United Nations Economic Commission for Europe
Group of Experts on Energy Efficiency

Task Force on Digitalization in Energy

Case study

Grid Edge Management Reference Architecture and Policy Recommendations for Interoperability and Resilience

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Contents

List of abbreviations

AI	Artificial Intelligence
AMI	Advanced metering infrastructure
CSC	Community Self Consumption (bottom-up energy market management model)
DERs	Distributed energy resources
DLT	Distributed ledger technology
EU	European Union
FSPs	Flexibility service providers
IoT	Internet of Things
ML	Machine learning
MSS	Microgeneration support scheme
P2M	Peer-to-Market (indirect transactions with peers via select market)
P2P	Peer-to-Peer (direct transactions among peers)
PV	Photovoltaics
TE	Transactive Energy

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Theoretical and Contextual Introduction

This case study addresses the challenge of distributed energy resources (DERs) integration to support grid resilience, identifying key infrastructure requirements, assessing policy developments and deriving recommendations. The underlying premise of this case study asserts that whilst the energy sector is making advances towards decarbonization, decentralization and digitalization, the increasing share of DERs in the energy mix is still not being sufficiently harnessed for their potential in the energy transition, yet continue to create challenges for grid management.[1]

Technologies that are driving digitalization of the energy sector include DER in the form of solar photovoltaics (PV), batteries (storage), electric vehicles (EVs) and their charging infrastructure, and the proliferation of Advanced Metering Infrastructure (AMI). However, despite some progress, investment in smart grids needs to more than double annually through 2030 in order to meet the Net-Zero Emissions Scenario by 2050, especially in emerging markets and developing countries.[2]

Three reference infrastructure requirements have been identified for enhanced DER integration:

1. Ease of DER Installation: standardized, transparent and simplified process for DER acquisition and installation to ensure consumer protection and encourage increased DER investment
2. Submetering Capacity: making available asset-level generation and consumption data to drive interoperability for diverse energy services, and
3. Flexibility Registry: providing DERs with identification and standardized interconnection functionality to ensure fair data access and interoperability of different services including grid integration, while maintaining privacy and security.

Additionally, this case study highlights community and peer-to-peer trading as a key shift towards a more effective energy market design, facilitating economic, environmental and social benefits for local community members, including DER optimization via higher local self-sufficiency, while providing flexibility for the grid to relieve congestion and strengthen system resilience.

[1] IEA. *Unlocking the Potential of Distributed Energy Resource*s; Power System Opportunities and Best Practices, Paris, 2022, https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c-ae78b645ce67/UnlockingthePotentialofDERs_Powersystemopportunitiesandbestpractices.pdf

[2] IEA (2022), Smart Grids, IEA, Paris https://www.iea.org/reports/smart-grids, License: CC BY 4.0

Ease of DER Installation

The main driver of exponential DER growth is the government, with policies backed by financial incentives, which have contributed to a significant reduction in DER cost, followed by corporate sustainability action, reinforced by the increased occurrence of extreme weather conditions and energy price volatility,[3] with the latter, combined with heightened environmental awareness, also encouraging greater individual action. However, there are also many obstacles to DER deployment, including administrative hurdles in the form of permitting regulation for large projects and grid connection as well as individual household use cases. These obstacles are compounded by limited workforce skills, supply chain limitations or disruptions, such as in the case of lithium, underdeveloped recycling and reuse of the raw materials used for DER production, and overall insufficient knowledge and ability to make DER investment decisions by both businesses and individuals. A specific policy challenge also relates to effective support of research and innovation and accelerating the implementation of emerging technologies.[4]

Submetering Capacity

As one of the most prominent energy Internet of Things (IoT) applications in the energy sector, AMI provides benefits to utilities and grid operators, while also serving as a conduit for emerging user-centric energy services. The number of installed metres is expected to exceed 227 million units in 2026 in the European Union (EU)-27+3 region (from 150 million units in 2020) and yearly shipments of smart electricity metres in North America will grow from 8.8 million units in 2019 to 19.9 million units in 2024.[5]

Connected technologies of synchro phasor measurement units (PMUs), supervisory control and data acquisition (SCADA) systems along with AMI are core enabling technologies for the smart grid. Deployment of these systems means that utilities can harness the power of remote metering for connection and disconnection services, and energy monitoring with a highly granular view of grid operations. Whilst installation of these systems can have relatively low initial costs, there are high maintenance costs, not the least of which are properly skilled and trained personnel.

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[3] Ben Hertz-Shargel, "Distributed energy is poised to take center stage in 2022, but policymakers and regulators must step up," *Utility Dive*, 4 February 2022, https://www.utilitydive.com/news/distributed-energy-is-poised-to-take-center-stage-in-2022-but-policymakers/618331/.

