D2.6: Framework for Community Grid Implementation

+CityxChange | Work Package 2, Task 2.3

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Authors	Mladen Antolić (MPOWER), Stephen Wright (MPOWER), Danijel Mulugeta (MPOWER), John Fullam (MPOWER), Dudley Stewart (MPOWER)
Contributors	Klaus Livik (POWEL), Padraig Lyons (ESB Networks), Michele Nati (IOTA), Duncan Main (IOTA) Lukas van Vuuren (MPOWER), Kenneth Mallabo (MPOWER), Anthony Junior Bokolo (NTNU)

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15-01-2021	v.05	M.A. S.W.	Conclusion and Introduction expanded with Task description and differences

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List of Acronyms And Definitions

BRP	Balancing Responsible Party
SUP	Supplier
CEC	Citizen Energy Community
CEM	Common Energy Market
CEFM	Common Energy Flexibility Market
CG	Community Grid
CGS	Community Grid System
CRU	Commission for Regulator of Utilities
CSO	Community System Operator
DN	Disturbance Neutrality
EV	Electric Vehicle
DNO	Distribution Network Operator
DER	Distributed Energy Resources
DLT	Distributed Ledger Technology
DPEB	Distributed Positive Energy Block
DPED	Distributed Positive Energy District
DSO	Distribution System Operator
DST	Decision Support Tool
eMaaS	E-mobility as a Service
EV	Electric Vehicle
FA	Flexible Asset
FC	Flexibility Contract
FFR	Fractional Frequency Reuse
ISR	Imbalance Settlement Responsible
LEM	Local Energy Market
LFM	Local Flexibility Market
LFFM	Local Energy & Flexibility Market combined

LMO	Local Market Operator
MRSO	Meter Registration System Operator
MIC	Maximum Import Capacity
MEC	Maximum Export Capacity
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
PMU	Power Monitoring Unit
P2P	Peer-to-peer
PLC	Programmable Logic Controller
PEB	Positive Energy Block
PEN	Positive Energy Neighborhood
PED	Positive Energy District
UoS	Use of System
RES	Renewable Energy Systems
REC	Renewable Energy Community
RMDS	Retail Market Design Service
TSO	Transmission System Operator
V2G	Vehicle-to-grid

Executive Summary

This report presents deliverable D2.6 of the +CityxChange project Task 2.3 and describes a framework for Community Grid System implementation. Community Grid is a local energy community network of consumers, producers, and *prosumers* connected in a way that they can trade energy and flexibility inside the network without disturbing the power balance outside such a created local network. The Community Grid follows a *demand response* approach, sets up the infrastructure, and empowers end-users with necessary ICT infrastructure so that they can monitor and manage usage of their *flexibility assets* in real time with the opportunity to realise certain benefits from the active participation. The report describes an innovative approach to the creation of a disturbance neutral local energy community that will be implemented in +CityxChange lighthouse city of Limerick (Ireland) and Trondheim (Norway). It is based on experience from Tallaght Community Energy Living Lab[1] enriched with new insights that came from further research and inputs from other project partners involved in this task (POWEL, TrønderEnergi, ESB Networks, and IOTA). The report is formed in a way that can be used for application in any other city, covering all parts that are necessary for the implementation of the Community Grid.

Community Grid concept is an essential part of the +CityxChange initiative for the establishment of Positive Energy Blocks/Districts. Elaboration of the Community Grid concept has led to the establishment of a Community Grid System (CGS). CGS aims to be the solution that will enable citizens to effectively manage energy consumption in their buildings and communities. The Community Grid framework consists of four main segments or pillars: Energy Community Establishment; Community Legal, Grid & Financial Governance Body; Community Grid Smart System Design, and Community Market Places. Each segment deals with different Energy Community aspects that should be taken into consideration for the successful implementation of the Community Grid System. These are technical, regulatory, legal, social, spatial and economic aspects.

A key component in the Community Grid framework is the creation of a new governing support body, a Community System Operator (CSO). It is envisaged that the CSO will be a legal entity that oversees, by franchise, the management and safe operation of a Community Grid System. A CGS comprises participants that operate under specific rules, set by, and agreed with a CSO i.e. Regulation by Contract implemented by way of a system distributed by Franchise Agreement to exacting Community Grid Standards.

[1] Tallaght Community Energy Living Lab also known as Tallaght Smart Grid Test Bed project was first supported by the SEAI Research, Development & Demonstration (RD&D) Funding Programme in 2013 which led to the development and demonstration of a trial of the first community energy grid in Tallaght.

1 Introduction

Demonstration of the Community Grid concept is an essential part of the +CityxChange initiative for establishment of Positive Energy Blocks/Districts. By definition, Positive Energy Blocks/Districts actively manage their energy consumption and the energy flow between the buildings inside the Energy Block and the wider energy system. By doing this, Positive Energy Blocks/Districts achieve annual positive energy balance. They make optimal use of elements such as advanced materials, local RES, local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating, and cooling), user interaction/involvement and ICT.

One of the prerequisites of Positive Energy Blocks/Districts is that they should be designed to be an integral part of the district/city energy system so that they can have a positive impact on it. Community Grid concept comprises all this together and makes the +CityxChange vision achievable (Figure 1.1).

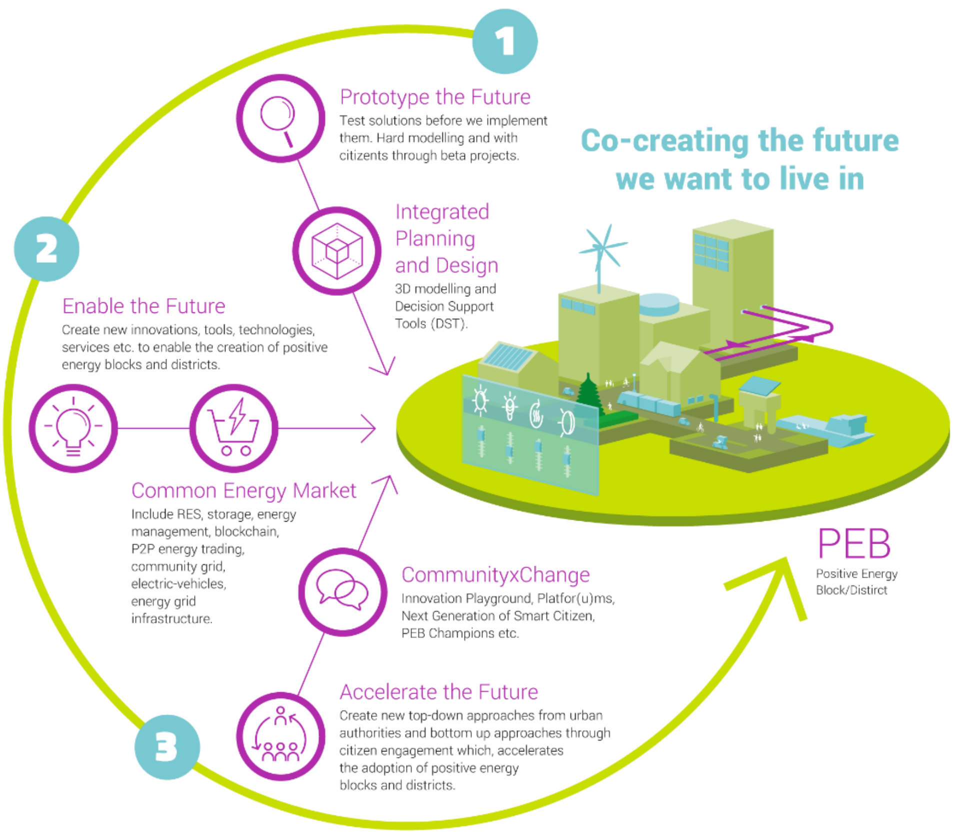

Figure 1.1. +CityxChange Vision.

The report describes the concept and all elements needed to form and operate a Community Grid System. The concept is applicable to any urban area in which buildings are connected to one electric power substation and together can generate enough electrical energy (cumulatively) either by themself, from individual renewable energy sources attached to the building, or/and from separate renewable energy sources attached to the same substation. The Community Grid system supports the PEB requirement to export excess energy by dispatch to the grid, this is discussed further in section 5.3.

The key elements that form the framework of the Community Grid System are outlined in Section 2 of this report. Section 3 describes Community Grid definitions of the Energy Community. The Community System Operator (CSO) and its role in the Community Grid concept is explained in Section 4. The Community Grid Smart System design is presented in Section 5. Section 6 explains Community Market Places and describes the local trading principles.

1.1 Shared Understanding of the Task

This task will establish the protocols for operating community grids in EU cities. This includes the creation of the Community System Operator (CSO) and the associated licence and regulatory parameters that would be required to set this up. It is envisaged that the +CityxChange CSO will be a franchise and each Community Grid will be a franchisee, typically 100% owned by consumers within the community, possibly in partnership with local authorities and energy agencies. The most likely legal form of a community grid is a co-operative, but various legal forms will be investigated in this task. The available choices will be implemented in the DST developed in WP1, so that communities can make an informed decision of the form most suitable for them.

Disturbance-neutrality will be implemented by 'smart' contracts, established in local Energy and Flexibility Market Places, and transacted as asset-backed tokens (assets for producing electricity and/or for FaaS) in the IOTA platform. As such, this task will create the automated trading strategies for the market places to be used by prosumers, and automated controls for the asset delivery on the contracts. These will be implemented in the MPOWER enerXchange™ client server. Each client communicates with the cloud-based enerXchange™ server, which implements the market places, supervises delivery and distributed controls, and settles the contacts (using enerXchange™'s proprietary metering solution). The enerXchange™ client can be cloud-based, but any real-time controls must run close to the asset, on a suitable smart home (HMS -Home Management System) or smart building (BMS – Building Management System) device within the building.
This task will also develop the market places required for +CityxChange, including the smart contracts and transactions based on IOTA asset-backed tokens, using the IOTA ecosystem

developed in task 2.5. The trading strategies will be developed in this task, based on open APIs to support an open market for trading strategies on different platforms. The controls for assets will be developed in Task 2.2, again based on open APIs since it envisioned that controls will ultimately be implemented by the manufacturers of the asset. The supervision of delivery on those contracts, and the ex-post settlement, will be implemented in this task, based on interfaces implemented in Task 2.2.
Finally, this task will also investigate how the DSO could implement the oversight role, and how a mutual beneficial relationship between the DSO and one or more local CSOs could be developed, both technically and commercially.
Participants Roles: MPOWER will develop the market places and trading strategies. IOTA together with MPOWER will develop state of the art distributed ledger technology for sharing data between different entities, via which intelligent market decisions can be made. IOTA will supply and provide this base layer for data exchange, to assure the security and integrity of the data and the system. ESBN and TE will develop the tools and procedures necessary to validate the performance of the CityxChange CSO, and provide knowledge about the transmission grid, both general knowledge about operating the transmission grid, and specific knowledge about the demonstration sites. This includes sharing planned and real-time data (metered or measured) with the +CityxChange CSO through the ICT framework developed in WP1, such as for points at which power flow reversals must be avoided. Together with MPOWER they will also develop the mutual beneficial relationship between CSO and DSO. POW will follow to understand how this could be applied to their own business in Trondheim.

During the preparation of the report the concept was updated in respect to the actual situation and possibilities of the implementation of Community Grid in Ireland and Norway. The major change is regarding the acquiring of Disturbance Neutrality. Disturbance Neutrality, which is discussed in detail in section 5.2, is defined in this work as a condition where the net electrical power, that is the power generated minus the power consumed, of all customers within the community grid is zero or less. It will be acquired through energy and flexibility trading but not by the IOTA Smart Contracts.

Smart Contract functionality of IOTA is useful when there is a possible P2P financial transaction. This happens in cases such as cryptocurrency wallets. There the two entities can exchange money without any intermediary agent. In case of energy transfer between two prosumers, it is not possible to avoid intermediary agent. None of the micropayments involved in an energy trade is a direct debit, meaning payment is not done with IOTA. IOTA will be used as the transaction ledger.

Exact data structure for transfer depends on the exact equipment and the interrupt protocol that will be used. The interface between SLUs and collection points is in the design phase. This is due to the fact that the exact nature of the communication network is not yet defined. The message types that will be exchanged, such as reading, bid, transfer result info, flexibility inquiry, timer synchronization, are well defined . So is the logical flow of exchange. The data fields that compose the messages such as quantity, phase, power factor, price are also well defined. However, the formatting of messages depends heavily on chosen communication infrastructure. In the case of LoRa the formatting must make the message payload as low as possible due to the considerations of strict duty cycle limits. For standard IP networks there is no big concern with payload size so REST API with JSON payload will be used. Problem is with devices that may not even be able to do full-duplex communication, which will affect the physical flow of exchange. The level of security required for a particular network may vary and thus the additional issues, such as cryptographic hash or client certificates would still affect the formatting of messages.

Direct real P2P energy trading between prosumers will be kept as an option to be implemented in the future once there is:

- Legal basis to execute and settle direct P2P payments
- Clear responsibility for collection of debt and enforcement of digital contracts
- Clarity on who bears responsibility for processing costs.

2 Community Grid Framework

To create a Distributed Positive Energy Block and District (DPEB) several aspects should be taken into consideration, from environmental, spatial, social, and technical to economic, regulatory, and legal aspects. Successful implementation of the Community Grid System depends on all these aspects. Community Grid System aims to be the solution that will enable citizens to take ownership of their buildings and communities.

The Community Grid framework supports +CityxChange framework for a smart flexible energy system and establishment of a Positive Energy Districts (Figure 2.1).

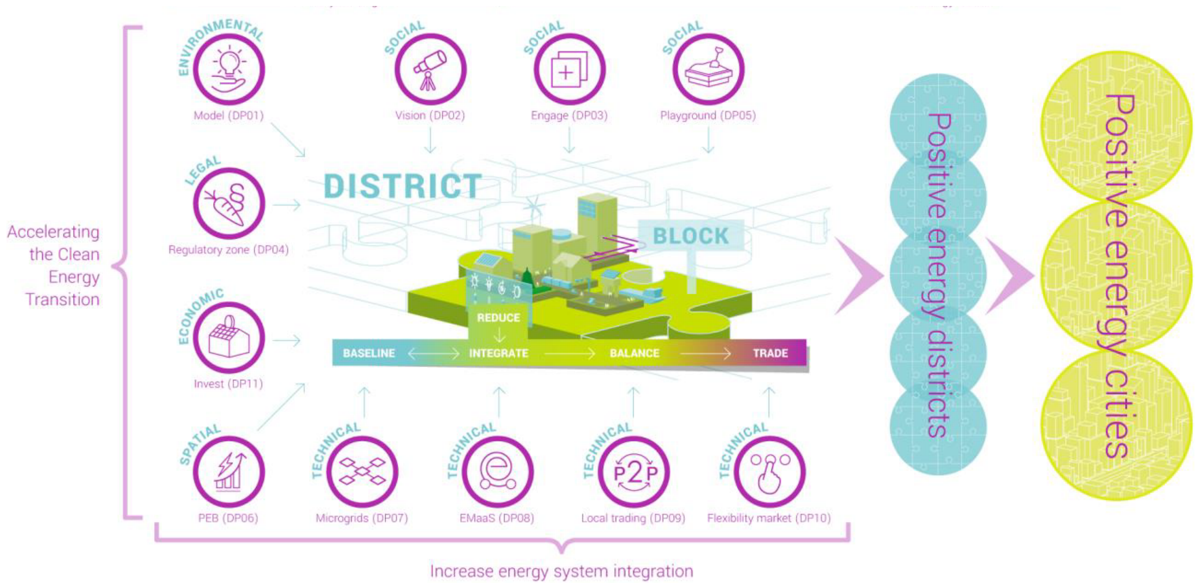

Figure 2.1. The +CityxChange framework for realisation of the Positive Energy Districts.

The following diagram below breaks down the Community Grid framework into its four main segments (Figure 2.2). The following sections of the report describe these Community grid framework segments in further detail.

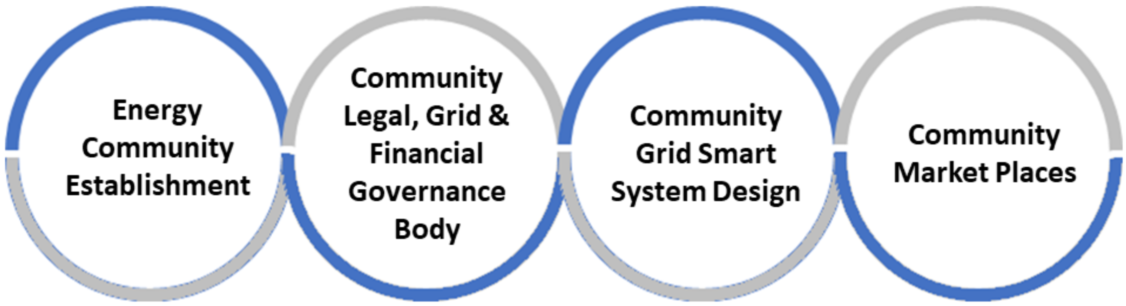

Fig 2.2. Main segments of the Community Grid Framework.

2.1 Background and Motivation

In our globalized world, cities are centers of communication, trade, and culture. They consume more than two-thirds of the world's energy and produce more than 70% of global CO2 emissions. Urban areas are among the main drivers of climate change, as urban activities are one the main sources of greenhouse gas emissions. Therefore, these are the areas where formation and development must be carefully planned, taking into account a wide range of activities that affect life and energy sustainability. Emphasis is placed on reducing the use of fossil energy sources and increasing the use of energy from renewable sources, which may become the major challenge to the existing power system. Centralised systems must be changed making place for the local distributed systems. Existing power system must be improved in a way to allow two-way communication of energy and data which is the main characteristic of the Smart Grid.

With the promotion of renewable energy sources and distributed energy systems, the question of stability and reliability of the power system arises where additional sources of flexibility on *demand side* are required which can be found inside district buildings. Consumption and loads that exist inside the buildings represent a valuable source of flexibility, individually or as a group (energy blocks). Along with the local production based on renewable energy they are able to source a community-owned energy.

To develop a PEB/D, new technologies, processes, frameworks, and business models need to be created and integrated. Regulatory barriers need to be challenged so that new standards and regulations can evolve to enable innovative solutions, which lead to the adoption of PEB/Ds.

In 2019, the EU completed the final step of the Clean Energy Package (CEP) where the emphasis was put on improvement of sustainability efforts. The energy policy framework was updated to facilitate the transition away from fossil fuels towards cleaner energy. The agreement on this new energy rulebook presents an important step to the implementation of the Energy Union Strategy, which was published in 2015[2]. Within the EU, the Clean Energy Package is the main driver for the development of Community Energy. It provides a framework for member states to integrate Community Energy into their electricity systems. The new rules should bring considerable benefits from a consumer perspective, from an environmental perspective, and from an economic perspective.[3]

The key takeaway for the final customer is that the Member States shall ensure that they can become active customers (or prosumers):

> "without being subject to disproportionate or discriminatory technical requirements, administrative requirements, procedures and charges, and to network charges that are not cost-reflective."[4]

The major change is that an active consumer can store, use and sell self-generated electricity. This opens the door to the implementation of new innovative concepts such as Peer-to-Peer energy trading, and local flexibility markets. Opening "the door" in this way enables people, and organisations, to take action to secure a better energy future and ever decreasing levels of greenhouse gas emissions. The Electricity system, in this way, is being opened up to vast new numbers of energy producers which could have significant unintended negative consequences to the Electricity System, in the absence of auto disturbance risk mitigation systems, and mechanisms, such are purpose of Community Grid Systems regulated, by contract, by a Community System Operator (CSO).

One of the consequences of the developments in the Clean Energy Package is that Energy Community Groups can now become recognised stakeholders in the electricity system, specifically around not-for-profit group ownership of renewable technologies and the sharing of profits amongst its members.

The Clean Energy Package presents new definitions for Energy Communities. These are *Citizens Energy Community* and *Renewable Energy Community,* where the *Local Energy Community* is abandoned and thus no longer in use in the regulatory sense. The *Local Energy Community* is connected to a technical concept used to describe specific activities, like a collective renewables self-consumption or micro-grids/local energy systems. The Community Grid System (CGS) brings together energy system integration and community engagement; thus, the new definitions of Energy Communities are important for the Community Grid establishment. In Section 3, it is explained how.

[2] https://ec.europa.eu/energy/topics/energy-strategy/energy-union_en?redir=1
[3] https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en
[4] Directive (EU) 2019/944 (2019)

The key role in the Community Grid concept is on the managing entity that controls the local smart electricity network. The name of this entity is the Community System Operator (CSO), which is a Community legal, grid, and financial body that operates the Community Grid System. It is envisaged that the CSO will be a legal entity that oversees, by franchise, the management and safe operation of a Community Grid System (CGS). The purpose and function of the CSO is described in Section 4.

CSO also brings in the concept of maintaining grid neutrality, whereby the members of the REC or CEC act together to minimise the impact on the local distribution system. Consumers or generators, or a combination of the two, including stand-alone devices, can be implemented to support Grid Neutrality for a CSO. Figure 2.3 shows the relationship between the concepts and position of the CSO. The CSO concept is developed further in section 4.1.

