the industrial manufacturing

[122] IEC 61724-1:2021

[123] BSI PAS 1879

[124] GreenSync: Navigating standards and frameworks for DER

[125] DNP: Overview of DNP3 Protocol

[126] Modbus: Modbus FAQ

environment. It has been implemented by hundreds of vendors on thousands of different devices to transfer discrete/analog I/O and register data between control devices."

IEC 61400-25: *Communications for monitoring and control of wind power plants*[127]

It provides uniform information exchange for monitoring and control of wind power plants. This addresses the issue of proprietary communication systems utilizing a wide variety of protocols, labels, semantics, etc., thus enabling one to exchange information with different wind power plants independently of a vendor.

OpenFMB[128]

The Open Field Message Bus (OpenFMB) interoperability framework is a a North American Energy Standards Board (NAESB) standard. It provides the ability to leverage new and existing grid assets to ensure that the future power system is resilient, reliable, safe, secure, and cost effective. Its foundational use cases focus on circuit segment management for the active coordination of power systems equipment to DER, including a microgrids.

EFI / FAN[129]

The Energy Flexibility Interface (EFI) is an open-source communication protocol for controlling various smart devices by means of energy management software. It has been developed by the Flexible Power Alliance Network (FAN), a membership organisation that aims to provide open standards for unlocking flexible energy in energy systems. A device driver is freely available to help reduce time-to-market for device manufacturers. The driver functions as both a monitor and a control interface and can utilize Zigbee, PowerLine Communications (PLC), and/or Wi-Fi. It uses a single message called the "EfiMessage" as the root for all communications which includes versioning, timestamping and identification for the resource as well as a "deviceClass" attribute which defines the type of device, for example refrigerator, PV panel, or floor heating.

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[127] IEC 61400-25-1:2017

[128] OpenFMB (Home Page)

[129] FAN: EFI - Energy Flexibility Interface