[4]NREL, Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035, 2022, https://www.nrel.gov/docs/fy22osti/81644.pdf https://www.energy.gov/eere/articles/nrel-study-identifies-opportunities-and-challenges-achieving-us-transformational-goal

[5] UNECE (2022). Policy discussion – Challenges of big data and analytics�driven demand-side management (GEEE-9.2022.INF.3). Available at: https://unece.org/sites/default/files/2022-08/GEEE-9.2022.INF_.3-DataAnalytics_rev.pdf, accessed 10 May 2023

Asset-level generation and consumption data is one of key preconditions for efficient DER management but there is scarce data on installed submetering[6] capacity. In terms of policy, in Europe, the Framework Guideline on Demand Response published by ACER in December 2022 provides the first legal guidelines on submetering in Europe, recognizing its importance for energy flexibility services, including data granularity and fair and secure data access:[7]

(para. 19) "It is important to note that this [Framework Guideline] considers the deployment of smart metres as a key for enabling the full potential of the participation of these resources in all electricity wholesale markets. At least where the deployment of the smart metres is delayed, the new rules shall specify the conditions for the usage of sub-meters, in order for the new rules to become effective. This does not mean that the use of sub-meters should only be restricted to the cases where smart metres have not been installed. Moreover, in order to ensure non-discriminatory access to the markets, the new rules shall specify the different models under which these resources may participate, and clarify the roles and responsibilities under each context. These general requirements, which are considered relevant for ensuring equal access of these resources to all electricity wholesale markets, are included in this Chapter."

(para. 33) "If the control of the provision of an [System Operator] service is based on measurement, the granularity of the metre needs to be at least equal to 15 min, which is the harmonised imbalance settlement period. The new rules shall describe the conditions for the use of sub-metering for the measurement of the provision of the service. The new rules shall define sub-meters, shall set up principles for the use of the data in order to avoid manipulation, shall include provisions i) for the respective roles, ii) for the collection of the data, iii) for the verification of the accuracy of the measurements, and iv) for the compliance with relevant standards, ensuring the coherence with the interoperability rules for access to data for demand response."

In Australia, data rights or contractual arrangements to allow grid operators and third-party service providers access to metre data are also being explored. Australia has also developed a

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[6] A utility submeter is a specialised type of electricity metre that measures the amount of electricity used by a specific appliance or group of appliances. Utility submeters are often used in commercial and industrial settings to measure the power usage of specific machines or groups of machines. They can also be used in residential settings to measure the power usage of specific appliances, such as air conditioners or water heaters.

[7] https://www.acer.europa.eu/news-and-events/news/acer-submitted-framework-guideline-demand-response-european-commission-first-step-towards-binding-eu-rules

DER Visibility and Monitoring Best Practice Guide[8] for manufacturers and service providers that offer consumers advanced monitoring of their household load and DER devices.[9]

Challenges for submetering include the lack of standardization and consistent regulation around submetering companies and the necessary retrofit measures required for effective installations. In the United States, twenty-two states, three counties and the capital of Washington D.C., have statutes, regulations and rulings on energy submetering.[10] Each state can establish their own procedures and regulations with regards to legality, installation, technology and billing.

Flexibility Registry

Smart grids integrate advanced digital technologies such as sensors, communication networks, and intelligent devices to improve the efficiency, reliability, and sustainability of energy generation, distribution, and consumption. However, the implementation of smart grids also raises significant privacy concerns, some of which include:

- Data privacy: Smart grids generate a vast amount of data, including energy consumption patterns, personal information, and other sensitive data. This data can be intercepted, tampered with, or stolen, compromising the privacy and security of the consumers.[11]
- Cybersecurity threats: Smart grids are vulnerable to cyber-attacks that can result in data breaches, power outages, and other damages. Attackers can exploit vulnerabilities in the communication networks, devices, and software used in smart grids to gain unauthorized access to the system and steal or manipulate data.[12]
- Surveillance: Smart grid technologies such as smart metres and sensors can collect granular information on the energy consumption habits of consumers, raising concerns about potential surveillance and profiling of individuals.

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[8] https://www.dermonitoring.guide/

[9] IEA. *Unlocking the Potential of Distributed Energy Resource*s; Power System Opportunities and Best Practices, Paris, 2022, https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c-ae78b645ce67/UnlockingthePotentialofDERs_Powersystemopportunitiesandbestpractices.pdf

[10] National Conference of State Legislatures, January 15, 2016, https://www.ncsl.org/energy/utility-submetering, accessed 15 May 2023

[11] Neeraj Kumar Singh, Vasundhara Mahajan, End-User Privacy Protection Scheme from cyber intrusion in smart grid advanced metering infrastructure, International Journal of Critical Infrastructure Protection,Volume 34,2021,100410,ISSN 1874-5482,https://doi.org/10.1016/j.ijcip.2021.100410.