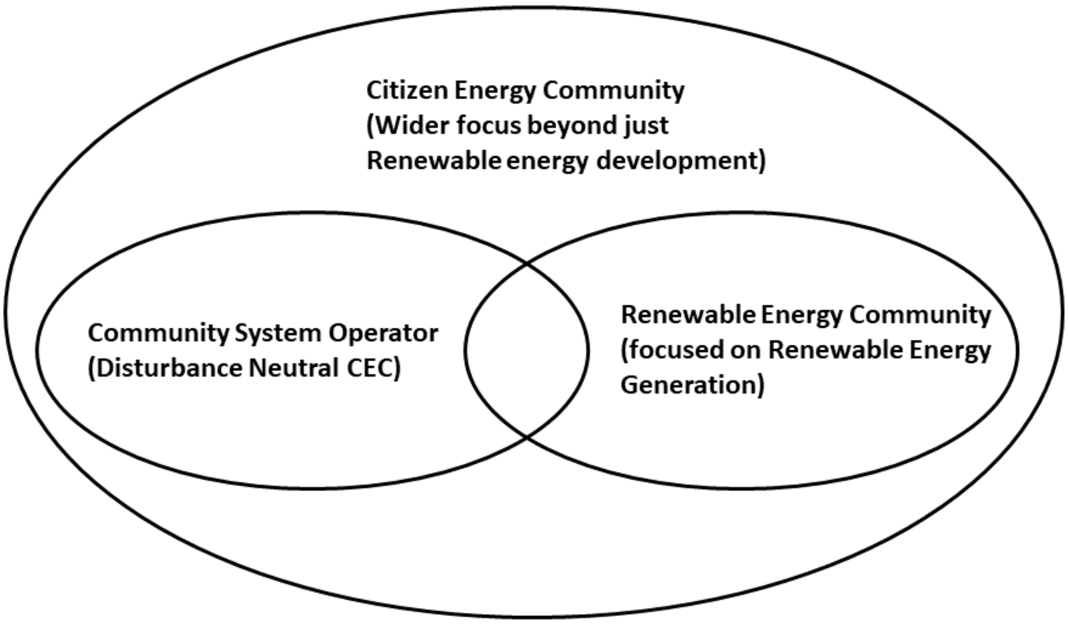

Figure 2.3. Energy Communities concepts relationship and CSO.

A smart Community Grid System uses intelligent transmission and distribution networks to deliver electricity while at the same time allowing energy customers and energy providers to manage and generate electricity more efficiently. The Community Grid concept is based on advanced ICT infrastructure and smart grid automation. Its design is critical in designing an electricity network which aims to be carbon free. In Section 5, various factors influencing Community Grid System design are presented, as well as the advantages and benefits that a Community Grid System would offer.

A Community Grid System involves the distribution grid and increased use of renewable energy coming from distributed resources along with the prosumers engagement in energy trading mechanism. Section 6 focuses on the framework for transactions between prosumers in an Energy Community. The energy trading mechanism, the settlement process, and the security of the local trading system is also described in Section 6.

2.2 PED Framework

The Strategic Energy Technology (SET) Plan[5], adopted by the European Union in 2008 and revised in 2015, is a first step to establish an energy technology policy for Europe, with a goal of accelerating knowledge development, technology transfer, and up-take in order to achieve Energy and Climate Change goals. Since Cities and the building sector play an important role in the energy transition process towards a considerable reduction of the carbon footprint, special interest was put on buildings inside the block and district. The SET Plan focuses on ten key action fields, with a key aim to support the planning, deployment, and replication of 100 Positive Energy Districts by 2025 for sustainable urbanisation.

The Positive Energy District (PED) is an urban neighborhood that is integrated into the urban and regional energy system, which aims to achieve zero energy imports on an annual basis by working on surplus renewable energy production. This would require an integration of diverse systems, infrastructure, and communication between the buildings, the users, the energy system and ICT systems. The integration should also take into account the social, economic and environmental sustainability. This system can be implemented on recently built districts as well as energy efficient retrofitted districts or even a mixture of both. The PED must find the right balance from the different functions, which may be unique from other PED as they need to utilise the available resources for their climate zone. The three main functions are;

- **Energy efficiency:** The PED must try to use the most efficient renewable energies available to avoid or reduce electricity wastes. The local energy consumption must be lower than the locally produced renewable energy. This would need to be done by taking into account the energy needs in the system, building the infrastructure to support energy needs, giving incentives for the prosumer to change behaviour to carefully manage energy consumption, using smart energy grids, having a solid ICT and data management and taking into account of EVs by minimising its impact on the grid.
- **Energy production:** The PED should only produce renewable energy in order to achieve climate neutrality, i.e., not creating or optimally reducing greenhouse gas emissions. This should also be economically viable.

[5] https://ec.europa.eu/energy/topics/technology-and-innovation/strategic-energy-technology-plan_en

- **Energy flexibility:** The PED needs to be able to optimise the energy system to reach disturbance neutrality. It needs to offer flexibility, consumption management, and energy capacity to handle grid stability due to the unpredictable nature of renewable resources. Management techniques such as peak shaving, load shifting, and demand response may be implemented to support this.

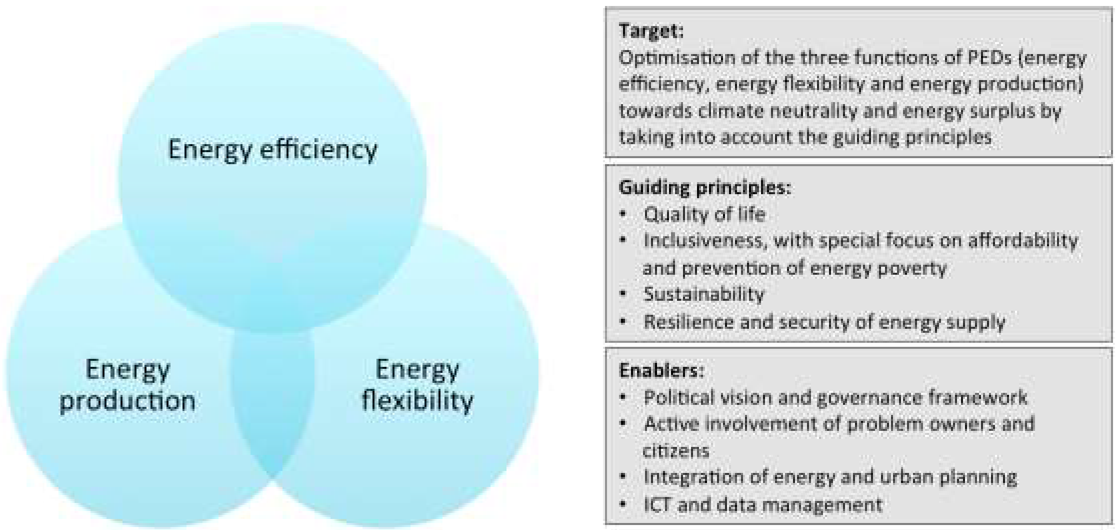

Figure 1.2. Functions of PEBs/PEDs in the regional energy system (White paper on Reference Framework for Positive Energy Districts and Neighbourhoods, Urban Europe, 23 March 2020).

The Community Grid concept follows the PED/PEN framework with the addition of disturbance neutrality as a necessary requirement for the successful integration. The ambition of the Community Grid framework is to act as a vehicle for the implementation and maintenance of PEB/Ds.

3 Energy Community Establishment

3.1 Energy Community groups

In the introduction section of this report, the importance of the Clean Energy Package (CEP) for Community Energy is introduced. The directives and articles within the CEP package are the key drivers for the development of the framework of the Community System Operator solution. In Ireland, the CRU (Commission for the Regulation of Utilities) is responsible for the regulation of legal entities and licence holders, which interact with the regulated aspects of the electricity system. The CRU is guided in these objectives through a combination of national legislation and EU Regulation and its own consultations and decisions in relation to relevant detailed matters. Other EU member states have similar regulating authorities.

The Clean Energy Package introduces two new Energy Community groups (Local Prosumer Community Enterprise), CEC (Citizen Energy Communities), and REC (Renewable Energy Communities), where the term Local Energy Community is abandoned.

Citizen Energy Communities (CECs) as envisaged under the new European Internal Market Directive (EU/2019/944), focussing on the non-for-profit cooperation of energy prosumers. Activities of a CEC are presented in Figure 3.1.

Renewable Energy Communities (RECs) as envisaged under the new European Renewables Directive (EU/2018/2001), specifically around not-for-profit group ownership of renewable technologies and the sharing of profits amongst its members. Activities of a REC are presented in Figure 3.2. RECs are seen as a subset of CECs.

Activities that fall under CECs organization, governance, and purpose fit into what is intended to do in the Community Grid. Ìt would not be viable for a CEC as a non profit organisation to incur excessive costs (overheads) in achieving Grid level governance systems. Community System Operator (CSO), commercial body, which takes the key role in the Community Grid concept, provides a framework for CEC's that functions to provide participants local trading leeway, good safety, and Disturbance Neutral Grid Connections. The role of the CSO is to operate the Community Grid System with the prosumers who are the primary source of the *flexibility*.

Figure 3.1 Activities of a Citizens Energy Community (CEC) (Adopted from Compile - Energy Community Definitions, Explanatory Note, May 2019).

Figure 3.2 Activities of a Renewable Energy Community (REC) (Adopted from Compile - Energy Community Definitions, Explanatory Note, May 2019).

For the +CityxChange objective to create local flexibility markets for PEBs, in LImerick a form of CEC will be established. The project will demonstrate electricity trading within the block and the exchange of flexibility locally and externally to other PEBs. The Electricity Directive, which is part of the Clean Energy Package, guarantees that such a form of Energy Community[6] can participate across the electricity market without discrimination and on a level playing field with other market operators.

3.2 Prosumer Engagement Process

The Community Grid System (CGS) brings together energy system integration and community participation (Fig. 3.4). In this way, CGSs are in a position to embrace technical and social innovations, creating sustainable and affordable local energy systems.

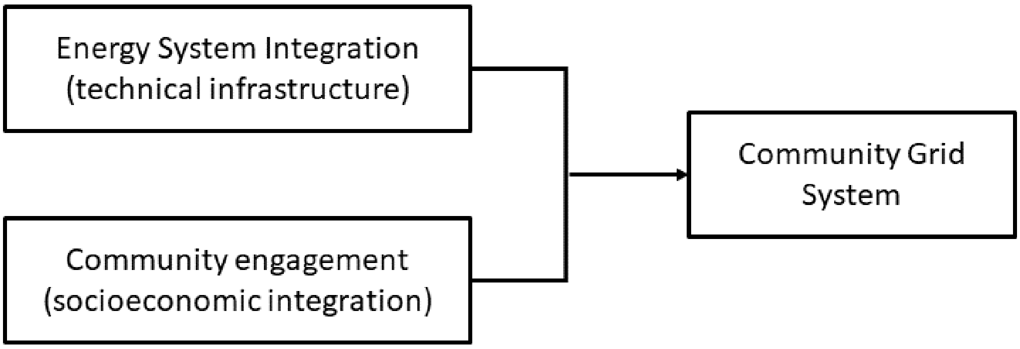

Figure 3.4. Technical and socioeconomic integration in the Community Grid System.

The process of engaging electricity consumers is closely linked to the development of electricity networks. Empowering consumers to manage their electricity consumption, while enabling them to actively contribute to the operation of the distribution network, requires exploiting the advanced capabilities of smart grid technologies. Figure 3.5 shows the level of consumer engagement in relation to the development of Smart Grid potential.

The initial level of consumer engagement starts by providing accurate data about electricity consumption in the form of electricity bills. This indirect feedback does not necessarily motivate the consumer to reduce energy consumption or consider implementing energy efficiency measures.

The next level of consumer involvement includes aggregated feedback at the level of household and appliance or end-use disaggregated feedback on the appliance specific

[6] Community energy refers to collective energy actions that foster citizens' participation across the energy system (Energy communities: an overview of energy and social innovation, JRC Science for Policy Report, EU 2020.)

level. These types of feedback come from different data sources including electric utility data, home energy audits, and other existing types of data. They are usually presented in web-based form. To provide the feedback to the consumer, the supplier or third-party service provider can empower the consumer with the information about basic energy consumption and cost information, and use existing data to provide personal and contextual feedback. Comparisons with neighbours and communities provide social context and information about actions others are taking. Nearly real-time, direct feedback provides a lot of contextual knowledge and enables consumers to learn by doing.

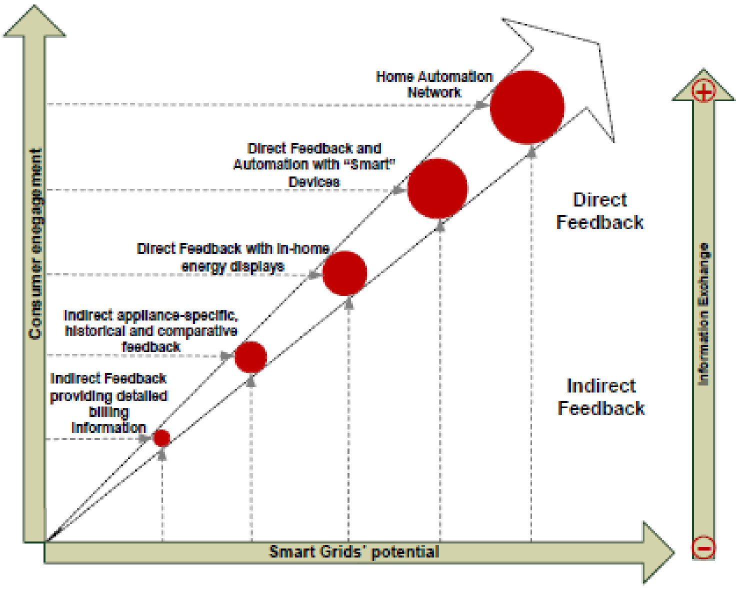

Figure 3.5. Consumer engagement vs. Smart Grid potential (The social dimension of Smart Grids - Consumer, Community, Society, Anna Mengolini, Julija Vasiljevska, JRC Scientific and policy reports, EU 2013).

The next level of end user empowerment consists of energy efficient and smart (automated) appliances that can provide direct, real-time feedback and include appliance-specific information and automation. Another important feature of these smart devices is their capacity to receive pricing signals and utility load control in some cases, which leads to potential alleviation of distribution network capacity or distribution infrastructure upgrade.

Finally, in order to achieve an ultimate dialogue with the supplier, the highest level of real time feedback is needed, including energy management system, energy generation, and storage systems. This combines all previously described types of feedback, including energy efficiency and automation. The complete home energy management system consists of all networks of residential wireless and wired sensor networks, display and feedback devices, and automation for communication with the utility.

In order to promote and encourage consumers to take an active role as electricity prosumer we need to:

- understand and engage the prosumer,
- turn intention into action (change behaviour),
- maintain behaviour over time,

and, at the same time, protect the prosumers from any possible risks.

Taking all this into consideration, the Prosumer Engagement Process was developed (Fig. 3.6). To be effective the Prosumer engagement process should be implemented by utilising with other engagement deliverables in particular D3.5 Energy Champions, 3.3 Smart Citizen & 3.2.

The process starts with Prosumer recruitment for which proper research has to be done, enable live registration and prepare a brochure. Then comes the contact with a survey that needs to be filled in. Consent for access and scoping is given by signing the Memorandum of Understanding. Depending on the result of this step process can go to signing a Memorandum of Agreement, which is a formal prosumer engagement. With this, all activities for enabling the prosumer with the tools and knowledge about the system and how to get the most of it to begin.

The diagram at Figure 3.6 identifies that the prosumer engagement process would be conducted in two phases, Phase 1 which is colour coded in blue, and Phase 2 coded in brown.

Phase 1 of the process would be conducted by CityxChange partners LCCC, UL, Space Engagers. Some of the data could be procured from Rates Register, Live Voters Register, other agencies such as HAP (Housing Assistance Payments Agency), Limerick City Engage events. Desk research and networking between relevant CityxChange partners would then compile a list of potential energy champions / prosumers who would then be contacted by LCCC and provided with essential information as to what the project is about and how citizens of Limerick could benefit by participating in the project this could also include a survey questionnaire which would help identify the most suitable potential participants, either by direct mail, email or effective social media platforms. The next stage of this phase of the process would involve CityxChange meetings and other events like Citizens Engagement events. The final stage of this phase of the process would involve potential prosumers citizens signing an MOU with LCCC.

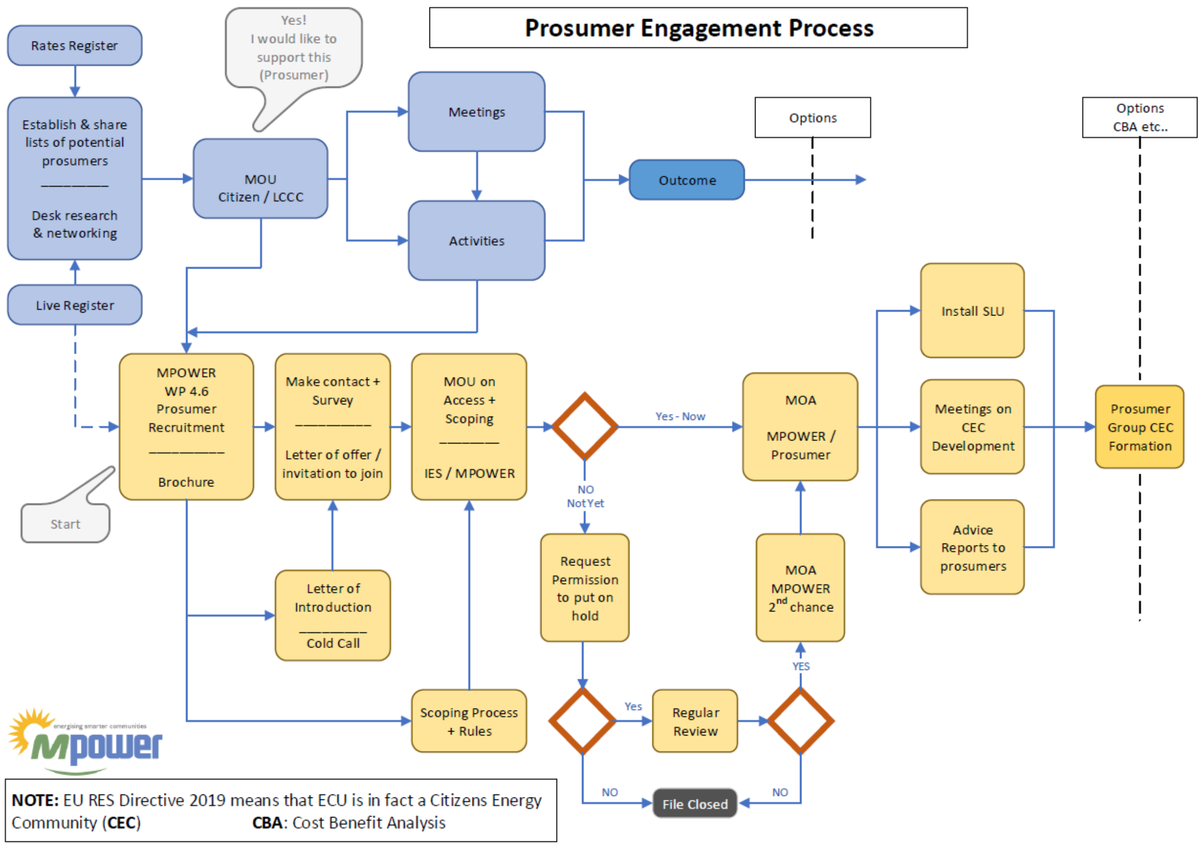

Figure 3.6. Prosumer Engagement process diagram.

The outcome of this phase should result in identifying the citizens who are not interested and also citizens who express an interest to become more involved in the prosumer engagement process.

When Phase 1 of the process is complete the Phase 2 can start. The first stage of this phase of the process would involve Prosumer recruitment as per WP 4.6. This would consist of sending a letter of introduction and a brochure to selected Limerick citizens deemed as potential prosumers from data supplied from phase 1 of the process. Alternatively where Covid -19 regulations allow contact could be made through a letter of introduction which could be sent to potential prosumers and followed up with a cold call where telephone contact was not possible. A further survey would then be conducted to identify which type /category of prosumer each participating citizen would qualify as.
The next stage of the process would result in all interested participating prosumers receiving a letter offer / invitation to join a prosumer group. On acceptance of the offer letter scoping of building process rules would be set out. A joint MOU on behalf of MPOWER and IES would then be presented to each participating prosumer at this stage the prosumer has two options YES, which means to proceed as a participating prosumer where they will then be offered the opportunity to sign a Prosumer MOA with MPOWER. NO

option indicates that the prosumer is not ready to proceed and requests to be put on hold with the option to review their participation at a later date. Following this review the prosumer decides either that they are no longer interested and their file is then closed, or the prosumer decides at this stage to say YES, for which they are offered a second chance to sign a Prosumer MOA with MPOWER. The next stage of the process involves the installation of an SLU in the prosumers property. Meetings would also be organised to discuss the development of a CEC. Reports and advice would be provided to prosumers on an ongoing basis. The final stage of the process would involve the formation of a Prosumer Group CEC.

4 Community Legal, Grid and Financial Governance Body

4.1 CSO - A new Governing body for the Community Grid and CECs

This section of the report will introduce certain regulatory aspects, which will form the basis for the introduction of Community System Operator (CSO) governed CEC's into the Irish Electricity System. However, the regulatory aspects will be covered in more comprehensive detail in +CityxChange task 4.4 entitled enabling regulatory mechanism.