[12] Kenneth Kimani, Vitalice Oduol, Kibet Langat, Cyber security challenges for IoT-based smart grid networks,International Journal of Critical Infrastructure Protection,Volume 25,2019,Pages 36-49,ISSN 1874-5482, https://doi.org/10.1016/j.ijcip.2019.01.001.

- Lack of transparency and control: Consumers may not have full visibility into how their data is collected, stored, and used by smart grid operators, limiting their ability to control the use of their data.[13]

Deploying Artificial Intelligence (AI) and machine learning (ML) models on smart grid infrastructure can also raise specific privacy concerns. Some of these concerns include:

- Profiling and discrimination: Smart grids can use AI and ML algorithms to analyse large amounts of data to predict energy consumption patterns, detect anomalies, and optimize the grid's performance. However, this can also lead to the profiling of individual consumers based on their energy consumption habits, which could potentially lead to discrimination. European Data Protection Supervisor (EDPS) highlighted the risk of profiling via smart metre data as part of rollout of smart metering systems in Europe [14]
- Lack of transparency and accountability: AI and ML algorithms can be opaque and difficult to interpret, which can make it challenging to identify when and how they are making decisions that affect privacy. This can limit transparency and accountability, making it difficult for consumers to challenge or contest decisions made by the algorithms[15].
- Biased algorithms: AI and ML algorithms can be trained on biased or incomplete data, which can lead to inaccurate or discriminatory outcomes. For example, if the data used to train an algorithm is biased towards certain demographics or seasonality, the algorithm may perpetuate or amplify these biases.
- Data breaches and misuse: The use of AI and ML on smart grids can generate large amounts of sensitive data, such as energy consumption patterns and personal information, which can be attractive targets for cybercriminals. Additionally, if this data falls into the wrong hands, it can be misused for nefarious purposes.

There are several ways to mitigate the privacy challenges associated with smart grids and the deployment of AI and ML algorithms. Some of the most effective measures include:

- Data anonymization and aggregation: Smart grid operators can anonymize and aggregate consumer data to protect individual privacy while still providing valuable insights for grid optimization. This can involve removing personally identifiable information (PII) from the

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[13] Cavoukian, A., Polonetsky, J. & Wolf, C. Smart Privacy for the Smart Grid: embedding privacy into the design of electricity conservation. IDIS 3, 275–294 (2010). https://doi.org/10.1007/s12394-010-0046-y

[14] https://edps.europa.eu/sites/default/files/publication/12-06-08_smart_metering_en.pdf

[15] Anna Volkova, Amit Dilip Patil, Seyyed Ahmad Javadi, and Hermann de Meer. 2022. Accountability challenges of AI in smart grid services. In Proceedings of the Thirteenth ACM International Conference on Future Energy Systems (e-Energy '22). Association for Computing Machinery, New York, NY, USA, 597–600. https://doi.org/10.1145/3538637.3539636

data, such as names and addresses, and aggregating the data at a larger geographic or demographic level.[16]

- Encryption and access controls: Smart grid operators can use encryption and access controls to protect consumer data from unauthorized access and theft. This involves encrypting data in transit and at rest, as well as implementing strong access controls to limit who has access to sensitive data.[17]
- Transparent and explainable algorithms: Smart grid operators should ensure that their AI and ML algorithms are transparent, explainable, and free from bias. This involves providing clear explanations of how the algorithms work, what data they use, and how they make decisions. It also involves testing the algorithms for bias and taking steps to eliminate any biases that are detected.[18]
- Consent and control mechanisms: Smart grid operators should provide consumers with clear consent and control mechanisms that enable them to decide how their data is used. This involves providing clear and easy-to-understand privacy notices, obtaining explicit consent for data collection and use, and providing opt-out mechanisms for consumers who wish to revoke their consent.[19]

To address privacy and security concerns and enable a higher level of grid visibility and system interoperability, the policy makers, as well as researchers and grid operators from Europe to Australia are considering energy asset identification tools and the development of flexibility registries.[20] This is also one of the critical policy recommendations by the International Energy Agency with the objective of unlocking the DER potential.[21]

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[16] C. Efthymiou and G. Kalogridis, "Smart Grid Privacy via Anonymization of Smart Metering Data," *2010 First IEEE International Conference on Smart Grid Communications*, Gaithersburg, MD, USA, 2010, pp. 238-243, doi: 10.1109/SMARTGRID.2010.5622050.

[17] Fursan Thabit, Ozgu Can, Asia Othman Aljahdali, Ghaleb H. Al-Gaphari, Hoda A. Alkhzaimi,Cryptography Algorithms for Enhancing IoT Security, Internet of Things, Volume 22, 2023, 100759, ISSN 2542-6605, https://doi.org/10.1016/j.iot.2023.100759.

[18] Williams, R., Cloete, R., Cobbe, J., Cottrill, C., Edwards, P., Markovic, M., . . . Pang, W. (2022). From transparency to accountability of intelligent systems: Moving beyond aspirations. Data & Policy, 4, E7. doi:10.1017/dap.2021.37

[19] https://energycentral.com/c/iu/how-does-gdpr-affect-smart-grids

[20] TSO-DSO Report, "An Integrated Approach to Active System Management", 2019, https://docstore.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/TSO-DSO_ASM_2019_190416.pdf. Florence School of Regulation, Roadmap on the Evolution of the Regulatory Framework for
Distributed Flexibility, https://fsr.eui.eu/distributed-resources-and-flexibility/; smartEn, A Network Code for Demand-Side Flexibility, 2021, https://smarten.eu/position-paper-a-network-code-for-demand-side-flexibility/.

[21] IEA. *Unlocking the Potential of Distributed Energy Resource*s; Power System Opportunities and Best Practices, Paris, 2022, https://iea.blob.core.windows.net/assets/3520710c-c828-4001-911c-ae78b645ce67/UnlockingthePotentialofDERs_Powersystemopportunitiesandbestpractices.pdf

According to a European business association smartEn, *"Flexibility registers should be bi-directional tools for service providers and system operators, with data access management rights. They should include not only information on the flexible assets but also data on flexibility needs by system operators and detailed information on congestion."*[22] One such implementation in Australia is presented below, followed by an overview of peer-to-peer trading regulatory developments and an analysis of its implementation in Ireland.

[22] smartEn, Spotlight Report on Data Sharing by System Operators, February 2023, https://smarten.eu/wp-content/uploads/2023/03/Spotlight-Data-sharing-from-system-operators_GA-approved.pdf

Rising Action I: Decentralized Data Exchange Platform for Energy Assets – Energy Demand and Generation Exchange Project (Australia)

By 2050, 40 per cent of the total installed energy system capacity in Australia will come from DERs.[23] The Australian Energy Market Operator (AEMO) engaged in project on Energy Demand and Generation Exchange (EDGE),[24] with the Energy Web Foundation,[25] aiming to showcase how a decentralized data exchange can contribute to maximising DER utilization and increasing grid resilience.[26]

This increasing deployment of DER, creates challenges for AEMO and distribution network operators in balancing and protecting the grid, but also creates new opportunities for consumers and other market participants to create value via supporting the energy transition with their DER. Enabling widespread and beneficial DER participation requires, among others, electricity network operators, market operators, flexibility service providers (FSPs), and consumers / prosumers to be able to exchange large volumes of data under common data models, commands, and communication protocols. Key challenges and innovations to enable DER integration and data exchange were identified across three core elements outlined in Table 1.

[23] DER Integration to provide flexibility services is remarked in Energy Security Board's Post-2025 reforms.

[24] The project partners included AEMO, AusNet Services, and Mondo, and the project is financially supported by the Australian Renewable Energy Agency (ARENA).

[25] https://www.energyweb.org/

[26] Policy shifts in many countries are being taken to enable access for DERs to wholesale and local markets, examples include FERC Order 2222 in the US, Ofgem's Call for Input on the Feature of Distributed Flexibility in the UK or CEER's Position Paper on the future of TSO and DSO Relationship in the EU.

Table 1: Key challenges and innovations to enable interoperable DER data exchange

	Key challenge	*Data exchange Innovations*
Identities and Permissions	DERs remain largely invisible and unidentifiable for Network Operators. Identifying and authenticating, is a precondition to exchanging data between parties. Only if an identity is asserted will parties communicate based on roles and responsibilities.	Self-Sovereign Identity technology Enabling participants to perform authentication and authorization processes for multiple markets and use cases with a single portable, self-sovereign digital identity.
Integration	DER data exchange requires integrating siloed legacy IT systems that support the current operations of network and market operators, retailers, FSPs, or DER owners.	Decentralized Data Hub A standardized integration mechanism allowing participants to exchange multiple data types and formats via a single integration.
Information Integrity	The increasingly large volume of DER data requires market participants to access and work with accurate and consistent data. DER data exchange needs validation processes to ensure data quality and integrity between systems are flawless.	Decentralized Logic Execution (DLE) By combining a shared messaging transport layer with identity-based message authentication, DLE’s novel distributed consensus technology ensures consistency and security in the exchange of information among stakeholders.