A mapping of the regulations for Limerick and Trondheim and the Follower cities were done in D2.1. Since there are no existing regulations at national level that are promoting processes towards the establishment and operation of PEBs, it is important that demonstrations and piloting is ongoing continuously. This is achievable with specific permissions or regulatory sandboxes as used in the fintech industry. A first step in the regulatory sandbox is performing a mapping of the regulatory mechanisms within the respective countries and a gap analysis to underline the regulations being affected when developing the PEB. One of the main findings is that flexibility must be specified as products that can be managed in the local flexibility market. Three flexibility products are defined: P1 - energy, P2 - capacity, and P3 - system services. P1 has a time resolution of one hour or more, P2 between 15 min and one hour and P3 less than 15 minutes. All of them will be established and demonstrated in an open market situation.

A key component in the Community Grid framework is the creation of a new governing support body, a CSO. It is envisaged that the CSO will be a legal entity that oversees, by franchise, the management and safe operation of a Community Grid System (CGS). A CGS comprises participants that operate to rules as set by, and agreed with the CSO.

A CSO contracts flexibility from end-users within the Community Grid and uses that flexibility to provide disturbance neutrality for the Community Grid. This concept of contracting flexibility is not new. TSO's and wholesale energy market places also contract flexibility to balance supply and demand of electricity. *Aggregators*[7] contract flexibility from end-users, often in long-term contracts, and offer the flexibility as a single unit to TSO's, for

[7] An aggregator is a new type of energy service provider which can increase or moderate the electricity consumption of a group of consumers according to total electricity demand on the grid.

CSO to provide Disturbance Neutrality. The difference here between aggregators and CSO's, is that CSO's are required to be Disturbance Neutral, while aggregators are not.

CSO's could act as aggregators, as well as provide Disturbance Neutrality, but these objectives could conflict with each other. While aggregation can be used to balance the imbalance of supply and demand, aggregation is vulnerable to other local imbalances closer to the consumer. As a market participant and part of the balancing system, CSO's are well positioned to avoid these conflicts.

By facilitating Community Grids, a CSO allows more Renewable Energy Sources to be connected to the grid. The CSO agrees to these connections and their local balancing capacities well in advance and will be held accountable for unexpected disturbances resulting from such connections.

Although CSO's do not explicitly provide services to the DSO's and TSO's, they are providing a distribution service. Herein lies the greatest challenge for CSO's - to be allowed onto this electricity supply chain, they must provide others in the chain, namely DSO's and TSO's, with the utmost confidence in the Disturbance Neutral Community Grid concept.

4.2 Citizen Energy Community Activities

The Electricity Market Directive (EU) 2019/944 outlines "new roles and responsibilities for 'Citizen Energy Communities' in the energy system covering all types of electricity". Directive (EU) 2019/944(2019) Table 4.1 below outlines the core activities of a Citizen Energy Community, with reference to the relevant CEP package details.

Table 4.1. Transaction Properties and their Definitions.

Activity	CEP Ref.	CEP Detail[8]
Membership Activities	Article 16(1)a & 16(1)b.	Free and open to join and leave a community, noting the purpose of EC in the definition of Citizen Energy Community
Trading between Members	Article 16(1).	Free and open to join and leave a community, noting the purpose of EC in the definition of Citizen Energy Community

[8] Directive (EU) 2019/944(2019) (Table CEP Detail)

Registration/ Licensing	Article 16(1)(e).	Energy communities are subject to non-discriminatory, fair, proportionate and transparent procedures and charges, including with respect to registration and licensing, and to transparent, non-discriminatory and cost reflective network charges in accordance with Article 18 of Regulation (EU) 2019/943, ensuring that they contribute in an adequate and balanced way to the overall cost sharing of the system.
Network Charging	Article 16(1)(e).	Citizen energy communities are subject to transparent, non-discriminatory and cost reflective network charges in accordance with Article 18 of Regulation (EU) 2019/943,
Cross Border Membership	Article 16(2)(a)	Are open to cross border participation
DSO Operation	Article 16(2)(b). More detail in Article 16(4)	Member states are entitled to establish regulatory processes....Are entitled to own, establish, purchase or lease distribution networks and to autonomously manage them subject to conditions set out in paragraph 4 of this Article;
Access Electricity Markets	Article 16(3)(a)	An Energy Community may either participate directly in the market or outsource that activity to a third party (such as an entity which is primarily engaged with aggregation, e.g. a Demand Side Unit operator in Ireland).
Balance Responsibility	Article 16(3)(C)	CEC are financially responsible for the imbalances they cause in the electricity system; to that extent they shall be balance responsible parties or shall delegate their balancing responsibility in accordance with Article 5 of Regulation (EU) 2019/943
Share value of exported energy	Article 16(3)(e)	Are entitled to arrange within the citizen energy community the sharing of electricity that is produced by the production units owned by the community, subject to other requirements laid down in this Article and subject to the community members retaining their rights and obligations as final customers.

4.3 CSO interaction with Electricity System Stakeholders

In the +CityxChange D2.1 report, the stakeholder roles for the EU framework for the power market are considered. A key new stakeholder is identified in the D2.1 report, the Community System Operator(CSO), on a pilot basis will operate the local energy market for the duration of the project, under the supervision of the current DSO. The following Irish stakeholders of the Electricity System stakeholder structure and their corresponding roles is common throughout Europe. The table below outlines the interaction between them and the CSO.

Table 4.2. CSO interaction with the Stakeholders.

Stakeholder	CSO interaction with the Stakeholder
System Regulator	Commission for Regulation of Utilities: for consideration of protection of the consumer, and the transposition of any European Directive (post transposition) or Regulation into industry structures, including determining any requirements for licensed entities. As part of the +CityxChange project, the CSO-CRU interaction is mostly focussed on EC regulation development. A major part of this development is the fair compensation for EC's as laid out in Article 16 of the CEP.
Distribution System Operator (DSO)	ESB Networks is owner and operator of the electricity distribution system with interest in any large potential coordinated actions at the distribution system level which can impact or assist with flows and stability. The DSO also operates as the Meter Registration System Operator (MRSO) and the Retail Market Design Service (RMDS) as ring-fenced entities within ESB Networks which have responsibility for the operation and design of the retail market respectively. In particular, the regulation of third party "aggregator" access to metering within the context of the new smart metering programme needs consideration.The CSO-DSO interaction covers a number of key technical and regulatory aspects which are covered in section 4.5.

Transmission System Operator (TSO)	EirGrid is the operator of the transmission system, with interest in any large potential coordinated actions at the distribution system level which can impact transmission system flows and stability; EirGrid is contractual counterparty for ancillary services, operators of the Balancing Market and as designated NEMO (Nominated Electricity Market Operator (NEMO)) for the ex-ante markets. The CSO interaction with the TSO will be focused on potential revenues for providing services.
Suppliers	The CSO will be required to Interface with retail customers, with obligations under the Supplier Handbook. This interaction is dependent on the degree to which suppliers are used as the channel to communicate with end users .The CSO is particularly interested in the smart metering programme for the presentation of time-of-use tariffs to customers or data from meters
Generators	Residential and Commercial Scale generates and sells production through CSO or bilaterally CSO Impacted to the degree to which a larger generator (e.g. 10MW windfarm, for example) participates as part of a CEC.
DSO Operation	As described in the EU 2019/944 directive CEC Article 16 paragraph 2 b) "Member States may provide in the enabling regulatory framework that citizen energy communities are entitled to own, establish, purchase or lease distribution networks and to autonomously manage them..."
National Energy Association	SEAI[1]: providing advice and funding in relation to energy efficiency.

4.4 Regulative Structure Development

The Community Grid will be piloted in the Limerick LHC. Therefore this part reflects mainly on the Irish regulations. MPOWER, in conjunction with the CRU, is developing a new regulative structure to enable the introduction of CECs.Through the +CityxChange project, MPOWER is presenting the case of developing a new community support and accountability organisation called a CSO (Community System Operator). The key detail is that the CSO will oblige CECs to uphold Disturbance Neutrality.

There is the option for new CECs to become a Closed Distribution Network under Article 38 of the Directive (EU) 2019/944 operated and maintained by the Closed Distribution System Operator (CDSO). However, MPOWER is proposing that the CECs will operate in DSO Distribution Networks, the DSO-CSO operational agreements will be developed further in +CityxChange task 4.4.

In terms of the license development, there is currently no prohibition in Ireland for demand consumers to act in concert in the negotiation of their tariffs from suppliers, or for co-ownership of generation projects in Ireland. In terms of the +CityxChange project, there is no impediment to this cooperative activity occurring. In time, regulations will be set down to describe the obligations of ECs (not-for-profit, open membership, free to leave, etc.). Currently, aggregators – which is the closest activity in Ireland – do not operate under a specific licence. Instead, they are obliged to hold a supply licence (even if they have no intent to supply a supply customer). The regulatory environment for aggregation in Ireland can therefore take on one of a few possible structures:

- Obligation on an EC to hold a licence of another electricity undertaking (e.g. generation, supply and as applicable DSO), combined with further transposed legislation and market rules setting out the further obligation and rights of an EC (e.g. non-profit membership, ability to trade power between members and not being subject to discriminatory tariffs, etc.); or
- A new licence for an EC, capturing all the associated rights and obligations, including obligations to the DSO, and prohibiting such activity under law unless said licence is granted.

There are also many other aspects to developing a new CEC enabling license structure. The license may have elements of Supplier, Generator and DSO licenses. Furthermore, there is needs to be a review of dependencies from local codes such as the Trading & Settlement Code, Balancing Market Bidding Code of Practice,DS3 System Services Contract, Connection Agreement, Grid Code, Use of System Agreement(s), Distribution Code, Metering Code, Market Registration Agreement, Supplier Handbook, CER levy process and NEMO rules. These will be further refined and the license for Ireland applied for in T4.4.

In terms of the accreditation of the CSO, the CSO would also act as the responsible party on behalf of the Energy Community for any interactions with the DSO or the CRU. As outlined to the CRU in a MPOWER submission on CEC development in Ireland. It is envisaged the likelihood is Energy Communities will be regulated, but for the CSO, there should be a system of accreditation to provide Energy Communities services. MPOWER do not envisage this to be a licensing regime, but a voluntary process for CSOs to demonstrate their competency to Energy Communities.

4.4.1 Phasing of CSO Regulation Structure into +CityxChange

The following are the order of the proposed phases for developing a license as part of the +CityxChange project:

1. MPOWER acts as a single point of contact for ESBN and each Supplier (where relevant) for the individual prosumers, which are members of the CEC. An initial design of the regulatory structure will be developed by MPOWER. The proposed structure of the regulatory framework will be documented as part of Task 4.4. However, in order to further develop the design of the regulatory structure framework, it is required that Irish Electricity System Stakeholders (CRU, ESBN) provide an input.

2. The Project moves from the Planning Phase WP2 to Implementation Phase WP4, whereby the focus on the +CityxChange project is to demonstrate Grid Neutrality to the CRU. These will coincide with a number of technical demonstrations such as the effectiveness of local trading operations, the integration of Distributed Ledger Technology, demonstration of communications solution etc. In parallel, MPOWER will hold meetings with CRU to get feedback on the proposed regulative structure. Also, MPOWER will present to the regulator a complete “valuation of service” of the CSO operations. This will be developed further in +CityxChange Task 4.11. The valuation of service involves some of the following services: operational governance services of Energy Community assets, distribution network flexibility services, reduced distribution system upgrades, and reduced system losses on a national level.

4.5 DSO Oversight of CSO and CEC

Directive 2019/944 details how Member States may provide in the enabling regulatory framework that citizen energy communitiesEnergy Communities have the right to act as DSO. This requires member states to enforce a subset of standard DSO obligations, particularly under the Closed Distribution Network concept in the Directive. The creation of a closed distribution network operator/owner regulatory framework is, in part, linked to Direct Line concepts (also known as "Private Wire" in Ireland). As part of the +CityxChange project in Limerick City, it is not envisaged that an Energy Community will act as a DSO. Since, the Community Grid Framework will be developed on the distribution system, which is planned, developed and operated by the DSO. There is a requirement to develop an enduring structure of operation between the CSO and DSO. it is envisage that this will be developed in Task 4.4. Enabling Regulatory Mechanism.

4.5.1 DSO Regulators and Operation implication for the implementation of CG

+CityXchange partner ESBN provided the following detail regarding potential benefits of Community grids.The core of the +CityxChange project is the decarbonisation of urban areas. Central to this is the PEB which will need large quantities of LV connected generation to become a reality. Due to the typically heavy loading of urban networks, there is considerable capability to absorb LV connected generation on these networks. Inevitably however there will be areas of the distribution system which will require additional capacity where large quantities of generation are connected. Where additional capacity is required it is likely that the additional generation would result in the system moving outside its operational constraints. This is outside the statutory voltage limits or infrastructure exceeding their kVA ratings. This is where the Community Grid concept would enable the connection of larger quantities of LV generation by near instantaneously matching supply and demand through flexibility providing value to the operation of the system. The CSO could enable the connection of RES generators.if conventional solutions do not provide an economical solution..The CSO could provide a Disturbance Neutrality solution to enable the RES plant developer. This is one of a number of potential revenue streams that will be investigated in 4.11.

In Limerick, it is unlikely that we are going to install enough generation connected that would require a capacity upgrade on the network or that we would have enough customers to carry out meaningful exchanges of flexibility on MV/LV transformers.

There is a substantial capability of the LV system to accept renewable generation and a proportion of this capacity, up to potentially 200kW, can be exported to the MV system via the MV/LV transformers. ESB Networks, as DSO will need to evaluate what capability the MV and LV networks will be able to accommodate.

Instead it is proposed to demonstrate the capability of the Community Grid by using it to solve synthetic constraints within the 38kV/MV substation with generators and flexibility providers connected downstream across a number of MV/LV transformers. This approach has been used previously trialed in other smart grid trials .

Recently, ESBN published a guide for Non Wire Alternatives to network development.[9] The document outlines ESBN operational requirements for distribution based flexibility service providers. MPOWER envisages ECs providing flexibility services for the DSO as a high revenue service. In task 4.11 , the valuation of services for a CEC and a CSO to provide such services is to be evaluated. However, this guide covers many aspects of the DSO perspective of how third parties can operate on their DSO network system, therefore is a very useful guide for how a Community grid could operate in DSO managed grid. Many of the DSO rules and requirements for third parties to operate on their managed grid is outlined in the report. Hence, this section mostly is based on the details outlined in the report. A positive conclusion from the report emphasises the market need for +CityxChange R&D learnings on flexibility markets, Furthermore, as part of the Price Review 5 process submission to the Irish regulator by ESBN, 18 projects have been identified that may be candidates for flexibility service solutions. A budget for €16.9m million was requested for flexibility service providers was requested, a material saving of estimated €60m to resolve issues through the traditional grid reinforcement investment approach. Another positive outcome from ESBN recent publications is the timing of the +CityxChange project , the R&D on local trading markets is a few years ahead of the market. The following diagram by ESBN illustrates the planned timescales for developing local flexibility Solutions.

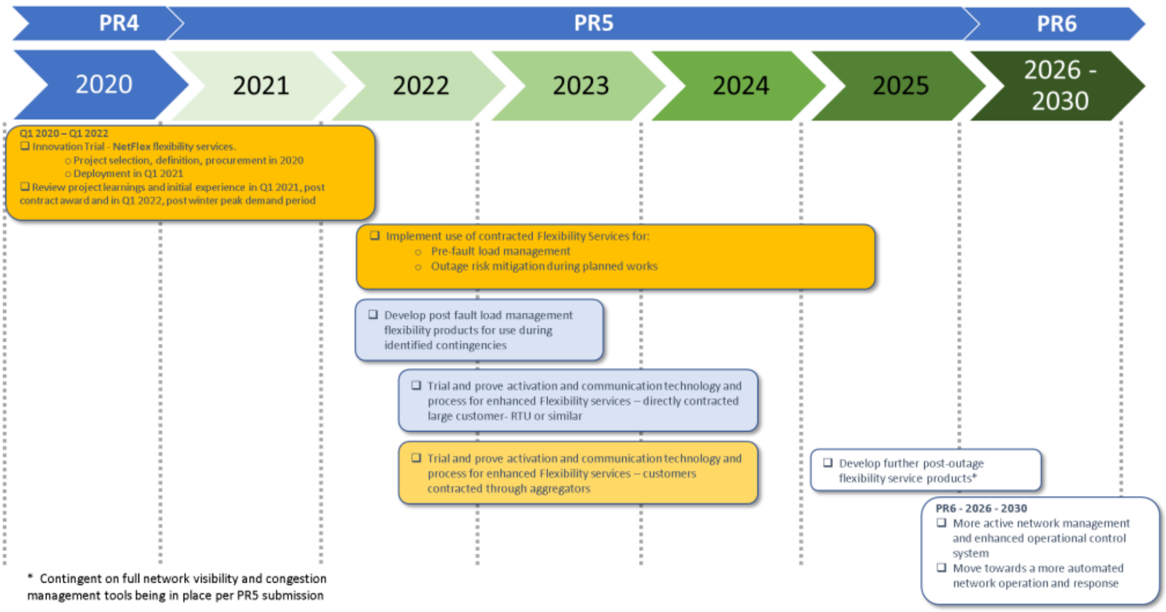

Figure 4.1. ESBN Managed Network Development Timeline (ESB Networks (2020)).

[9] Guide Non-Wires Alternatives to Network Development (ESB Networks (2020))

ESBN outlined that Flexibility services could be provided "by varying the export from a distributed Generator (DG) unit or an Energy storage unit ,also increasing an export, releasing/exporting stored energy or reducing customer demand, all have the same net effect on the network"(ESB Networks(2020)) So, therefore all these flexibility mechanisms are the specific process requirements to resolve network issues. A fundamental mechanism within the Community Grid system design is the controlled measured dispatch/absorption of Distributed Generation and Energy Storage Units which aligns with ESBNs requirements.

As part of the ESBN guidelines for Flexibility Service Providers requirements, it states that the requirement for flexibility downstream of 38kV/MV substations. This aligns with the agreed trading boundary as part of +CityxChange project. However, ESBN would need to provide FSP with access to congestion management platform developed and/or adopted by ESB Networks, this may act as input for a local trading algorithm. This is a very positive direction by the DSO giving clear direction that they are moving into the Smart grid space, moving from passive to managed networks. In parallel MPOWER is developing their Community Grid Smart System Design Solution.

4.5.2 +CityxChange - an arena to demonstrate local trade platforms

In the +CityxChange it is realised two innovative trade platforms. One is established for being demonstrated within the framework of Community Grid with disturbance neutrality. The other is developed within the common market framework for trade of local flexibility including local generation, storage and system services - without any disturbance neutrality restrictions. The first one is demonstrated in Limerick and the second one in Trondheim.

The two platforms have some overlap regarding general architecture and features. In table 4.3 it is described more in detail how the platforms are complementary.

Table 4.3 +CityxChange common market Trade platform prototypes similarities.

Characteristics	Community Grid Platform (MPOWER)	Local Market Platform (Powel)
Community Grid Framework	x	
IOTA verification procedures	x	x
ABB Optimiser for dispatch/operation		x
Manages all local resources/assets	x	x

Double Auction principle	x	
Bids and Asks for price calculation		x
In line with current EC and REC regulations (compare D2.1 on regulatory aspects)	x	
Algorithm trade		x
Linked to global market (day-ahead)		x
Cloud based	x	x
Scalable due to number of assets	x	x
No lowest limit for participation	x	x
Manage energy, capacity and system service products	x	x

Both trade platforms are at a prototype level and will be demonstrated and evaluated during the project period. It is supposed that features and functions will be further developed and tailored to fulfill project scope.

5. Community Grid Smart System Design

5.1 Community Grid Overview

This chapter describes the Community Grid concept in detail. Various factors influencing Community Grid design are presented, as well as the advantages and benefits that a Community Grid would offer. Lastly, some design elements that would need to be considered are explored.

A smart Community Grid uses intelligent transmission and distribution networks to deliver electricity, while at the same time allowing energy customers and energy providers to more efficiently manage and generate electricity. The key drivers of the development of a smart grid are reliability, efficiency and as well the opportunity for the electrical system to integrate renewable energy sources such as wind and solar power into the existing grid infrastructure. This approach aims to improve the electricity system's reliability, security, and efficiency through two-way communication of consumption and production data and dynamic optimization of electric-system operations, maintenance, and planning.

Smart Community Grid design is critical in designing a carbon free grid. Energy producers and consumers data is required for many functions, such as establishing load profile, developing and operating control mechanisms and to support local Energy and Flexibility Markets. As a part of +CxC project, MPOWER is integrating a bespoke flexible system known as a Disturbance Neutral Community Grid that can communicate via LoRa (Long Range wireless radio frequency technology). An underlying Smart Grid is crucial for the Community Grid. Figure 5.1 below shows the Community Grid Architecture and the various elements contained within. It is an example of Community Grid concept application that connects different kinds of consumers, from school, residential houses to industrial facilities each with different attributes: E - facility has energy from renewable sources; F - facility has Flexibility assets to offer; F+E - facility has both RES and Flexibility.