These core elements form the backbone of the digital infrastructure needed to enable DER coordination at a system-wide level. The innovations listed above seek to fill the gap precluding flexibility market integration and preventing DERs from delivering valuable grid services. Decentralized data exchange of EDGE delivers the following functionalities:

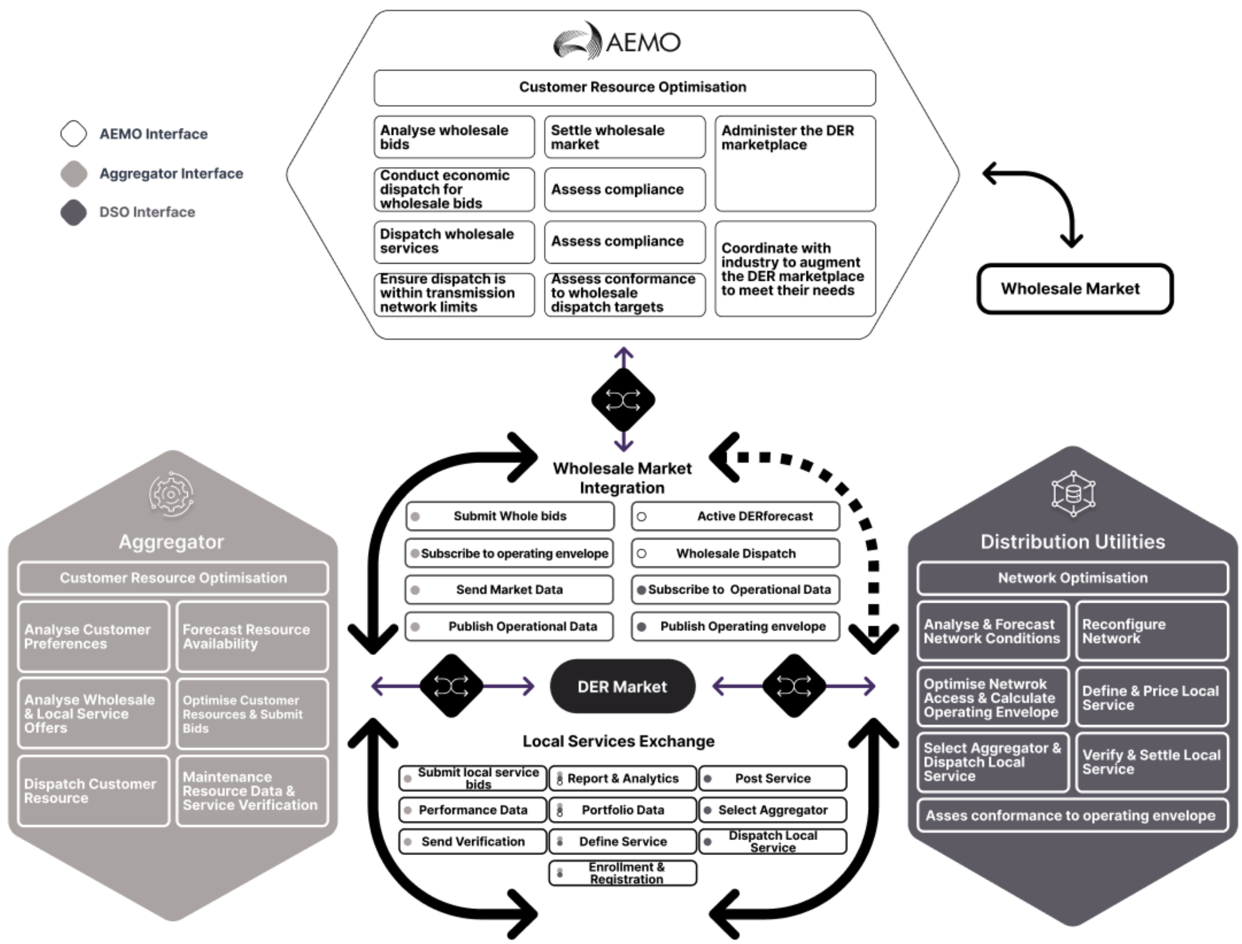
- Scalable Data Exchange: DER data comes in large volumes and in a variety of types and formats. A single integration Data Hub (as opposed to bespoke IT integrations) for market actors enables scalable multiparty data exchange.
- DER Registry: Authentication and authorization frameworks are needed to establish trusted relationships between systems, assets, and organizations. EDGE showcases a digital “passport” and “visa” solution for DER to be fully engaged in market transactions and services.
- Data Processing for Wholesale and Local services: Data from market actors (e.g., distribution utilities, FSPs, or market operators) is ingested and processed to deliver

several use cases at the wholesale level (e.g., dispatch DER fleets as a forecasted resource) and local level (e.g., enrol DER in demand and response schemes).[27]

- Governance and system integrity: Organizations can encode business logic and enforce rules based on requirements and responsibilities needed for specific use cases. By having a decentral logic execution predefined and embedded into the solution verifiability is ensured without relying on a single broker.

Having a DER data exchange built leveraging the functionalities listed above can host a diverse set of business functions and use cases with data flowing between market actors and devices (Figure).

Figure: Project EDGE Data Exchange Functions and Data Flows



[27] Tests under EDGE at the wholesale level included activating DER capacity aggregated by FSPs on a 5-minute periodicity following simplified dispatch rules (e.g., market signals, limits to DER imports and exports). While at the local network level, a Local Service Exchange was facilitated as a communication channel between the DSO and FSPs to procure local network flexibility services on a bilateral basis. See more in Project EDGE's _DER Data Hub Lessons Learnt Report_.

Project EDGE showcases that a decentralized data exchange, in comparison with point-to-point or centralized data exchange solutions, is the most suitable approach because:

a) it has no single point of failure by design,
b) the architecture is modular and highly interoperable providing greater flexibility,
c) there is no single entity under control but a shared governance, and can support any agreed upon data model and communication protocol.[28]

[28] *Ibid.*

Rising Action II: Peer-to-Peer Energy Marketplace Development – Cooperative Energy Trading System Project (Ireland)

Transactive Energy (TE) in the form of Peer-to-Peer (P2P) or Community Trading and Community Self-Consumption (CSC) are three emerging models in bottom-up energy market management that typically leverage distributed energy resources. These decentralized systems generate electricity close to where it is consumed, turning consumers into "prosumers" – a term for consumers who are also energy producers. While each approach has certain similarities, it also presents its own unique characteristics and challenges presented in the Table 2 below.

P2P method enables direct energy trading between consumers / prosumers, with any additional market needs supplied by other energy suppliers, namely utilities. P2P benefits can be significantly enhanced in terms of market access fairness and transparency, as well as automation of clearance and settlement by deploying emerging distributed ledger technology (DLT or blockchain). P2P systems can distribute energy more efficiently, promote energy savings, and reduce costs for consumers, while supporting grid resilience. The benefits can be further enhanced if a market-based pricing mechanism is enabled,[29] including dynamic grid tariff implementation by grid operators to source and manage system flexibility. The method requires a more advanced metering infrastructure with submetering capacity and investment in DER.

A more limited form of TE is Peer-to-Market (P2M) community trading whereby consumers / prosumers trade energy against a single community-level price that is usually established by a regulator and not based on market conditions in a certain timeslot. This also requires submetering capacity but can be managed with less sophisticated energy trading digital applications, although even in this case DLT would provide additional functionality. This more conservative approach is currently pursued by several EU member states, including a project in Ireland discussed below.

CSC, on the other hand, is a model in which groups, organized as energy communities, cooperatives and alike, within a specific geographical area produce and consume energy together, primarily from local renewable resources such as solar power and wind turbines, sometimes investing in shared storage (battery).

All the described local energy actions can facilitate community cooperation, encourage the use of local renewable energy, and reduce energy costs for participants. Initial costs can be high, both

[29] Exemplified by the technology approach by open-source developer Grid Singularity, https://gridsingularity.com/.

in terms of investment in DER and digital technology, and ongoing government support may be required, including in education and organizing a community (Table 2).

Table 2: Comparison of bottom-up energy market management models

	P2P / TE	*P2M / Community Trading / Limited TE*	*CSC*
Short Description	Decentralized or centralized exchange operating a marketplace where prosumers/producers/consumers trade energy directly	Decentralized or centralized exchange operating a marketplace where prosumers / producers / consumers trade energy with the community at a single community price (usually set by regulator)	Community generates and consumes energy together, typically from shared DER such as a community PV or battery but other than sharing common resources there is no trading
Ownership	Individual and possibly also community-owned DER; marketplace operated by software in line with local regulation and community usually registered as a legal entity	Individual and possibly also community-owned DER; marketplace operated by software in line with local regulation and community usually registered as a legal entity	Community-owned DER
Benefits	Most efficient energy distribution / DER use, cost reduction, especially if trading between communities is also enabled (bottom-up energy market design)	More efficient energy distribution / DER use, cost reduction, energy conservation incentives, such as demand response or other flexibility services	Use of renewable energy, cost reduction, community building
Challenges for Greater Adoption / Scale	Requires digital infrastructure (submetering) and sophisticated marketplace operation technology, investment in DER; limited user-friendly applications available	Requires digital infrastructure (submetering) and simple marketplace operation technology, investment in DER; limited user-friendly applications available	Investment in DER required; administrative hurdles for shared resources and governance of these resources