When disturbances are caused by producers, a Community Grid System can compensate within the community using traded flexibility from other community members, be it consumers, other producers, or community owned assets such as storage. Figure 5.2 depicts CSO dispatch center (ECO Hub) which is the central point of the Community Grid System infrastructure and the location of the Community Grid Stabiliser.

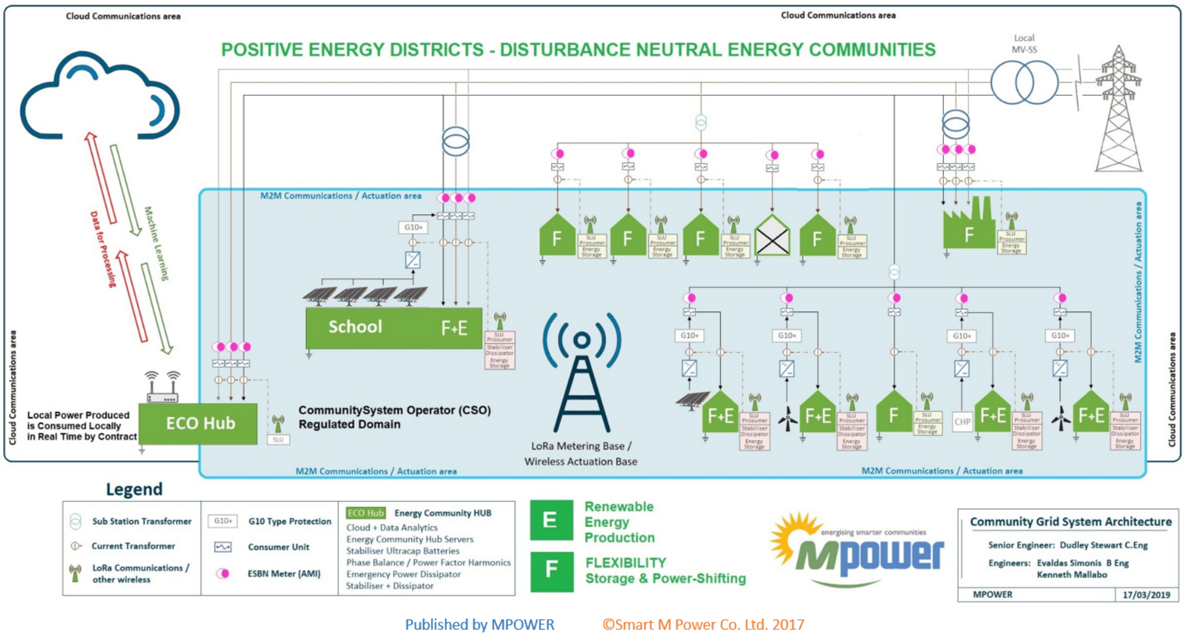

Figure 5.1. Community Grid System Architecture application example.

While LoRa/LoRaWAN networks typically have the gateways send their uplink data to a cloud network server such as The Things Network, using a private network server like Chirpstack that is placed physically close or even on the gateway is not uncommon. MPOWER has chosen using a private network server with a "store and forward" approach due to a few reasons.

First reason is due to a need to focus on lowering dependencies on third parties. If a fault were to occur on the public network server, MPOWER would have little to no control to fix the situation. Second is that it provides the network some greater resilience from disruption in the internet. If the internet were to go down, the cloud network server can no longer connect to the gateway which will cause a complete disruption of the network. In comparison the private network server will no longer be able send data to the partners/prosumers, but the LoRa network can continue to collect meter data without disruption.

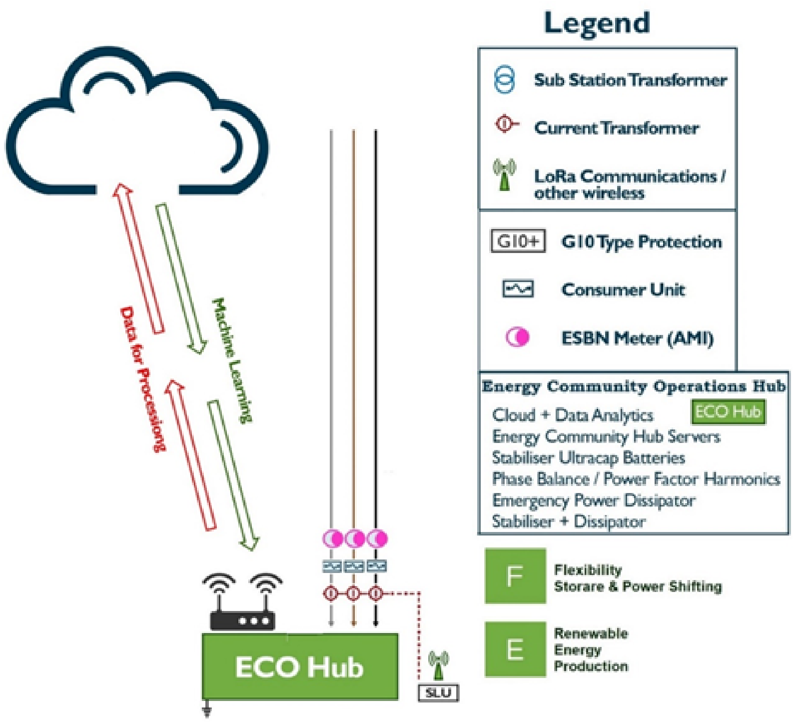

Figure 5.2. Energy Community Operator (ECO) Hub - Prosumer Groups in Local Smart Grid - Disturbance Neutral Community-Grid, Power-System Architecture: Note F = Flexibility Provider and E = Energy Provide/production

5.2 Disturbance-neutrality

Disturbance Neutrality is defined in this work as a condition where the net electrical power, that is the power generated minus the power consumed, of all customers within the community grid is zero or less.

This concept is the overriding objective of the CSO and the Community Grid System. Section 5.3 covers the topic of Boundaries within Community Grids. Distribution networks are currently typically operated as passive networks. It is envisaged, as part of the transition to a smart grid, theDSO has the capability to indicate a disturbance neutrality setpoint. The DSO's disturbance neutrality setpoint can therefore be used by the Community Grid System to provide a more flexible interpretation of disturbance neutrality where the net electric power can be negative, zero or positive.
Ensuring Disturbance Neutrality of the Community Grid implies that the Community Grid is acting to ensure that the local distribution system is operational within the statutory voltage limits and thermal limitations of the local distribution system infrastructure. Distribution system statutory voltages on the LV system in Ireland are defined, as per I.S. EN50160:2010, are 230V +/- 10%. The CSO will be investigating the reporting of local voltage levels using the SLU infrastructure.

Thermal limitations of the infrastructure of the distribution system are given by the DSO and reflect the thermal limitations of the local infrastructure e.g. transformers and/or cables and are effectively represented as the DSO disturbance neutrality setpoint. As the community grid concept does not require all customers to participate in the concept the connectivity to the infrastructure has to be provided as well as the limits at the logical interface point need to be provided to the DSO who has overall responsibility for the operation of the distribution system.

Distribution system power quality can be affected by a wide range of factors i.e., including disturbing loads, the power electronics coupled with DERs and DER supplying system services and local infrastructure issues. As stated in the SEAI report for Extension of the Smart Micro Energy Cluster Test Bed: “to maintain this disturbance-neutrality in the Distribution System, DSOs ensure there is enough local distribution capacity (to avoid congestion), and grid-embedded specialised devices that respond, often semi-automatically, to local disturbances. It is these local disturbances close to consumers that is the focus of the Community Grid solution”. [10]

Traditionally, disturbance-neutral delivery of electricity is achieved through

1. DSO’s who connect consumers to the grid through specialized equipment to make electricity delivery less sensitive to local disturbances,

2. TSO’s who connect Distribution Systems, who constantly balance supply and demand. Balancing is achieved by controlling flexible production and consumption between TSO and flexible consumers and producers.

As a result of a changing load and generation profiles on the grid arising from increased EV chargers and RES generators, respectively, managing the MV and LV distribution system is becoming an ever more challenging task for DSOs. Matching the local production with consumption can mitigate congestion issues caused by local variable RES generation. In the same SEAI report it is outlined that an “alternative approach is to use *flexibility* in distributed resources instead, i.e., resources owned by third parties (other than the system operators). They respond to disturbances through appropriate distributed controls implemented in each of these resources e.g., *bi-directional flows* can be avoided by making sure local consumption is always more than local production, using *flexibility* in consumption (also known as Demand Response) and/or other resources such as batteries.”

The TSO’s and DSO’s main objective is to ensure a safe, secure, and reliable supply of electricity to all customers. A fundamental process to achieve those objectives is maintaining power quality within the specified limits. The TSO operates the transmission

[10] Extension & Integration of Tallaght Smart Energy Living Lab – SEAI 2017 RDD00150

system and is responsible for managing the voltage and powerflows on the transmission system and the system wide frequency. The DSO operates the distribution system and manages voltages and powerflows on this system. +CityXchange partner ESBN provided the following detail in relation to maintaining disturbances of a Community Grid.

The impact in practice of the large-scale proliferation of inverter coupled generation and load on harmonic distortion and other power quality phenomena is unclear at present and is not currently part of this trial.

It is planned to develop the concept of Disturbance Neutrality to include Power Shifting (Peak Lopping & De-congestion), Power Exports by Dispatch, and Power Quality Mitigation.

5.3 Factors Influencing Community Grid Design

This section details some important factors to consider when designing/implementing a Community Grid. The benefits a Community Grid offers over traditional electricity systems is also briefly discussed.

5.3.1 Technical

There are several aspects where Community Grid System can improve the technical performance of the local distribution grid. The main aspects are:

- energy loss reduction
- improved voltage quality
- relief of congested networks and devices
- enhancement of supply reliability
- better energy flow management.

The level of technical benefits depends on optimization of the local energy source allocation and effective coordination between the prosumers and an ECO hub.

Few places worldwide provide an easy connection to the grid for micro and small scale Renewable Energy production, which is generally variable and intermittent. This is a barrier to the Clean Energy Package (CEP) implementation. In Ireland, local trading of local production in "real time" with Disturbance Neutral results is being pursued as the model for unlocking this barrier. Disturbance Neutrality is covered in detail in section 5.3. This solution provides the opportunity for maximum exploitation of renewable energy sources in whichever grid it is implemented.

5.3.2 Economic

Community Grids may remove lots of pressure from grid operators to ensure grid stability. Currently, DSOs rely on new equipment installations and upgrading old equipment to provide additional capability to the distribution system. The advance of ICT, smart grid technologies and the anticipated proliferation of prosummers is giving DSOs more options to provide additional capability to the distribution system. . For the DSO, the enhancement and reliability of local power system management, easy integration of small local RES, and guarantee of Disturbance Neutrality should be the main incentive for them to allow Community Grids to be established.

By producing and consuming their own energy, prosumers have the potential to save on their electricity bill. The biggest problem with this approach traditionally has been the cost of purchasing and installing the RES system. However, the cost of small scale RES has reduced dramatically in recent years. For larger scale prosumers, like businesses with ample space for RES production, this could turn into a small source of revenue due to trading in the local energy and flexibility markets. There are a number of potential system services for system operators.

These include the following:

- local services for DSO
- better management of DERs on a National Level
- increased Renewable Energy Capacity
- reduced Grid System Losses.

CSO managed CECs could provide quality governance of DERs. In the near future an inhibitor for the deployment of Renewable Energy Generation will be access to grid connections for Renewable Energy Generation. CEC's integrated trading solution with the ability to maintain disturbance neutrality should allow for increased deployment of Renewable Energy Resources without using conventional infrastructural reinforcement. The local generation has the potential to reduce system losses in contrast to a model based on large-scale centralised based generation. ESBN has issued a guide for requirements to become a Flexible Service Provider[11].

The evaluation of CSO and CEC services for the local DSO and TSO will be evaluated as part of +CityxChange Task 4.11

[11] Innovation for the Network of the Future, ESB Networks, Feb 2020.

5.3.3 Social

Community engagement is a key aspect to a successful Community Grid. If prosumers within the Community Grid do not cooperate with the CSO to establish and maintain a Community Grid, the Community Grid will fail. Prosumer engagement is thus a vital design consideration. How a Community Grid solves local grid and community issues will be a key contributor to winning over potential prosumers. The prosumer engagement has been explored in Chapter 3.2.

Community market places, where prosumers trade energy and flexibility, further create a sense of community within the Community Grid. This encourages prosumers to want a successful Community Grid. The establishment of a Community Grid will also create new jobs in the local community. These could include CSO administration, solar PV maintenance, and new RES plants. In addition to local jobs, Community Grid implementation also provides new roles and opportunities for those tasked with its design.

5.3.4 Environmental

The reduction of greenhouse gas emissions is a major driver in the Clean Energy Package, as mentioned in Chapter 1.

Community Grids embrace this requirement. Prosumers in a Community Grid will produce their own energy using RES, most likely photovoltaic solar panels, in conjunction with batteries to store and dispatch energy as needed. This shift towards renewable energy production is a vital part of the fight against climate change. The most notable benefit of RES is the reduction of greenhouse gas emissions, but there are also a number of benefits for the prosumer, namely moving towards energy independence.

Increased efficiency arising from optimizing Community grid assets will ensure that energy produced and consumed within the Community Grid is not wasted, saving money for the prosumers,optimizing, and reducing grid load requirements. This will also help to accelerate the widespread adoption of these energy efficient improvements in homes and businesses, not within the Community Grid.

5.3.5 Legal

When establishing a Community Grid, there will inevitably be some key legal obstacles that must be overcome. The establishment of a CEC is the backbone of the legal requirements of a Community Grid. Coordination and cooperation with local and national authorities to pass the required legislation is key.

The confirmation of the boundaries of the Community Grid must be legally defined with the cooperation of the key electricity stakeholders. This ensures that the question of whose legal responsibility it is of supplying electricity to consumers is clear and well defined.

Adding RES to the distribution network will require the authority to do so from various organizations, including the local council and grid operators. This is seen as a major potential hurdle in establishing a Community Grid. This has been explored in detail in Chapter 4. In the same way, legal permission must be obtained from prosumers before any equipment can be installed on their premises - such as metering devices, solar PV, and batteries.

Smart grids fall under GDPR[12] purview because they utilize consumer data from polled smart meters in order to configure demand response and forecast energy demands. The same applies to the Community Grid System. To make an assessment and propose adequate measures, the Smart Grid Task Force prepared the Data Protection Impact Assessment Template for Smart Grid and Smart Metering System.[13] This DPIA template helps for an evaluation and decision so that any installation or application complies with the legal requirements foreseen by Article 35 of the GDPR and voluntary commitments. It helps Data Controllers to take adequate measures in order to reduce risks and to mitigate the potential impact of the Risks on the Data Subjects, the Risk of non-compliance, legal actions, and operational risk. Explanation of how to conduct DPIA with the template can be found at the official GDPR EU site.[14]

A Data Protection Impact Assessment (DPIA) is "required any time a new project that is likely to involve "a high risk" to other people's personal information begins." (GDPR.eu) As a part of the preparation actions for the implementation of the Community Grid System in WP4 a DPIA was initiated and performed. The assessment of threats has been carried out over four meetings with all the partners involved in processing personal data. A Data Protection Risk register has been developed. The risk register consists of 66 identified risks across 11 categories, as presented in the summary table (Table 5.1.).

Table 5.1. Risk register.

No.	Risk Category	Identified	Risk Assessment

[12] https://gdpr-info.eu/
[13] https://ec.europa.eu/energy/content/data-protection-impact-assessment-template-smart-grid-and-smart-metering-systems_en
[14] https://gdpr.eu/data-protection-impact-assessment-template/?cn-reloaded=1

1	Inadequate information of the data subject	5	28/05/2020
2	Violation of the data subject's rights	3	28/05/2020
3	Personal Data integrity loss	5	28/05/2020
4	Damage to individual	3	28/05/2020
5	Physical attack	8	04/06/2020
6	Unintentional damage	9	04/06/2020
7	Failures/ Malfunction	5	11/06/2020
8	Disasters	1	11/06/2020
9	Outages	4	11/06/2020
10	Eavesdropping /Interception / Hijacking	5	11/06/2020
11	Nefarious Activity/ Abuse	18	11/06/2020
	TOTAL	66	18/06/2020

For each risk identified the mitigation actions have been identified and the residual risk accepted as presented in Table 5.2.

Table 5.2. Risk mitigation.

Risks Impact	Identified	Residual
High	13	0
Medium	35	6
Low	18	60

5.3.6 Regulatory

It is envisioned that Community Grids, along with the Community System Operators, will be regulated in two ways - namely supervision by the DSO and reporting to a regulatory authority.

Supervision by the DSOr is necessary to instill confidence that the Community Grid will not disturb the delivery of electricity to their normal consumers. Adding new large scale RES plants, installing small local RES, and dispatching energy between prosumers are all possible areas of concern for DSO Supervision will ease these tensions and allow for cooperation in the long term. Regular reporting to a regulation authority ensures continued compliance with any and all regulation put forth by said authority.

5.4 Community Grid Boundary

Basic Community Grid Concept was developed and demonstrated in the Tallaght Community Energy Living Lab project. Part of the Community Grid demonstration was at South Dublin County Council with its buildings and offices. PVs installed at the roof of the building were used as a generation source, the production part of the Community Grid. The physical boundary was confined within the local MV/LV consumer transformer to which the Community Grid Stabiliser was connected and the communication network providing two-way communication between the buildings and SLUs that were attached to each building. Such an infrastructure enables further expansion to include all the buildings in that area that are under the same boundary. In the case of Tallaght Community Energy Living Lab, also known as Tallaght Smart Grid Test the project won the SEAI Energy Award in

2018.[15] Demonstration of the successful management of electricity demand and supply at the community level proved that the Community Grid concept is a solution for the problem of disturbances, which is troubling the grid.

As explained in detail in previous sections, established infrastructure enables *Prosumers* to actively trade *energy* and *flexibility* within the Community Grid, where the energy produced in the Community Grid is used in the Community Grid. In this way, the necessary balance between supply and demand is obtained. If trading energy and flexibility is not sufficient to keep the Community Grid neutral, a Community Grid Stabiliser steps in to balance the power. As a last resort power can be dissipated with a dissipator.

As explained in Section 4, a key component in the Community Grid framework is a Community System Operator (CSO), the new governing entity that oversees the management and safe operation of a Community Grid System (CGS). Core principles of MPOWER CSO are described in the D2.3 Report (section 5.2.2.1).[16] A CSO may operate across several DSOs and even TSOs, but a Community Grid is always restricted to a single DSO (Fig. 5.3).

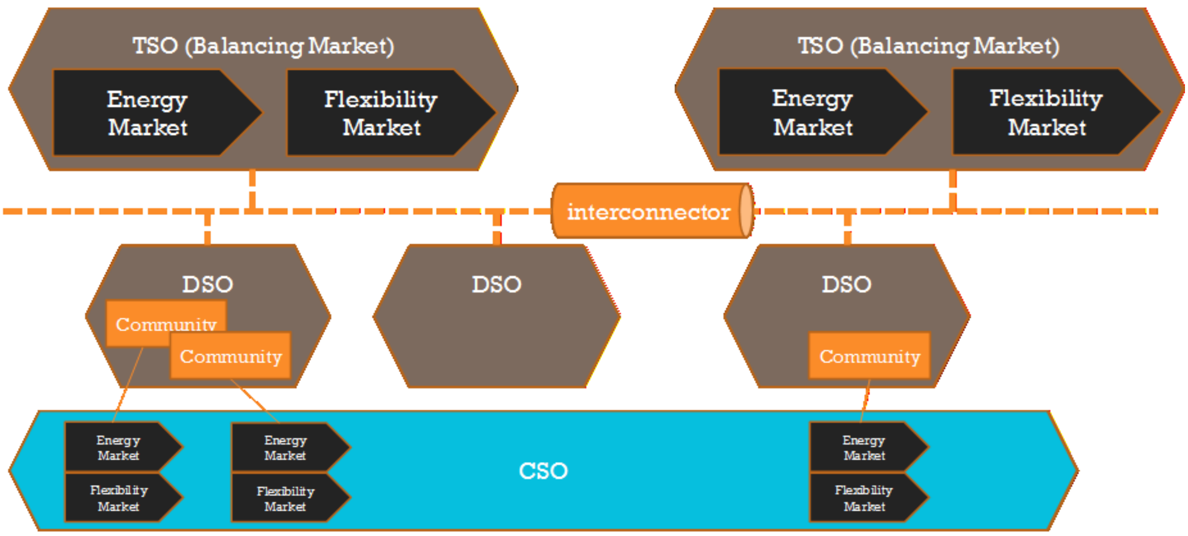

Figure 5.3. CSO operational domain (SEAI(2017)).

The CSO also operates *Local Energy and Flexibility Markets* and manages the relations with external (wholesale) *Energy and Flexibility Markets* (Fig. 5.4).

[15] https://www.seai.ie/case-studies/tallaght-community-energy/
[16] https://cityxchange.eu/knowledge-base/report-on-the-flexibility-market/

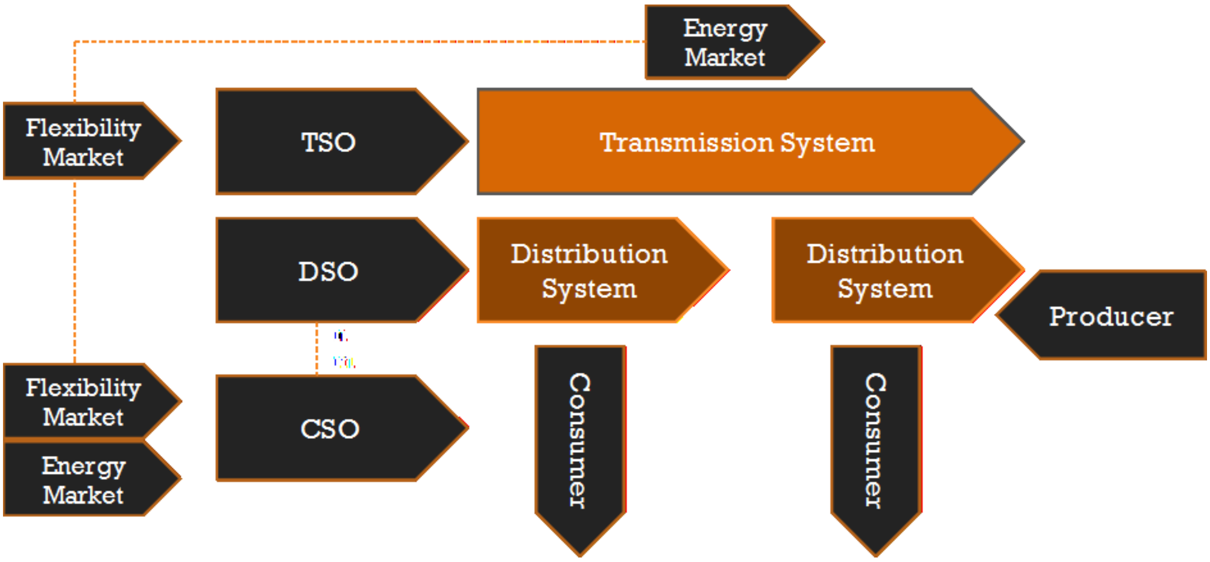

Figure 5.4. CSO position in respect to DSO and TSO (SEAI(2017)).

Trading of flexibility can be done using the physical grid or the virtual one. As described in Report D2.1 (Section 9.1)[17], physical energy flows to the nearest demanding asset within PEB, and virtually, over the trading platform, flexibility asset is sold to the best offer at the Local Flexibility Market.

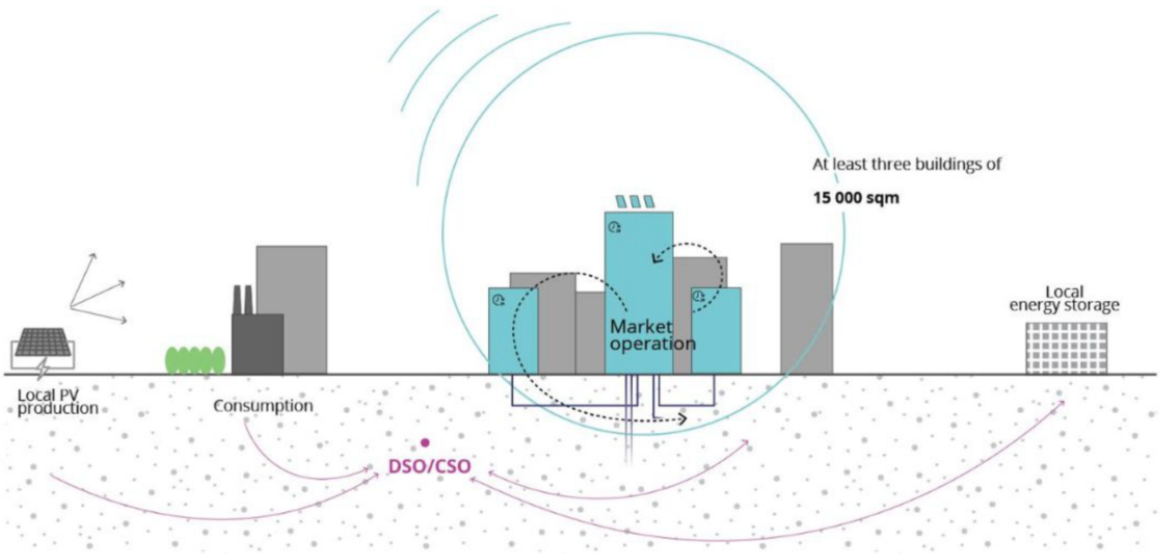

Figure 5.5. The physical (purple line) and virtual grid (blue lines) of the +CxC PEB (Source: D2.1 Report on Enabling Regulatory Mechanism to Trial Innovation in Cities, +CityxChange - Work Package 2, Task 2.1)

17 https://cityxchange.eu/knowledge-base/report-on-enabling-regulatory-mechanism-to-trial-innovation-in-cities/

Participants in the local market are made up of local prosumers, producers, and consumers. Prosumers are participants that can both consume and produce local energy. They can also provide flexibility. The prosumers and their assets are called a Community Grid and the flexibility offered by these prosumers are referred to as flexibility as a Service. The Community Grid is defined as the following:

> "A group of grid-connected electrical resources, within a clearly defined electrical boundary in the Distribution System (e.g. sub-station), interconnected through a logical connection point to the grid for which it acts as a single controllable entity to maintain disturbance-neutrality."SEAI(2017)

Each building in the *PEB* has equipped with the bespoke Smart Link Unit (SLU) device that provides *real-time two-way Smart M2M communication* with the central HUB and the possibility to control the loads to match local power making the so-called White Energy Community possible (Fig. 5.6). *White Energy* works on the basis that through sharing/swapping power on a local level and smart devices, all local power can be consumed locally. The subject of demand flexibility is covered in great detail in +CityxChange D2.3 report on Flexibility Markets. One of the main conclusions in the report, flexibility trading for the Limerick Community based demonstration will involve decreasing energy demand as a flexibility mechanism, rather than increasing demand.

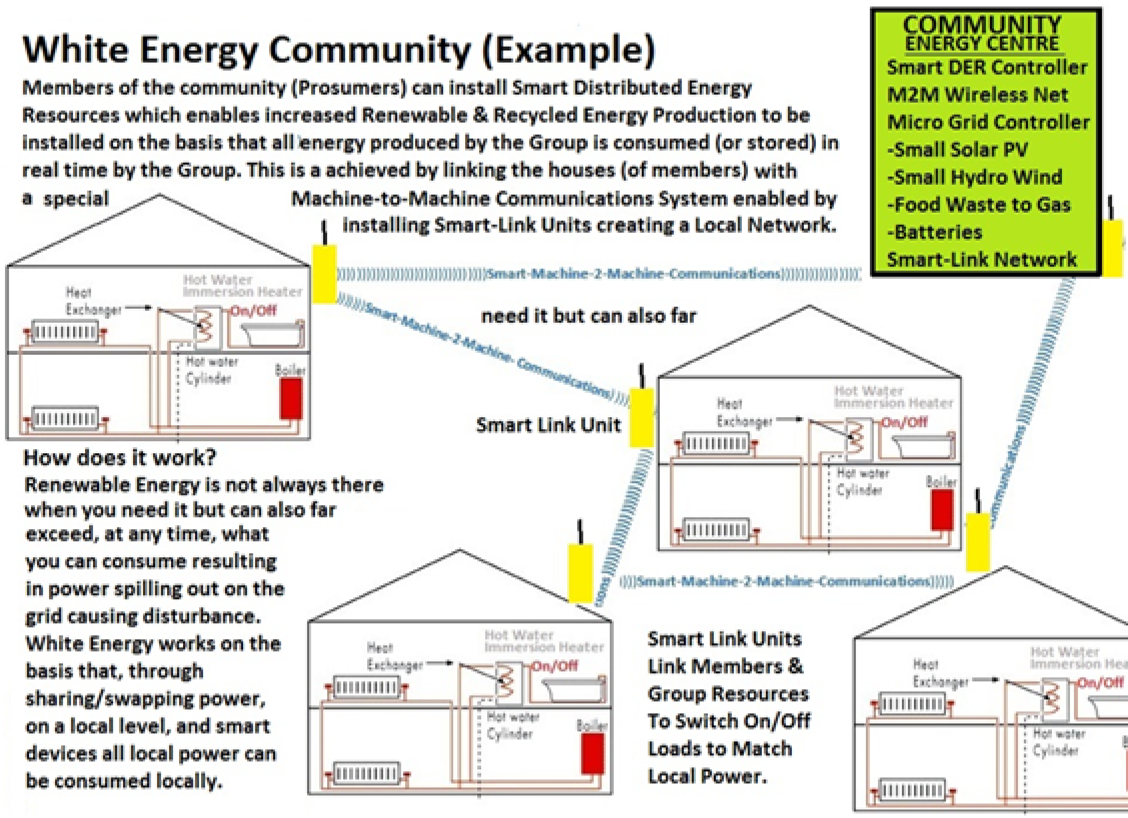

Figure 5.6 Presentation how Local Network based on Smart Link Units can make White Energy Community[18] possible (Source. Tallaght Smart Grid, https://www.tallaghtsmartgrid.com/radical-new-solutions/).

Figure 5.7 shows a graphical representation of the Community Grid definition within its physical and virtual boundary. CSO manages the Community Grid System internally and externally through logical infrastructure based on SLUs that are installed at each prosumer's building, making it a *Smart auto-producer cluster*. The Physical boundary of the Community grids is discussed in the preceding paragraphs. Community Grid Stabiliser is explained in section 5.6.

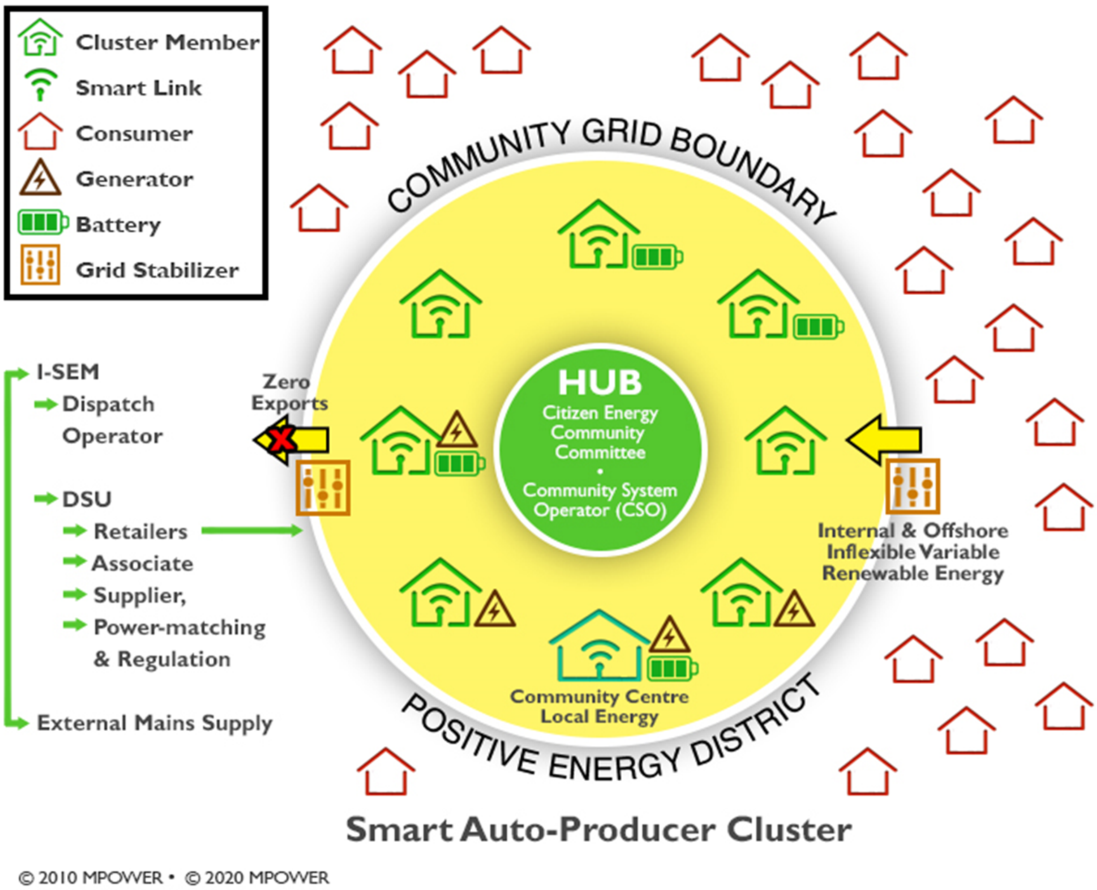

Figure 5.7: Community Grid Boundary concept (Source. Tallaght Smart Grid, https://www.tallaghtsmartgrid.com/radical-new-solutions/).

As outlined in section 4.5.1, for the Limerick city demonstration, the physical boundary for the Community Grid is within the 38KV/MV substation. In order to mitigate disturbances, the stabilizer will be a distributed unit so it can be located in close proximity to Community assets. MPOWER and ESBN factored in the limited number of customers within the 10kV

[18] Energy Community based on energy saving principles.

ML/LV transformers in Limerick City.The limited number of customers would not be viable to develop a feasible local market.

Another agreement for the project is that there can be trading across MV/LV transformers. Power can flow back through MV/LV transformers from the LV system to the MV system. The exact limitations of what can be exported will depend on local infrastructure and loading. However, in the future, such large complexed urban based networks present a challenge in maintaining disturbances due to the network size. Third party local energy market providers will be further aided by power management congestion data from the tools selected by DSO as stipulated in the ESBN Guide Non-Wires Alternatives to Network Development guide[19]. The guide clearly outlines the provision of Congestion Management software for Local Market Operators to assist in maintaining disturbances. As part of +CityxChange, MPOWER is focussed on developing a community grid system that operates within the DSO managed network. The Irish DSO is accelerating its transition from passive to managed networks. The Community Grid solution may very well pivot towards becoming a flexibility service provider. The Community Grid System is developing the building blocks such as DLT, controlled dispatch, Comms Solution etc. The +CityxChange boundary agreement aligns with the Irish DSO (ESBN) guide for boundaries for Flexibility Service Providers' operation.

5.5 Communications Infrastructure

The creation of a Community Smart Grid, as visualized in figure 5.,1 requires a functional, reliable, and secure communications infrastructure. Smart meters are the devices used that retrieve the energy readings at participating prosumer buildings. Each of those smart meters is connected to a Smart Link Unit (SLU). The main purpose of an SLU is the bidirectional communication between the prosumer to an Eco Hub. The Eco Hub is a community microgrid stabiliser that will store the prosumers' excess energy to help ensure disturbance neutrality. Another function of the Eco Hub is to act as a gateway for the local community's SLUs that will go to the enerXchange™ platform.

The proposed technology used for communication is the LoRa protocol in 868 MHz frequency. Lora is an LPWAN (Low Power Wide Area Network) solution along with others such as SigFox, Telensa, PTC, etc. LPWAN offers low power sensors and applications that need to send small amounts of data over long distances. Generally, these technologies have a varying range and data transmission rates, but they aim to support over 10 km. Lora supports up to 5 km range in urban areas and 10-15 km in rural areas. The transmission

19 https://www.esbnetworks.ie/docs/default-source/publications/doc-140220-fol-non-wires-alternatives-to-network-development.pdf?sfvrsn=659201f0_0

rate of Lora is between 300 bps to 50 kbps. It is a half-duplex communication, which means while it is bi-directional, it cannot send and receive data at the same time. The diagram in figure 5.8 shows and compares different kinds of wireless technologies that are used for communication based on coverage.

The main problem of LoRa is that it has to act in accordance with the duty cycle, as outlined by the European Telecommunications Standards Institute (ETSI). The duty cycle is the proportion of time during which a device is allowed to transmit signals. This restriction was meant to make sure that users of the LoRa technology do not completely congest the network since LoRa's 868 MHz is an unlicensed frequency. However, this has the unfortunate consequence that retransmissions of lost data are limited. This means that a device only has a limited amount of retransmissions before the data would be too outdated. The duty cycle is 1% for uplink communication and 10% for downlink communication. For example, if the time on air is 1 second, the device has to wait for 99 seconds before it can transmit again.

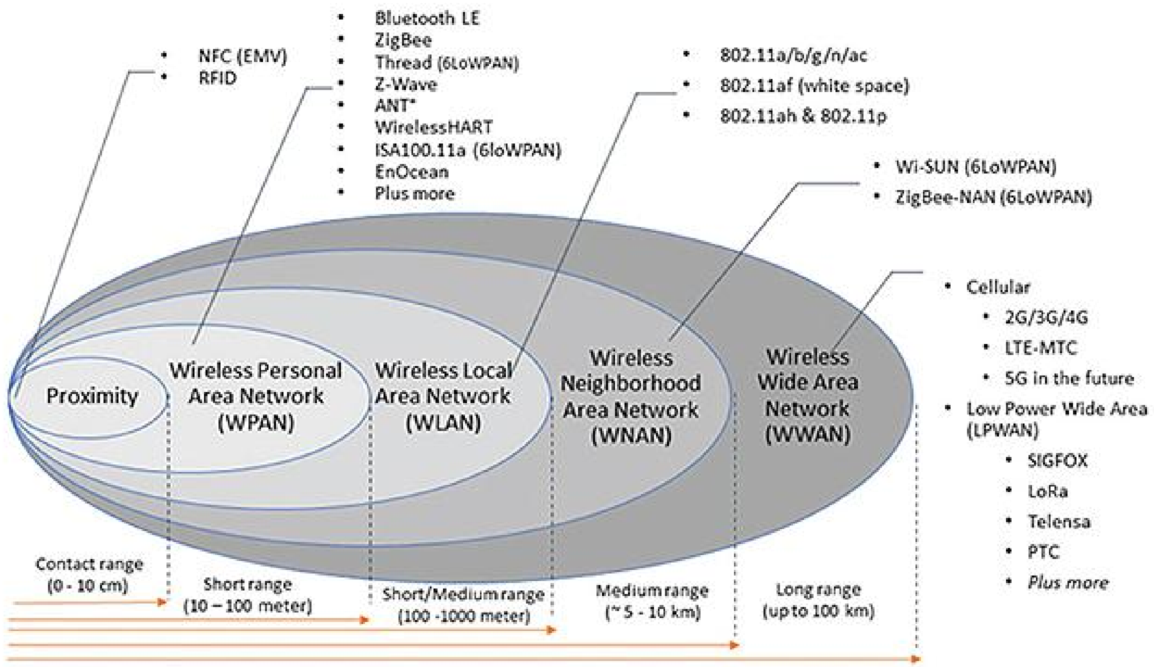

Figure 5.8. Comparison of different wireless communication technologies based on coverage.[20]

Next to the duty cycle limitation is a lack of security features. There is no payload encryption and no secure way to make sure that received data are really from who they say they are. This allows for hackers to impersonate devices and then create damage to the infrastructure by providing false information. To tackle this problem, we used LoRaWAN.

[20] Mahmoud, M. and Mohamad, A. (2016) A Study of Efficient Power Consumption Wireless Communication Techniques/ Modules for Internet of Things (IoT) Applications. Advances in Internet of Things, 6, 19-29.

LoRaWAN is on the MAC layer of the OSI (Open Systems Interconnection) model. It handles the configuration of radio parameters, device activation, message integrity checking, session management, and application payload encryption. When end nodes have transmitted data packets, and if there are multiple gateways in range, both gateways receive the packet, and forward them to the network server to deduplicate (eliminate duplicates) the packets. The packets are protected by using 128-bit AES encryption.

Besides LPWAN technologies that are relatively new, there are LAN (Local Area Network) and Cellular technology solutions that are used for connecting the smart devices or IoT communication. Local Area Network solutions like Bluetooth or WiFi are used for short range communication, which standards are very well established and, as such, widely used for short distance connectivity, data transmission, and control. Cellular Network solutions are used for wireless M2M communications for its existing coverage and high data rates. For its high operational costs and power requirements were not used in major IoT applications, but with the development of LTE-based[21] IoT connectivity solutions and the introduction of 5G, it becomes more suited to a wider variety of IoT applications.

In the demonstration area of Community Grid in Limerick, which is an urban area, it is planned to set-up a LoRaWAN network. Communication between the End Nodes and the base stations goes over a wireless channel utilizing the LoRa physical layer. The connection between the gateways and the central server will be handled over to the backbone IP-based network, as can be seen in Figure 5.9.

End Nodes are LoRa enabled SLUs, and they transmit directly to the gateway. This is because the SLU's position depends on the location of the main power supply box, and it is usually on the ground floor or in the basement of the building. Measuring the signal strength should be done for each SLU location before fixing the SLU, so it reaches the gateway. How much it will reach also depends on the strength of the antenna that is attached to the gateway. Gateways relay messages between SLUs and a central network server using IP.