	P2P / TE	*P2M / Community Trading / Limited TE*	*CSC*
Policy and regulation considerations	Needs a regulatory framework that supports P2P trading based on market conditions, ideally using DLT for marketplace operation and support for community management and uptake of digital solutions with higher user interaction and more user choices	Needs a regulatory framework that supports P2M (community) trading, support to community registration and uptake of digital solutions	Policies that support renewable energy and community energy initiatives are beneficial. Regulatory barriers might include zoning restrictions and utility regulations. Other barriers include permitting related to DER acquisition and knowledge gap.
Environmental Impact	Positive impact as it encourages the use of renewable energy and conservation, while any carbon footprint of digital solutions should be mitigated by a choice of sustainable tools	Positive impact as it encourages the use of renewable energy and conservation, while any carbon footprint of digital solutions should be mitigated by a choice of sustainable tools	Positive impact as it encourages the use of renewable energy and conservation, while any carbon footprint of digital solutions should be mitigated by a choice of sustainable tools
Social impact	Prosumers/producers/consumers empowerment but may also increase the digital divide, although studies have shown that households with less resources also benefit from reduced prices	Prosumers/producers/consumers and community empowerment but may also increase the digital divide, although studies have shown that households with less resources also benefit from reduced prices	Community collaboration improves and potential reduction of costs for community members.
DLT integration benefits	Enables a range of new choices for the individual energy user, transparency of market operation (equitable market access), optimized clearance and settlement	Enables enhanced market transparency and optimized clearance and settlement albeit with a reduced impact due to limitation posed by single price	Not applicable

	P2P / TE	*P2M / Community Trading / Limited TE*	*CSC*
AI/ML Integration / Benefits	Enable dynamic pricing and smart trading strategies, provide intelligent condition monitoring and enhanced security for threat detection	Enable dynamic pricing, provide intelligent condition monitoring and enhanced security for threat detection	Enable improved asset management

EU has a range of directives and initiatives aimed at promoting renewable energy and making EU carbon-neutral by 2050, such as the European Green Deal introduced in 2019[30] and its Renewable Energy Directive (REDI)[31], fostering clean technologies and novel frameworks such as energy communities. As an EU member state, Ireland had set a target to produce 16 per cent of all its energy from renewable sources by 2020, revising it to 14 per cent by 2030[32] and launching several national strategies and programmes, including the microgeneration support scheme (MSS)[33]. MSS scheme is designed to provide a way for homeowners, farmers, businesses, and communities to generate their own renewable electricity, and to be paid for the excess power they export back to the grid. MSS operates on a self-consumption first principle, so producers, using micro-generation technologies such as solar PV panels, micro-wind turbines, micro-hydro generators, and micro-combined heat and power units, who export excess energy back into the grid are only paid for 30 per cent of the energy exported in an attempt to encourage micro-generators to use energy when its being generated to reduce demands on the grid at times of low or no renewable generation.

Cooperative Energy Trading System (CENTS), project funded by the Irish Government under its Disruptive Technology Innovation Fund (DTIF)[34], enables both individual consumers/producers and their broader communities generating their own electricity to use a blockchain-based platform to trade electricity based on a cooperative model. CENTS aims to co-exist with the current market by providing additional services to current consumers to generate income from exported excess energy and participation in other grid related services such as demand response and flexibility services. The project identified several challenges with the introduction of P2P energy trading, but were able to provide solutions (software and hardware) to help address these, as a result of these solutions it also opened up opportunities for other flexibility services and demand response by providing localised management of DER assets and real time data gathering and analysis. CENTS is now part of other projects, such as trading energy from battery storage, which further increases the maximising of renewable energy when it is being generated, if there is little demand then it can be stored until it is needed by using storage elsewhere on the grid. Other project findings and studies have also demonstrated benefits in terms of reduced cost (and increased revenue for prosumers) and increased self-sufficiency, importantly not only for

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[30] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[31] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

[32] https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/renewables/

[33] https://www.gov.ie/en/publication/b1fbe-micro-generation/

[34] https://enterprise.gov.ie/en/news-and-events/department-news/2018/december/10122018a.html

resource-rich communities but also for communities with no DER investment who engage in local trading with neighbouring DER-intensive communities.[35]