[21] https://en.wikipedia.org/wiki/LTE_(telecommunication)

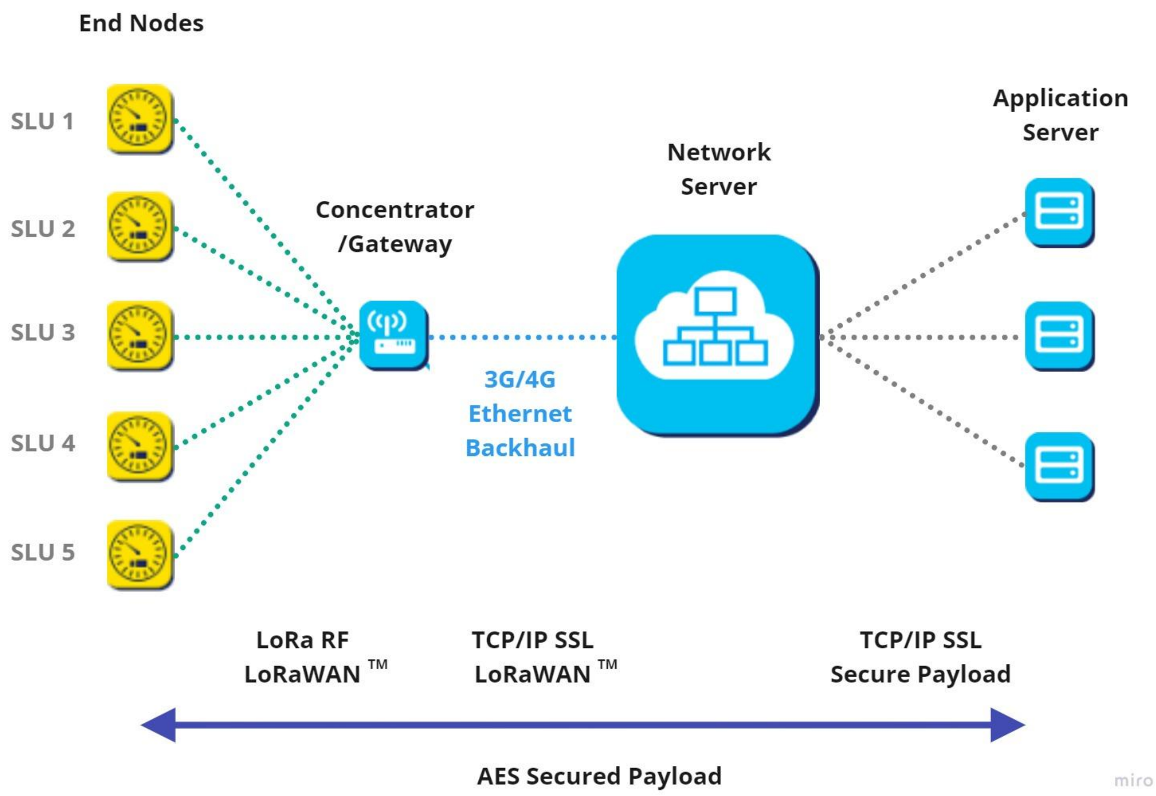

Figure 5.9. LoRaWAN(™) network architecture in the PEB.

5.6 Community Grid Stabiliser

A Community Grid Stabiliser is a collection of specialized equipment designed to provide additional flexibility and grid stability to the Community Grid. This is achieved through batteries located in the stabiliser that can be charged/discharged as needed and with power electronics that provide phase balancing, power filtering, and power dissipation, amongst other functions. Grid Stabiliser is part of the ECO Hub container, which is located and connected to the Local MV Substation (see Figure 5.1). The arrangement of the Grid Stabiliser components is presented in Figure 5.4.

To ensure efficient grid operation, it is essential that under changing-power demands over time and physical locations, grid power is supplied at as near to ideal voltage and frequency as possible. The specifications for supply from the entire distribution system are defined in *Distribution Code,* which is issued by DSO and approved by the CRU. In general steady state voltage deviation of ±10% is allowed in almost all Grid Codes. All grid codes have 50 Hz as nominal frequency and normal operation range around this frequency.

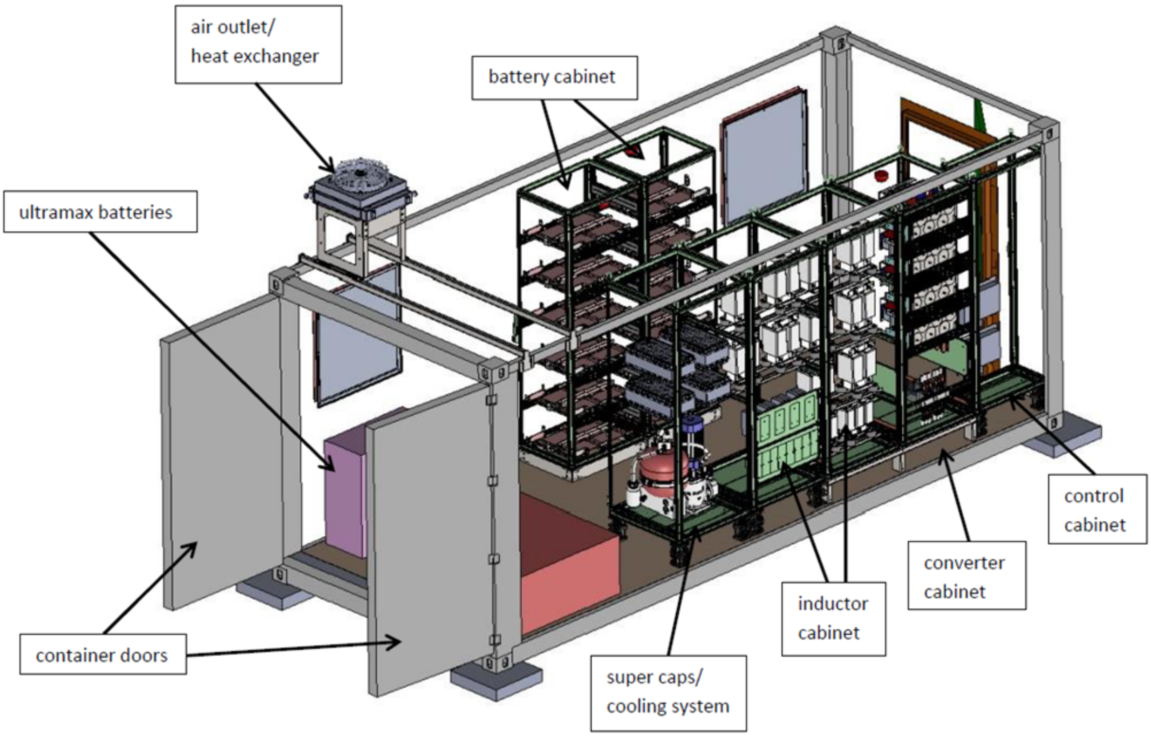

Figure 5.4. Grid Stabiliser components arrangement in the container (ECO Hub).

The Community Grid Stabiliser acts as the Automated Regulator cutting in where *contracted prosumers* within the Community Grid fail to respond or are otherwise unable to respond i.e. *phase balancing* – correcting the imbalances each of the three phases. It is done through *power injection* or *extraction* by the RES powered Battery Banks and arrays of Power Converters.

Power dissipation is of particular interest because when trading in a Community Grid fails to ensure Disturbance Neutrality. The Community Grid Stabiliser will dissipate power as needed. In situations when production is higher than consumption, and no available loads or energy storage to consume or store it, the Stabiliser would automatically dissipate power until it is safe to not do so.

The addition of batteries in the Stabiliser provides additional flexibility to the Community Grid for the purpose of achieving required Disturbance Neutrality. When prosumers are unable to purchase flexibility on the flexibility market, the Stabiliser can help and ensure that any generated electricity is not wasted.

In addition to providing dissipation and more flexibility, the Community Grid Stabiliser also provides other functions that are key to ensuring a stable Community Grid. These include:

- STATCOM capabilities - reactive power control improves voltage stability and consequently ensures more efficient grid operation.[22]
- Fast Frequency Response (FFR) - sudden changes in supply and/or demand can affect the frequency of electricity delivery. FFR allows rapid reactive power injection to ensure a stable frequency.
- Harmonic filtering - harmonics in the local grid can cause damage to equipment. Harmonics filtering keeps harmonic power levels within accepted limits.

STATCOM works as a reactive current source that can be flexibly controlled and automatically compensate reactive power. It uses three phase Voltage Sourced Converter from which the voltage output connects the system and regulates AC voltage amplitude and phase of the inverter to absorb or produce reactive power. A detailed description of the Grid Stabiliser, which was already tested and used in *Tallaght Smart Grid Testbed* project, can be found at FREQCON official site.[23]

The Community Grid Stabiliser, which is integrated into Community Grid infrastructure communicates with the enerXchange™ platform, and informs the system when any actions are taken by the Stabiliser. This is done to monitor the status of the Stabiliser and the grid. Any corrective actions taken by the Stabiliser could be indicative of a larger issue. Thus, there is a Stabiliser PC attached to the Stabiliser in the ECO Hub container, which monitors the Stabiliser and communicates with the enerXchange™.

There are then two possible ways to share information with enerXchange™. The Stabiliser PC could act as a server and host a RESTful API so that enerXchange™ can request information and data when required. This would require a stable internet connection. The other option would be to create a specialized SLU that would use LoRa, like other SLUs, to send information and data to the enerXchange™ server. In the Limerick pilot the first possible solution will be deployed. The LoRa System is only committed to safe measurement and buffered dispatch. It is not designed for FFR but the Community Grid Stabiliser is multimodal (+ 4G) linked to FFR Needs Owner and fronted by UltraCaps. The minimum capacity of a Generator/Battery for FFR & Synchronous Inertial Response is far too high for individual Prosumers.

5.7 Community Grid Control Infrastructure

Community Grid System (CGS) is an active type of local network that makes the integration of RES and energy storage and demand side integration (DSI) easier without disturbance to the main power grid. Power flow assessment, voltage control, and protection require

[22] https://en.wikipedia.org/wiki/Static_synchronous_compensator
[23] https://www.freqcon.com/products/grid-storage/ultracapacitor-grid-stabilizer/

advanced automation equipment where Information Communication Technology (ICT) is playing a key role. The Community Grid System, like a Microgrid, presents the "building block of a smart grid" and, as such is the most promising, novel network structure. The organisation of the Community Grid System is based on control capabilities over the local network operation inside the CEC's energy block. The system architecture of the CGS is presented in Figure 5.1.

The main Community Grid System components include loads, DERs, SLUs, protective devices, as well as communication, control, and automation systems. Loads are of two types: fixed and flexible. Fixed loads cannot be controlled and must be covered under normal operating conditions. Flexible loads, which are also known as adjustable or responsive are controllable. DERs consist of DGs and Energy Storage Systems, which are installed at prosumers' premises and/or as a separate electricity utility facility inside the Community Grid System boundaries. DGs are either dispatchable or non-dispatchable. Dispatchable units can be controlled to the extent specified by their technical constraints like capacity limits. Certain Energy resources which do not have the inbuilt control capability or have a variable output (Solar PV system containing no battery storage) for dispat are classed as Non-dispatchable units.

The main variables used to control the operation of CGS are voltage, frequency and active and reactive power. An important point to take care in CGS operation is synchronization with the grid voltage. It is essential that the grid current reference signal is in phase with the grid voltage. This grid synchronization can be managed using PLL (phased locked loop) techniques[24].

The overall control can be centralised or decentralised. In the case of the Community Grid System. it is centralised where the communication network is set up in a way so that control signals can be transferred to every CGS component.

The +CityxChange Deliverable 2.3 report outlines many types of assets that can be used to provide Energy or flexibility on request. The report categorises these assets under different headings such as stand alone batteries, Energy Production assets, space heating assets, appliances, etc. A number of these assets are being investigated as part of the asset integration feasibility study in the 4.6 Implementation of PEB guide. A key device will be inverters that have the dispatchable capability for absorbing and dispatching active power. The inverters will be connected to a stand alone battery and RES Assets. As part of deliverable 4.6, many other assets are being assessed for suitability inside the Positive Energy District.

[24] https://en.wikipedia.org/wiki/Phase-locked_loop

6 enerXchange^{TM} Trading Platform

A part of the +CityxChange project solution is establishment of a local energy and flexibility market and launch of the trading within the Community Grid. Trading in the Community Grid is an essential part of ensuring Disturbance Neutrality. Before any prosumer can cause a disturbance in the Community Grid with excess energy production, it is traded to other prosumers in the grid.

This chapter focuses on the framework for transactions between prosumers in an Energy Community, how energy and flexibility markets are managed and how these markets can work in the context of local trading within a Community Grid. It is based on the report D2.3 which describes how a local flexibility market (LFM) can be designed. The purpose of LFM is to prevent grid congestion and enable efficient integration of intermittent renewable energy sources on local level. The LFMs are envisioned to be built around the trading platforms. For the case of +CityxChange lighthouse city of Limerick, enerXchange^{TM} trading platform is used and adapted to the situation of DPEBs in Limerick.

The basic function of enerXchange^{TM} that was developed and deployed in Tallaght Smart Energy Living Lab project was to connect and provide information on consumption and production from the consumer premises which were connected by specially designed smart control devices into the local grid. Prosumers were able to interact with the system over the *Prosumer Dashboard* which visualised the current situation in the local grid. There was no energy or flexibility trading in place.

New enerXchange^{TM} was built following this basic functionality for disturbance neutral operation which was extended with advanced energy and flexibility trading mechanism. And it is exactly that mechanism that will enable better control and utilisation of available flexibility assets and renewable energy sources. The proposed solution is similar to the logic of the trading platform in Norway. The trading platform for +CityxChange lighthouse city of Trondheim is explained in the report D2.7.

The enerXchange^{TM} trading platform modelled in the developed overall project ICT architecture as described in D1.2 is presented as shown in Figure 6.1. Thus, Figure 6.1 demonstrates how the enerXchange^{TM} trading platform enables energy and flexibility trading inside the community grid and with a grid stabilizer for optimization and balancing purposes within the +CityxChange project as demonstrated in Limerick.

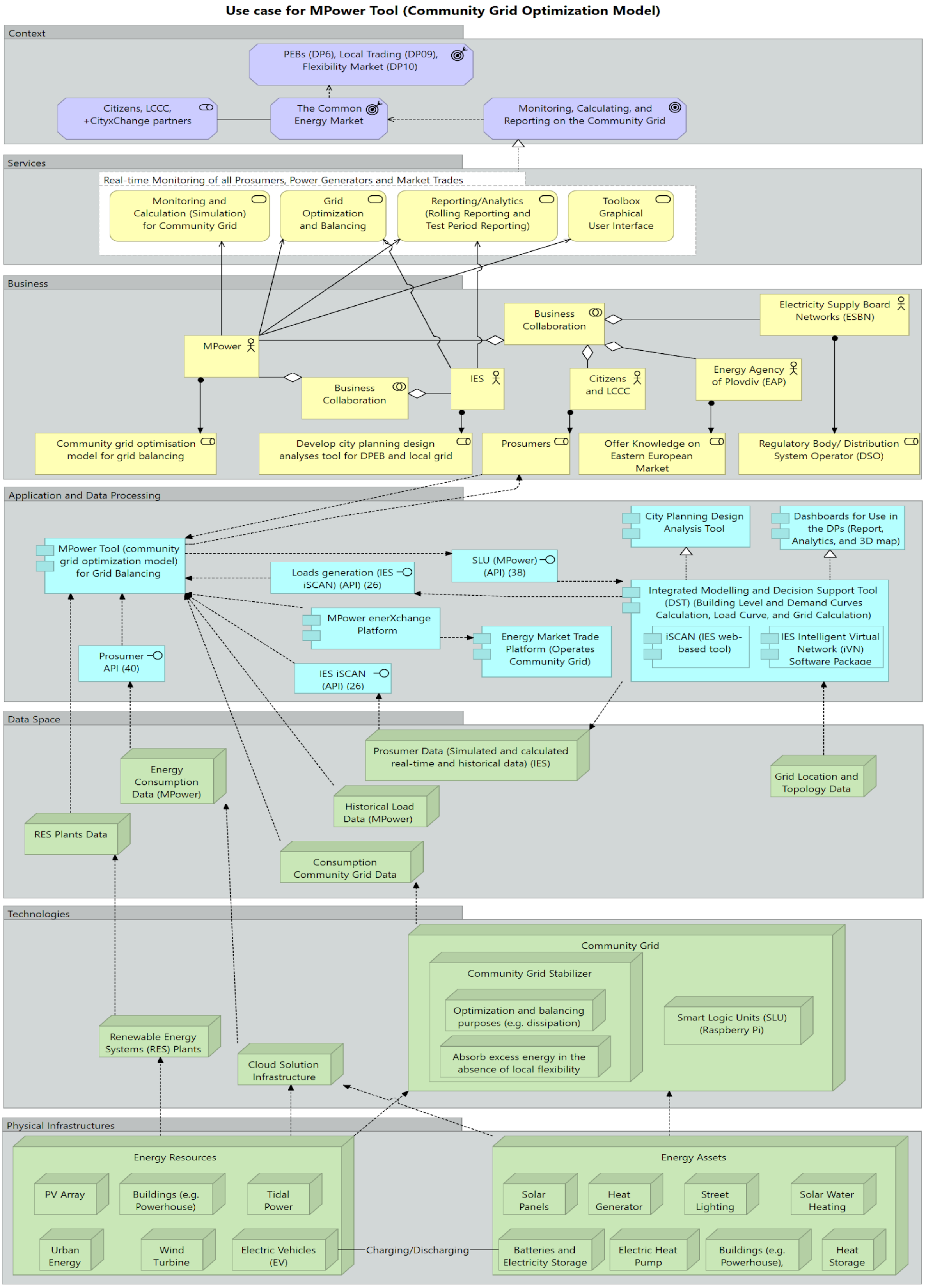

Figure 6.1. Use case for MPOWER enerXchange in the project's ICT enterprise architecture framework. (Source: +CityxChange D1.2).

The enerXchange™ trading platform connects to the energy market trade platform and MPOWER Tool (community grid optimization model) for grid balancing which uses prosumer data, historical data, community grid data, energy consumption data and RES plants data. The MPOWER Tool also uses the SLU API provided by MPOWER to connect to DST provided by IES and receives data from IES via IES iSCAN API. The SLU API and IES iSCAN API are presented in D1.3: Report and catalogue on the ICT data integration and interoperability.

6.1 Local Energy and Flexibility Markets

There are certain aspects of traditional electricity markets that can be incorporated into the design of a local trading system. Results of reports D2.1 and D2.5 show that by using only the main principles of the global electricity market (roles, regulation) it is possible to apply aspects of it in a new approach to establish and operate PEB/PED.

6.1.1 Local Trading

Similar to the Balancing Market[25] , a key function of local trading is to balance supply and demand mismatch locally. The local energy trades within the Community Grids will be coordinated through the trading platform, whereby the sellers and buyers trade requests and bids. In software the flexibility is defined as a configurable agent that creates energy bids.

Configuration includes location, time scheduler and quantity. Once a flexibility agent creates a bid it enters the trade mechanism like any other energy bid. The types of trades that exist in the local community markets can be defined as local energy trades and local flexibility trades.

1. **Energy Trades**

As part of the Community Grid Design, there will be local energy trades whereby the buyer requires local energy in the next time period, and a seller can provide said energy. The next time period will be defined by trade. An important key detail is a duration and acceptable shape of the Energy trade. The local Community will be dispatching the Energy on the local DSO managed network. Therefore, an agreement between DSO-CSO regarding the specification is required. In Ireland and as part of the +CityxChange project, the energy profile of trade will be in kWh energy parcels. The trade instantaneous power (kW) value is limited within agreed percentage limits.

[25] SEMO - Balancing Market, https://www.sem-o.com/markets/balancing-market-overview/ (last visited 23/11/2020)

2. **Flexibility Trades**

The +CityxChange report 2.1 presents three flexibility products (P1, P2, P3), all based on products defined by time periods that have a time resolution range over an hour to less than 15 mins. The Community Grid system on the +CityxChange project will not implement these defined products. For the Community Grid System, Flexibility trades will be similar to energy trades. However, one of the main differences between energy and flexibility trades is that flexibility products promote changing consumer's behaviour in one way or another. This is achieved by offering discounts for reservation of flexible asset control or reduced rates for activation of these flexible assets in a certain time period. Consumers and producers of electricity can trade flexibility by increasing or decreasing the consumption of flexible assets, in cases of high and low production, respectively.

The +CityxChange report 2.6 presents flexibility trading models for a DSO to become a buyer of flexibility through reservation or activation pricing or both. Currently, the electricity grid in Limerick is stable and power quality is not a concern. So, therefore as part of the +CityxChange project, it is not envisioned there will be requests from DSO for flexibility to deal with bottlenecks.

6.1.2 Bidding Mechanism

Consumers with a high minimum baseline consumption can forecast short term demand with a high degree of certainty. It is ideal to have high baseline consumers within a specific trading block in order to get an adequate demand for offers. As part of the trading evaluation process, which analyzes the balance of generation and demand, the baseline of participants is determined. Large office blocks can use the Building Management System to provide information from their HVAC and lighting schedules.

Consumers with a low baseline will have to rely on using a battery state of charge (SOC) for making offers. However, in many European countries, PV systems are now required to have batteries integrated to reduce grid disturbances. The challenge is that many current PV inverters on the grid do not have dispatch capability. In order to dispatch and receive power, an inverter needs to have bi-directional power flow and have programmable control capability. Bi-directional flow is required so power can flow to and from the inverter. Inverter programmable control capability is required for dispatch.

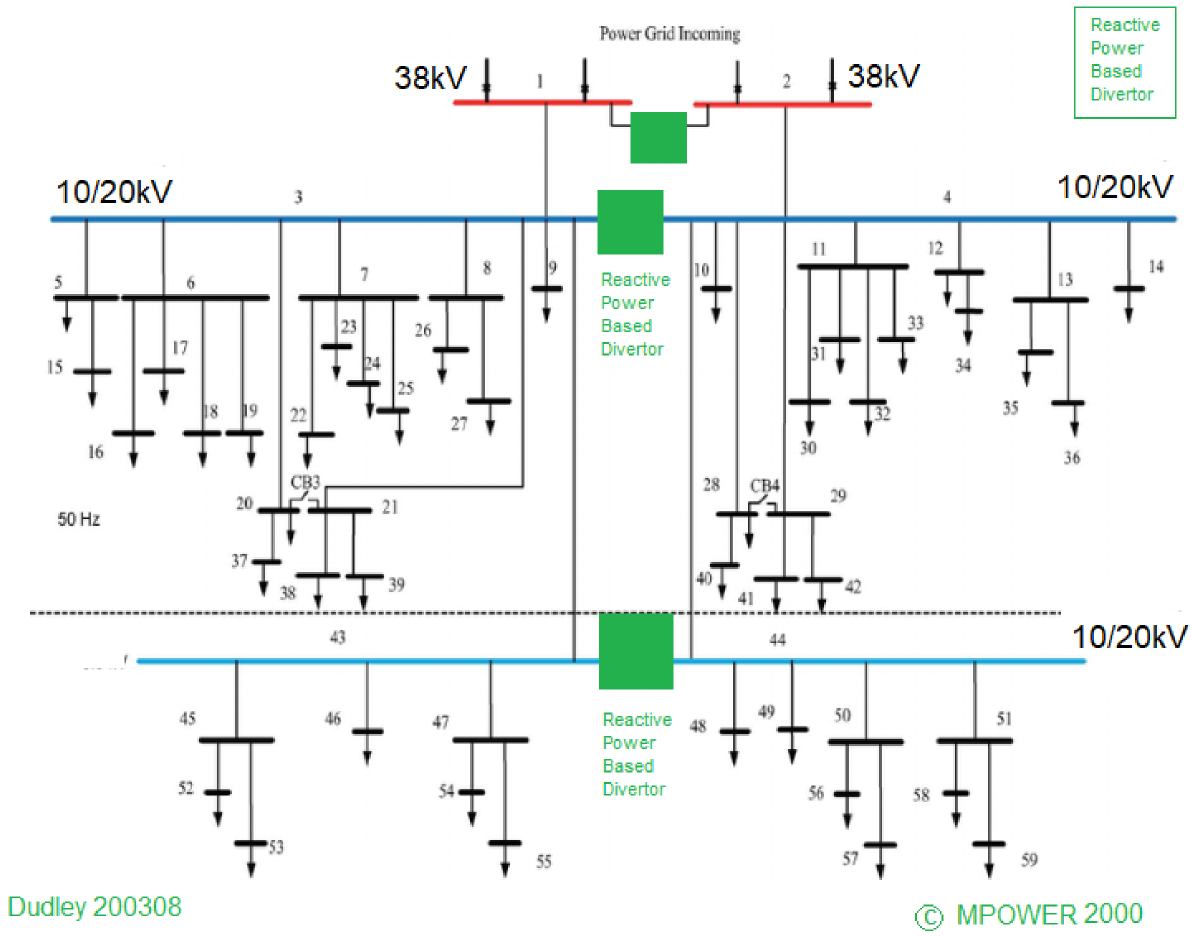

Figure 6.2. Example of power distribution system.

Variable RES sources will be required to use a battery's SOC levels for offers. There is substantial research in the area of using weather to forecast output. However, there is a major challenge to forecast weather with a high degree of certainty in the short term. Solar PV can experience a high degree of variance in a matter of seconds due to passing clouds. Using SOC levels on batteries is a key mechanism in +CityxChange for dispatch and offer process. Using SOC levels for this function was implemented as part of the Community Grid demonstration toolkit as part of the +CityxChange 2.2 task.

Non-variable dispatchable RES Sources have the potential to dispatch without the need for batteries. An example of such an asset is a heat driven Combined Heat and Power with a variable output. However, in practice, many CHPs are generally designed to work with constant output. There is very little research that validates the effectiveness of the current state of the art CHP as a flexible asset.

6.1.3 Energy Balancing and Trading Pre Assessment

Performing analytics is an essential process to determine how an individual building, Energy Community, or a Positive Energy Block (PEB) will perform in terms of local trading over a sample duration. The methodology involves using the building's net positions to determine the local trading performance of buildings and their corresponding PEB. The net position for a prosumer is the difference between its generation and load. High granularity data can be obtained by using metered data or by using modeling software packages. This exercise of evaluating the trading potential and energy balancing was conducted as part of CityxChange Task 2.2. This exercise be also be key for the task 4.6 to develop the DPEB Implementation Guide.

Performing analytics on accurate building models enables the trading system to evaluate key trading information, such as the evaluation of a building's potential for local trading, the identification of ideal PEB's for local trading, and the identification of the appropriate balance of Energy and Flexible Assets. It provides feedback for the Community System designers to optimally design the Community System with an appropriate balance of assets and flexibility mechanisms.

Establishing a baseline of consumer behaviour is critical to understanding how a PEB is performing and how this performance can be improved. As noted in report D2.3 one of the key decision points in the design of the Local Flexibility Markets lie in the price-setting mechanism. There are three main classes that can be implemented in different combinations: Unpriced contracts, Reservation pricing, Activation pricing [26]

For the *Unpriced contracts*, flexibility providers are setting certain limits for their flexible assets, and then offering the asset as available in the flexibility market. There is no upfront payment, and the flexibility providers will know over time how much their flexibility is worth.

For the *Reservation pricing*, flexibility providers are setting limits for flexible assets based on agreed prices. These are agreed with the CSO, and can be set using auctions. Providers are paid simply for having their flexible assets available at certain times. A reduction in the providers electricity bill in exchange for some control of the flexible asset is an example of such a scheme.

For the *Activation pricing*, flexibility providers are setting detailed prices for how and when their flexible assets can be regulated. The provider could be offered a price per kWh of reduction of their net position (turning off flexible assets), or a price per kWh of increased net position (turning on flexible assets). Activation pricing is more complicated than

[26] D2.3 Section 4.2.2.2. Pricing alternatives for flexibility

Unpriced contracts and Reservation pricing with some unintended incentives for exploitation. All is explained in detail in report D2.3 (Section 4.3).

6.2 Energy Trading Mechanism

6.2.1 The Double Auction

The double auction mechanism is a mechanism whereby multiple sellers submit the amount of energy for sale and the asking price for said energy. Buyers provide how much they are willing to pay for energy.

Both the buyers and sellers trade requests are sent to a market institution/auctioneer. This is where a *p* value (price) is chosen that would influence commerce and settle the market. A transaction will be allowed to take place when the seller's price is below or equal to *p*, and the buyer's price is higher or equal to *p*.

6.2.2 enerXchange™ Double Auction adaptation

Since the bids are created and checked according to the real needs and physical state of SLUs, those bids are also good for keeping the disturbance risk low. Since SLUs are 'honest' the auction is safe from speculations. Vickery-Clarke Groves is not applicable to the scenario where there are many buyers and many sellers. Non-auction mechanism is too rigid and is not using smart capabilities of end units to generate best bids. The adjustments to the auction mechanism are all due to the specifics of trading energy.

The main difference between an energy trade, as compared to trade of other merchandise, occurs after the trade is completed. Energy must be transferred from one place to another, without causing disturbances. This issue is relevant no matter what trade mechanism is being implemented.

In the enerXchange™ adapted Double-Auction mechanism is used. The bids and offers enter the trade matching mechanism from the following SLU's, Prosumers and Flexibility Agents where for:

1. **SLUs**

The minimal unit of energy that can be transferred is indicated by *q*, which is eventually translated into real world kWh units. The SLUs are arranged in an array M. For every SLU the following information is stored:

- ➔ where the money for energy will be settled: financial account - f(k)
- ➔ upload speed for k^{th} SLU - u(k)
- ➔ last energy transfer request (bid) sent from SLU

Each bid contains :

- ➔ SLU number k
- ➔ bid quantity b(k) as positive or negative integer multiple of *q*
- ➔ price p(k) per energy unit; price is set as negative for buy requests and positive for sell requests
- ➔ preferred rate of energy release r(k) as time to release one *q* (translates to real world power [kW])

The algorithm keeps the array M sorted by price, in ascending order. The buyers' prices (which are negative) are listed first, and then the sellers' prices (which is positive). Each time a new bid is received from the network, the SLU record is moved and there is a new permutation of *M = m1, m2, m3, ... mN*. To perform the trade we start from both ends of the array M and match bids as long as the prices match.

```
// Start from both ends of array and go toward the middle
head = 1
tail = N

// As long as there are buyers and sellers we can continue - p = price array
// example of price array here
while p(head) <= p(tail) AND p(head) < 0 AND p(tail) > 0
  if exists sell with financial account f(head) trade head with it)       //(1)
  if exists sell with financial account f(tail) trade tail with it)       //(2)
       set transfer quantity T(e) = min ( q(head, q(tail) )
       increase bid of SLU(head) for quantity T(e)     // the buy request gets smaller
       decrease bid of SLU(tail) for quantity T(e)     // the sell request gets smaller

  // the buy has zero units, go to the next one
  if bid quantity (head) = 0 set head = head + 1
  // the sell has zero units, go to the next one
  if bid quantity (tail) = 0 set tail = tail - 1
       set transfer rate  smaller then  T(r) = max ( r(head, r(tail) )       //(3)
       set transfer start time T(s)                                          //(4)
       send transfer T to both SLU units
done loop
```

The pseudo code above is a double auction algorithm with energy trade specifics indicated in line (1) - (4).

In lines (1) and (2) we treat the case when there is a possible trade between two SLUs that use the same financial account. This is prioritized because such trade can be created with zero price and no financial transaction will be created. The prosumer essentially moves its energy from one place to another. An example of this would be a company that has two separate sites, each with its own SLU. The company could trade energy with itself between sites at no financial cost.

In line (3) we have to set the rate of transfer. If the network currently has the capacity to do so, the rate can be set to the maximum (i.e. shortest time to discharge one *q*) of both SLUs. Otherwise, the algorithm may decide to set an even slower discharge depending on the number of currently running trades and communication speed. Similar considerations are done in line (4), where the start time that will be sent to SLUs may be delayed.

Another characteristic that is unique to the algorithm, is that there are bids that are not due to financial trade, but rather a consequence of SLU demanding a release or consumption of energy. These bids are not motivated by financial interest, but rather by minimizing disturbances. Such bids do not have a price set, so we set the price of such sells to zero (give away free energy) and such buys at infinitely expensive (get some energy at any cost). In practice, 'infinite price' is set to the maximum contracted price.

The algorithm tries to efficiently release or consume energy requests created by software units that operate on premises, near the prosumer devices and hardware. It also includes requests created by units such as Community Grid Stabilisers. The point is that these requests are created automatically and have a priority over human-generated requests.

2. Prosumers

Prosumers are physical traders in the market that make requests through a user interface. They include price and start time for bidding. These are one-off requests. The user interface could be a mobile or web based application.

3. Flexibility agents

Prosumers will have an option to create one or more 'flexibility agents'. These agents are software commands that automatically generate bids at certain times and with certain pricing on behalf of the prosumer.

Usually double-auction algorithms would be linearly dependent on the number of SLUs. When it finishes all trade it starts all over again. However, in order to run the collection point the above double auction algorithm is just one program thread. What also needs to run simultaneously is the read and write communication service for the whole SLU network.

There is also a notion of delegating trade from some collection point. It means that a collection point C can actually behave as an SLU within a wider network of some collection point W. The collection point W essentially has C as one of its SLUs. Both C and W run the same type of software. That way the Community Grid can have a whole hierarchy, a tree of collection points.

This is possible if collection point C actually has an SLU mechanism to release/consume energy from network W. Then if C anticipates a need to release/consume energy based on the state of its SLUs it can do so by trying to bid within network W. This method further reduces the disturbance risk. If a bid for some quantity z from C is accepted and the transfer completed, the whole network of C now has a better stabiliser value.

In conclusion:

1. The double auction algorithm for energy trade within a network of smart energy units has to create the transfer parameters such that the disturbance risk is minimized. Parameters of transfer include quantity rate and start time. The algorithm dynamically calculates those based on the current number of running transfers, network and computer speed, and Community Grid Stabiliser state.

2. The program for energy trade must immediately react to any interrupted transfer by informing the other side of the transfer. interrupted transfer by informing the other side of the transfer. Such messages have absolute priority. . Trade keeps track of network latency since any latency issues must be treated as a calculated risk in advance and considered as part of the algorithm.

3. All collection points run the same type of algorithm over their own SLU networks. If possible, one collection point shall delegate collection points as SLUs within wider collection points so that the disturbance risk is spread more thinly.

6.3 enerXchange™ IOTA Integration

This section details how the enerXchange™ will integrate IOTA and related technologies to create a functional trading platform.

6.3.1 IOTA and the Tangle

IOTA was created in 2015, and is a 3rd generation public permission-less distributed ledger technology. IOTA is open source and with no transaction fees, while at the same time providing a scalable solution for data and value transfer. Some notable features of IOTA include de-centralised networks, secure encrypted data, future-proof against the next generation of computing power and being free to use.

> "IOTA is a distributed ledger technology (DLT) that allows devices in an IOTA network to transact in micropayments and to send each other immutable data". [27]

[27] IOTA Documentation. https://docs.iota.works/

IOTA is valuable as a transaction ledger and 'proofed' storage provider for any system that stores critical records that may be disputed. Two important point to note about IOTA:

- IOTA ledger can be used for micropayment - value transactions
- IOTA ledger can be used to store immutable data without need to own or use cryptocurrencies - data transactions.

IOTA operates using Direct Acyclic Graph (DAG) instead of the more commonly known blockchain. In a blockchain network, transactions are stored in "blocks", and the blocks are sequentially connected (or "chained"). The DAG used by IOTA is called the "Tangle". The Tangle stores data in objects called transactions. Transactions store transactional information, e.g. person A gives ten IOTAs to person B. These transactions are immutable. Transactions can only be created by "Nodes", which are interconnected devices keeping up to date records. "Clients" are the users of the IOTA network. They send transactions to the Nodes to be added to the Tangle. IOTA services which are web services on IOTA tangle can be consumed by clients to store, retrieve data etc. according to IOTA API.

Creating transactions is a 3 step process:

1. Signing: the client device creates a transaction and signs it with a private key
2. Proof of work: the client device compute proof of work by solving a cryptographic puzzle for the given transaction in order to comply to spam prevention mechanisms
3. Tip selection: the client device sends the transaction to a node; the node chooses 2 tips (unapproved transactions) to approve using the Random Walk Monte Carlo algorithm.

Once a Node has received a valid transaction, the Node will replicate the transaction across all other Nodes, updating the Tangle and maintaining it as a source of truth. When a new transaction is added to the Tangle, it chooses two tips which the new transaction then approves. How the new transaction chooses which tips to approve is a vital part of what makes IOTA unique. Figure 6.1 shows a basic Tangle. The new transaction, block 6, approves tips 4 and 5.

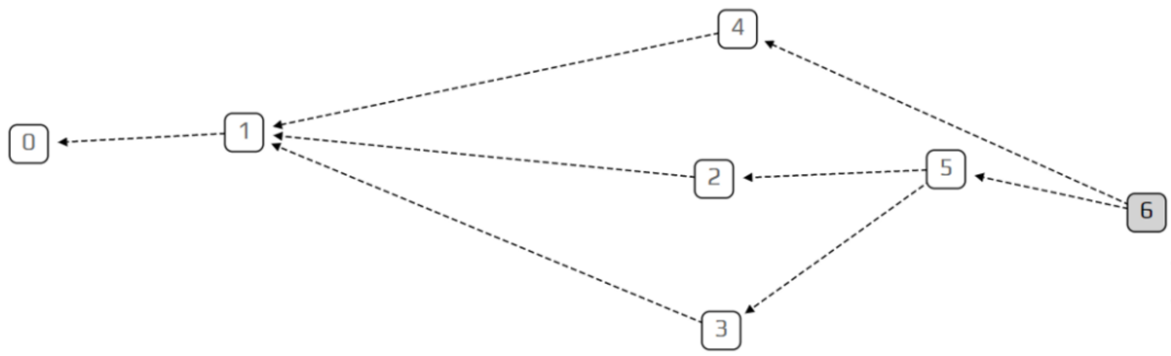

Figure 6.3. Basic Tangle Example[28]

Scalability of the IOTA network is a key advantage over traditional blockchain technologies. If more transactions are created, the confirmation rates for new transactions go up. IOTA transactions carry no transaction fees, which make it ideal for micropayments. This is an advantage over blockchain technologies that do have such a fee.

6.3.2 Blockchain and Energy Trading

Blockchain is a distributed decentralised, public ledger. This means that data is not placed in a central location like a database, but rather everyone participating will have a copy of the data. Ever since the creation of the first blockchain, the technology has advanced over several generations from Blockchain 1.0 to Blockchain 4.0.[29]

6.3.3 Integration of IOTA in enerXchange™

When designing the system it is important to define what are the functionalities requested to a client in the trading platform. A client needs a seed to perform value transactions; seed proves authenticity of spend token and ownership of the involved wallet. IOTA Network of nodes maintaining the ledger is accessed by clients sending value and data transactions to the ledger.

Usually, the node is a device (wallet) and the seed is stored on the client's local storage. Within the Community Grid system that will be SLU devices. In case SLU performs payment they will need to manage a wallet, own seed and use them. In such a case they might need proxies to perform such operations, if the above capabilities are not available in the

[28] The Tangle: an Illustrated Introduction https://blog.iota.org/the-tangle-an-illustrated-introduction-4d5eae6fe8d4 accessed: 01/06/20
[29] Blockchain evolution: from 1.0 to 4.0 https://medium.com/@UnibrightIO/blockchain-evolution-from-1-0-to-4-0-3fbdbccfc666 accessed: 13/10/20

embedded SLU. However this won't be needed in case SLU connect to the IOTA to only perform data transactions.

6.3.3.1 Integration Details

There are some important points to be made about SLUs, IOTA and their integration into the enerXchange^{TM}. These are key distinctions from other similar systems.

1. SLU cannot be assumed to have good access to the Internet.

The application shall use the lowest amount of data in exchange it can – the radio spectrum on the frequency is subject to duty cycles. So, the 'seeding' and signing cannot be done on an SLU since the SLU cannot use IOTA API. The IOTA nodes will be kept at the server. The server will perform all IOTA client calls 'in the name of the node.'

However, the record that is sent as 'immutable' to IOTA will always be signed with an SLU private key that is only know to the SLU and ensure authenticity of the message

2. SLU will not implement direct P2P payment

Facilitating local disturbance energy trade, and related grid balancing are the responsibilities of the CSO. Thus, the CSO is involved in every trade acting as an intermediary agent. None of the micropayments involved in an energy trade is a direct debit, meaning payment is not done with IOTA. IOTA is used as the transaction ledger.

Direct real P2P energy trading between prosumers will be kept as an option to be implemented in the future once there is:

- Legal basis to execute and settle direct P2P payments
- Clear responsibility for collection of debt and enforcement of digital contracts
- Clarity on who bears responsibility for processing costs.

3. For grid stability, absolute priority is to execute trade - even when the transaction can't be temporarily recorded

When working with financial transactions, the priority is to record it and then to execute said transaction. There would be no sense (it would in fact be illegal) to post transaction amounts if the processor cannot keep an auditable and immutable transaction record. This is not the case for energy trades. If there is an energy trade from prosumer A to B, the reason that this trade is created (by double auction algorithms), is the actual energy imbalance - which is not good for either party or for the health of the grid unless the prosumers offer flexibility by reducing current power consumption. Correcting this imbalance has an absolute priority. The system will do the following:

1. Make a trade record
2. Transfer energy by informing SLUs A and B involved
3. Trade record is stored in the IOTA transaction ledger and a payment is triggered from prosumer A to prosumer B.

If step 3 fails, the reporting system will register a problem, and the background survival programs will try to perform step 3 asynchronously. But energy will still be transferred.

4. There are other entities that may perform a transaction

It is not just SLUs – there are other entities that will act as IOTA clients. There are also other actions, beside payments, that shall be recorded in the transaction ledger. These are explored further in the next section.

6.3.3.2 MPOWER – IOTA Calls

MPOWER will generate a request for a new client before a new client is generated in enerXchange™ database. Thus, we define what the client can be within enerXchange™ system. Table 6.1 defines terms that are used when discussing ledger transactions.

Table 6.1 - Transaction Properties and their Definitions.

Term	Term Definition
Installation instance	One installation instance corresponds to one 'computer' that is part of the physical SLU installation on premises. One such computer may create several 'virtual SLU' units. 'Virtual SLU' is simply a client application endpoint that can create bids and that has a unique identity on Trading server. Each one of virtual SLUs is trading a particular kind of merchandise: ❏ Energy trade ❏ Flexibility trade ❏ System services Each of these 3 virtual SLUs will be a separate IOTA client with is own seed.
Grid device	Specific devices such as a Community Grid Stabiliser.