[35] See for instance, studies of P2P trading in Germany and in Columbia: https://gridsingularity.medium.com/modelling-study-to-assess-the-potential-benefits-of-trading-in-and-between-local-energy-d721395ddd4b;https://smartcities.ieee.org/newsletter/january-2022/advancing-from-community-to-peer-to-peer-energy-trading-in-the-medellin-colombia-local-energy-market-trial

Conclusion: global policy recommendations

The conducted analysis and review of the case studies allows making the following recommendations, which are aligned with UNECE policy discussions on accelerating the electricity system transformation through digitalization:[36]

1. To further ease DER installation and enhance submetering capacity:
   (a) DER acquisition and installation, including submetering, and necessary retrofit installations to be provided as turnkey or packages, with permitting simplified.
   (b) Legal and standardization frameworks are needed to ensure clear discernment among different submetering options for end customers and options to apply different forms of submetering, be they actual smart metres or home management system with the relevant functionality (one such example is the Australian DER monitoring guide).[37]
   (c) Standards for submetering systems should be consistent in their requirements for areas such as location of commodity (i.e., electricity, water and gas) entry into the building (or unit - be it interior or exterior), property size, building structure, system lifespan, ease of maintenance, and how the sub-meter will be read. Billing systems are an understandably bespoke setup based on the needs of the premise owner and yet consumer help and call centres need to ensure that homeowner questions or complaints can be addressed in a timely and consistent manner. Allowing customers self-help options should be part of the standard offering.
2. To advance DER flexibility management with increased interoperability, privacy and security:
   (a) Smart grid operators and service providers should ensure that they are compliant with relevant privacy and data protection regulations, such as the General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA). This involves conducting regular privacy impact assessments, maintaining records of data processing activities, and appointing a data protection officer (DPO) to oversee privacy compliance and ensure that consumer privacy rights are respected and protected. Anonymising data and using decentralized databases additionally improve

[36] UNECE (2022). Digitalization: Accelerating the Electricity System Transformation. Joint Paper by the Task Force on Digitalization in Energy of the Group of Experts on Energy Efficiency and the Group of Experts on Cleaner Electricity Systems. Available at: https://unece.org/sites/default/files/2022-07/ECE_ENERGY_GE.6_2022_4_ECE_ENERGY_GE.5_2022_4_Final.pdf
[37] https://www.dermonitoring.guide/

data security. Techniques like differential privacy and federated learning can also be applied to ensure secure and private analytics.

(b) Implementing a data exchange hub/flexibility registry, should be a priority across jurisdictions. Such action can simplify, reduce cost and increase the security of data exchange between industry participants.[38]

(c) A data exchange hub should be based upon well-designed interconnection standards, rules and regulations[39], outlining procedural and technical requirements for connecting DERs to the grid or otherwise accessing DER data to provide a range of energy services.

(d) A decentralized data exchange can potentially offer greater scalability, resilience, and security benefits than centralized systems.[40]

3. To enable peer-to-peer energy trading for a more optimal DER use and grid resilience:

(a) Findings from regulatory testbeds and pilot projects[41] should be reviewed and objectives set for any further testing, supporting development and accelerating application of emerging technology to enable local energy trading methods that bring most benefits to individuals while supporting grid resilience, especially based on peer-to-peer trading, and encompassing not just intra but also inter-community trading.

(b) Review for applicability national policy from other countries that are specifically made to remove barriers for DERs to compete fairly in the regional organized capacity, energy and ancillary services markets.[42]

(c) Explore dynamic tariff model research and implementation to benefit from local flexibility.

For successful implementation of improved and new grid edge business models, diverse stakeholders should be engaged and educated, particularly empowering communities and

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[38] For more details see Project EDGE's *DER Data Hub Lessons Learnt Report* produced by the Energy Web foundation and published by AEMO..

[39] Radina Valova and Gwen Brown, Distributed energy resource interconnection: An overview of challenges and opportunities in the United States, Solar Compass, Volume 2, 2022, 100021, ISSN 2772-9400, https://www.sciencedirect.com/science/article/pii/S2772940022000157

[40] Phase examples include deploying under a controlled environment, testing with a limited number of use cases and/or assets, and operating in parallel or separately from existing systems.

[41] Europe has called for further support for energy sector regulatory testbeds in the *EU action plan on digitalising the energy system*, adopted in October 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6228.

[42] FERC Order No. 2222: A New Day for Distributed Energy Resources, FERC Order No. 2222: Fact Sheet, https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet, September 17, 2020.

community members to take on a more active role in the energy market and use the emerging technology to enjoy a wider set of choices. This effort should be complemented with workforce education and upskilling to bridge the identified skills gap in production and installation of DERs, as well as in development and accelerated uptake of advanced AI/ML and DLT/blockchain technologies.