Customer – enabled software agents	Using a web application or mobile application, a customer may define the conditions under which they want to trade. This defines a software agent that will periodically make trades and thus IOTA transactions.
Other legal entities such as external grids or other CSO/DSO operators	These entities can potentially trade, so they will be seeded as an IOTA node.

The following actions, shown in Table 6.2, will be recorded in a transaction ledger.

Table 6.2 - Actions Recorded in a Transaction Ledger

Term	Term Definition
Configuration changes (administrator)	Triggered when: ❏ System wide changes ❏ Definition of human users ❏ Definition of grid, CSO, external servers
Prosumer contract entries (human operator)	Triggered when: ❏ New prosumer contract added, changed, or deleted
Installation instance (human operator)	Triggered when: ❏ New installation request generated
SLU initialization (installation instance)	Triggered when: ❏ SLU has exchanged first message with its server ❏ This means SLU may start communicating with its server
Trade	Involves all types of nodes such as installation instance, customer, software agent, CSO or other legal entity. It will always have the 'ID value' from two nodes. Payload contains no personal data, just non-descriptive identifiers and numbers. Includes GUID of 2 SLUs involved, details of energy transfer status, the agreed trade price etc.
Micropayment	Involves CSO and a contracted prosumer. Payload contains amount, time, and account GUID identifiers of the transaction posted from CSO account to prosumer's

	account. Payload is anonymous and is recorded in IOTA for immutability proof.
Failed financial authorizations	Denied for non-technical reasons - involves CSO and a contracted prosumer. Happens when there are no available funds or for other financial reasons.
Bill	Involves CSO and a contracted prosumer triggered when CSO generates a monthly bill.

All actions shown in Table 6.2 will have a JSON payload.

Only trades and micropayments would (occasionally) be done asynchronously. All other requests would first be recorded in IOTA and only after that has been confirmed and validated, does the request get recorded in enerXchange™.

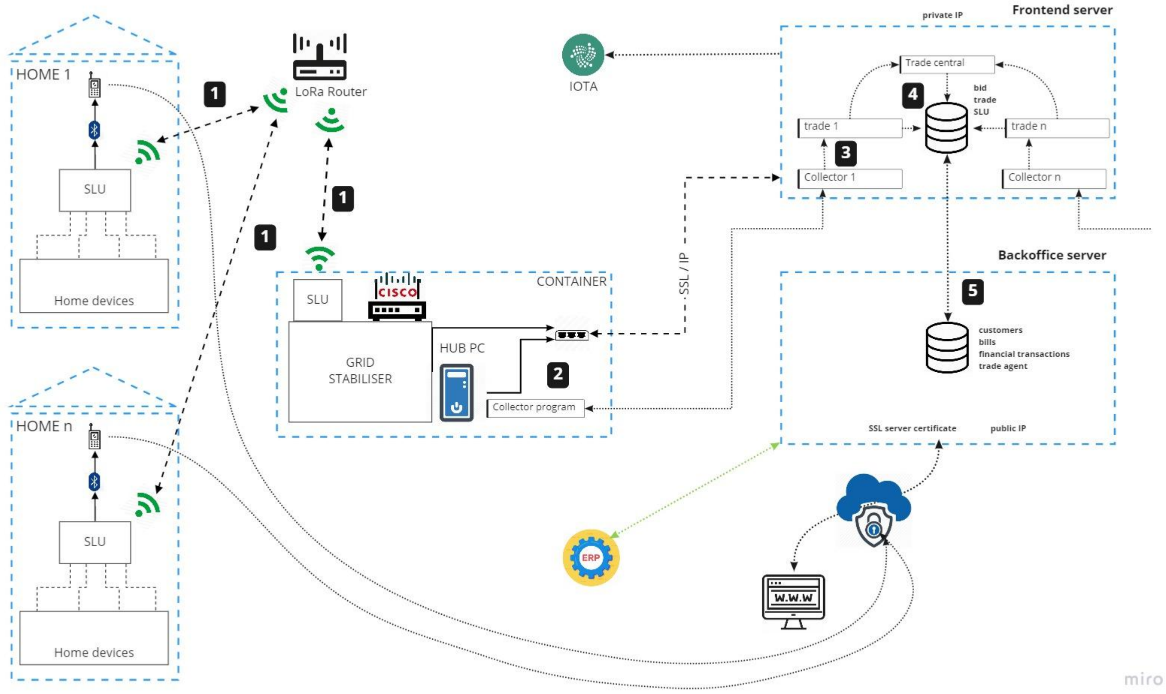

Figure 6.4. Community Grid communication operation structure.

Figure 6.4 represents the basic operation and flow of information through the Community Grid. Below is a step-by-step explanation of the process. Table 4.3 defines the data entities in the data model for IOTA interface:

1. SLUs send sensor and meter readings. This can be either energy/flexibility available or energy/flexibility required.

2. The Collector is a local process that aggregates such data from a cluster of SLUs (this can be a neighborhood, a district, etc.). There could be many Collectors receiving and aggregating this data from different SLUs (and corresponding homes).
3. Collector matches demand and offer (using existing information from SLUs, available energy, and trade details). It creates one trade record for one match between offer and demand.
4. The Collector first releases the information about created trades to the SLUs, and waits until energy is really transferred. Only after the physical transfer is confirmed by readings will it send trade data to the back office. If anything goes wrong with the energy transfer, the trade is cancelled, and urgent action is taken to stabilize the disturbance that may occur. However, once the trade reaches the back-office it must be sent to the transaction ledger.
5. Payment is triggered by the back office and either sent back to the local home device or to a web account. When payment is triggered, it will collect multiple trades into one financial transaction. The relationship of trade:the transaction is N:1. It is desirable to also record financial transactions in the transaction ledger.

Table 6.3 - Data Entities in the Data Model for IOTA Interface.

Data Entity	Data Entity Description
SLU	Any unit with software that can read/release/collect energy from the grid.
Reading	Foreign key to SLU arrives every few seconds.
Bids	Release or collect energy - the foreign key to SLU.
Trade	This means a trade of energy - a match between two bids that creates energy transfer, one SLU releases, one collects energy from the grid - entity has two foreign keys of SLU entities that participate in trade. Also, has a foreign key to the transaction, but that key is generated later when bills get generated.
Transfer	This is an entity linked to exactly one trade that controls the actual energy transfer until it is completed. It includes : ❏ start time ❏ rate of transfer ❏ end time first SLU ❏ end time 2nd SLU ❏ interrupt data if any error occurs

Transaction	A Financial transaction implicitly includes a collection of all trades that were collected.

Trades and transactions should be stored as data value objects in ledger. Figure 6.5 presents a sample of energy trade record and transaction record that will be a payload for trade.

```
// trade
{
    "trade_id" : "sdf3adbd6bm7mgm4gnsvas",
    "epochtime" : 1583334304
    "slu_from" : 65665,
    "slu_to" : 87544,
    "quantity" : 45.1
    "unit" : "kWh"
    "amount" : 0.44,
    "currency" : "EUR"
    "flexibility_id" : "7jdghghghsfadd"
    "transfer" : { "json data": 1 .... }
}
```

```
// transaction
{
    "transaction_id" : "sdfad6676767gnsvas",
    "epochtime" : 1583334304,
    "account_id" : 77665,
    "amount" : 455.441,
    "currency" : "EUR"
    "due_date" : 1583334304,
}
```

Figure 6.5. Sample of energy trade record and transaction record.

It makes sense to send energy transfer data along with a trade - especially if energy transfer failed - this may cause a small penalty fee. Exact data structure for transfer depends on the exact equipment and the interrupt protocol that will be used. It will, however, be JSON data.

When a payment for a given trade is done, there are two options:

1. Payment done by the backend account in any normal currency is logged to the Tangle (just for auditing purpose, so an interface between backoffice and the Tangle is required).

2. Payment triggered directly in IOTA by the SLUs. If the SLU does not have direct internet connection this will have to be done by other means, such as the local

devices connected to the SLU via bluetooth. Real P2P (that does not involve any mediator) is not likely in a production environment, at least not at the beginning. However, this can be simulated in order to prove the concept of real P2P payment and trade.

6.3.3.3 IOTA Verification Service

The IOTA Verification Service has been implemented in order to guarantee integrity of the information shared within the enerXchange™ platform and listed in Table 6.2.

A number of IOTA technologies have been integrated for developing the Verification Service. Since the same entity can generate different versions of the same data, information is organized in the IOTA Tangle using IOTA Streams. Using Streams, transactions generated by the same entity can be all linked together. This allows the IOTA Tangle to act as a time series database, where each transaction in a stream can represent a different version of the same information.

Creation and management of the IOTA Streams is provided by the Verification Service. The Verification Service allows to accept and store data payloads in JSON format; for a given data payload associated to the same entity a message in a dedicated Stream is created. In figure 6.6 it is presented example of the structure of a given message stream.

```
{
   "uuid":"string",
   "versionid":"number",
   "partnerid":"string",
   "type":"TRADE_MP|METER_MP|FINANCIAL|PROS|INSTALL|CONFIG",
   "timestamp":"TIMESTAMP",
   "hash":"hash of the payload, no timestamp included",
   "payload":"json formatted string - optional"
   "signature":"string - optional"
}
```

Figure 6.6 Example of the structure of a given message stream.

The following information are recorded:

- UUID: is a unique identifier for the message (this can be a tradeID, a sensorID or other)
- Versionid: is an incremental number. In case of information with no version, this is 0
- Partnerid: identifier for partner
- Type: this is used to identify the external system calling the service. So far we have identified the following types (TRADE_MP, METER_MP, FINANCIAL, PROS, INSTALL,

CONFIG). The CONFIG can be removed since new configuration of the same installed device can be represented as new versions of the same installation

- Payload is the exact message that needs to be recorded in the IOTA Tangle; it can optionally be encrypted
- Hash is the hash of the message above
- Signature is optionally used to guaranteed the message source authenticity and it is generated using the service private key[30]

The service exposes a Write and Read APIs to external services. The Write API is used to store information provided by an external service on the IOTA Tangle ledger and guarantee its immutability. After writing the information on the IOTA Tangle a unique transaction ID generated and returned to the calling service. The transaction ID is indexed locally by the requesting service. Once any service needs to verify the immutability of a given information stored locally, the Read API is called using the provided transaction ID. The IOTA Verification Service accesses the IOTA Tangle and returns the content of the selected transaction. The calling service compares the received (timestamped) information to the one locally stored and checks its integrity if no changes have been identified.

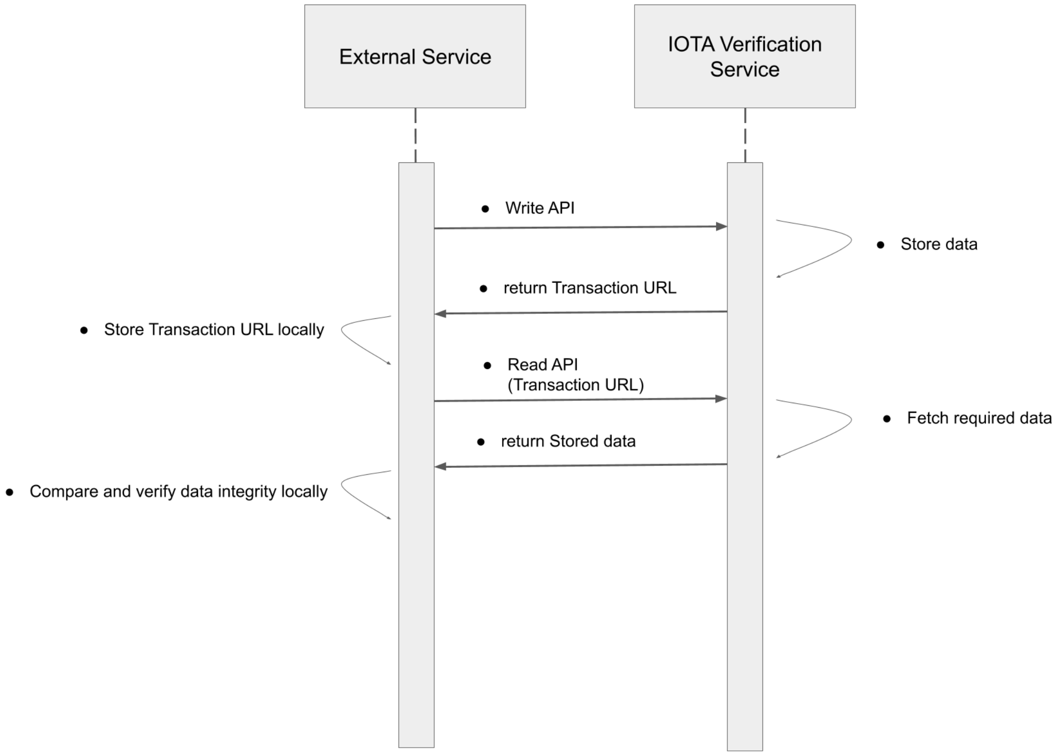

Figure 6.7 Trading service steps.

[30] In case of this functionality being requested, a decentralized identity system for SLU and based on IOTA identities will be provided.

The sequence diagram on Fig. 6.7 shows the different steps a service uses to interact with the IOTA Verification Service.

7 Conclusion

This report presents deliverable D2.6 of the +CityxChange project Task 2.3 and describes a framework for Community Grid System implementation. Community Grid concept is an essential part of the +CityxChange initiative for the establishment of Positive Energy Blocks/Districts.

The Community Grid framework is broken into four separate pillars: 1. Energy Community Establishment; 2. Community Legal, Grid and Financial Governance Body for Energy Communities: 3. Community Grid Smart System Design and 4. The Community Market Places. The following are key details that are central to Community Grid Design.

The Energy Community establishment encompasses new Energy Community opportunities arising from the Clean Energy Package. The framework focuses specifically on Citizen Energy Communities, the Electricity Directive guarantees that the Citizen Energy Community can participate across the electricity market without discrimination and on a level playing field with other market operators. In Limerick City, it is envisaged that a CEC will be developed.

The Community Grid System (CGS) brings together energy system integration and community participation. The process of engaging electricity consumers is closely linked to the development of electricity networks. Empowering consumers to manage their electricity consumption, while enabling them to actively contribute to the operation of the distribution network requires exploiting the advanced capabilities of smart grid technologies. To achieve an ultimate dialogue with the supplier, the highest level of real time feedback is needed, including energy management system, energy generation, and storage systems. To promote and encourage consumers to take an active role as an electricity prosumer sense of ownership must be given. The prosumer engagement process works on that part and should be implemented by utilising with other citizens engagement activities.

One key component in the Community Grid framework is the creation of a new governing support body, a Community System Operator (CSO). It is envisaged that the CSO will be a legal entity that oversees the management and safe operation of the CEC. The report concludes that a CEC, a nonprofit organisation, would incur excessive costs (overheads) in achieving Grid level governance systems. There needs to be a separate commercial body to provide a framework for CEC's that functions to provide participants local trading leeway, good safety, and Disturbance Neutral Grid Connections. This commercial body is Community System Operator (CSO) .

Directive 2019/944 details how Energy Communities have the right to act as DSO. This requires member states to enforce a subset of standard DSO obligations, particularly under the Closed Distribution Network concept in the Directive. As part of +CityxChange, it is not envisaged that an Energy Community will act as a DSO. Since, the Community Grid Framework will be developed on the DSO operated grid. The CSO-DSO enduring engagement structure is a key part of the Community Grid Design.

Another key concept in the Community Grid Design is Disturbance Neutrality.Disturbance Neutrality is defined in this work as a condition where the net electrical power, that is the power generated minus the power consumed, of all customers within the community grid is zero or less. This has been put forward as the optimum system standards of operation that should, for all proposed Community Grids, ease grid DSO tension and concerns about new RES Connections. However, the CGS disturbance Neutrality net position can be adjusted based on the DSO requirement. The DSO has a responsibility to its consumers to ensure grid stability, hence the desirability of Disturbance Neutrality in Community Grids. This neutrality is achieved through Energy and Flexibility trading, and Community Grid Stabiliser responses.

Trading in the Community Grid is an essential part of ensuring Disturbance Neutrality. Before any prosumer can cause a disturbance in the Community Grid with excess energy production, it is traded to other prosumers in the grid. The trading of energy, flexibility, and system services between all players in the Community Grid is facilitated by the IT trading platform, whereby the sellers and buyers trade requests and bids. Similar to the balancing market, local trading is completed in shorter time periods.

The trading platform will use IOTA as a trusted transaction ledger. Thus, critical actions such as energy or money transfer that are performed will be recorded in a ledger. For these records the proof of immutability is a critical feature. IOTA ensures an immutable track record and thus provides additional security to all users of the trading platform.

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9 Appendix

Powerline Communication for Smart Grids

Generally, wired communication is faster, more stable, secure, and has lower latency than wireless communication. For wireless, it provides convenience, and it may be just sufficient enough to get the job done. MPOWER is currently focused on using wireless technologies like LoRa and potentially Wi-Fi as the communication network between the Prosumers' smart meter and the stabiliser. Instead of wireless communication, this section looks at the possible use of a wired communication using powerline communication (PLC) and which devices are suggested to be used for testing. Powerline uses the existing electrical infrastructure to empower communication. The significance of this is that the typical Prosumers on low voltage networks already have a physical medium to communicate. Another positive is that PLC can be a private connection that does not need a third party like an ISP to facilitate the network. Powerline communications for Smart Grids can be grouped into two types, narrowband PLC (NB-PLC) and broadband PLC (BB-PLC).

NB-PLC

NB-PLC operates from 3 kHz to 500kHz. They are subdivided into low data rate (LDR) and high data rate (HDR). LDR has throughputs of a few kbit/s and is only operating on one carrier. This is usually used for industrial and building automation. HDR operates up to 1Mbit/s and uses the Orthogonal frequency division multiplexing (OFDM) modulation scheme. OFDM is a technique that allows large data to be transmitted over a medium by splitting the signal into smaller sub-signals that will be transmitted concurrently at different frequencies. All devices using NB-PLC are interoperable with each other and can be used over other media such as twisted pairs and, in some cases, wirelessly. There are two examples of HDR NB-PLC systems, PRIME and G3-PLC.

BB-PLC

BB-PLC operates from 1 MHz to 300 MHz and has data rates around 200 Mbit/s. BB-PLC has shorter ranges than NB-PLC and, therefore, may require repeaters to reach distance nodes. BB-PLC is more vulnerable to interference from devices using the same frequency, cross chatter, and some devices can introduce noise or attenuation into the signal. Devices like relays, transistors, and rectifiers create noise, which increases signal degradation. Due to their higher cost from their higher speed and the potential need for repeaters, BB-PLC is mainly utilised on medium voltage networks and high voltage networks. This means that BB-PLC will not be the focus of this document. An example of products using this technology is Devolo Smart Grid PLC.

PRIME

Powerline-Related Intelligent-Metering Evolution (PRIME) was developed by the PRIME alliance. This system has 96 OFDM subcarriers on frequencies 42 kHz to 89 kHz. Its peak data rate reaches up to 128.6 kbit/s. In comparison LoRa's maximum data rate is 27 kbit/s. A feature that PRIME uses is the automatic repeat request. This is the use of acknowledgements and timeouts to increase the reliability of service. Once the sender transmits data, it requires that an acknowledgement message be sent back from the receiver before the timeout. If a timeout occurs the receiver will retransmit the acknowledgement until the sender receives it, or the predefined number of retransmissions has been reached. System architecture involves a base node and several service nodes. The base node is the master controller of the subnetwork's resources and connections using a periodically sent beacon signal. It also controls which node has access to a channel with the use of time division multiplex (TDM). TDM is a method of transmitting and receiving signals on one transmission channel. Data is encrypted with 128-bit AES. The service nodes listed by PRIME Alliance are chipsets and meter devices. The meter devices will be chosen as they are a complete product in comparison to chipsets that will need other components to be used. The base nodes also have two types, the gateways and data concentrators. The main purpose of a data concentrator is to periodically poll the meter devices that are connected to the same secondary substation. The data collected is stored and then sent to the management system. Data concentrators apart from voltage and current can monitor power quality, service continuity and even detect faults. A useful detail to note about PLC gateways is that they do not need to be installed in secondary substations and can be installed in different locations in low level networks such as fuse boxes or even close to the smart meters. Typically, PLC gateways are used in low-density areas that serve up to 25 service nodes. Data concentrators because of their extended grid monitoring functions are used in higher density areas as they can provide real-time data of the state of the grid.

5CTM / 5CTD Prime PLC smart meter | Single phase / Three Phase (ZIV Automation)

Product Source:
https://www.zivautomation.com/metering-solutions/meters/prime-plc-threepahse-smart-meter/ &
https://www.zivautomation.com/metering-solutions/meters/prime-plc-threepahse-smart-meter/

ZIV claims to use their own technology for PLC standards that improves high-power transmission without distortion for low impedance lines without affecting line impedance. This would lessen the impact of the noisy environment over the powerlines by high receiver sensitivity and efficient data communications.

Key Features:

- 5CTM smart meter integrates a PLC service node that is automatically identified in the PLC network (plug & play).
- LCD display for meter readings and standardized messages/symbols.
- Instantaneous measurement of V, A and PF.
- Bidirectional energy registers (active/reactive).
- Instantaneous values profile (7 channels: V, I, P+, P-, Q+, Q-, PF) with a configurable integration period.
- Load profile (6 channels: A+, A-, R1, R2, R3, R4) with a configurable integration period.
- Monthly (15 registers) and daily billing data (45 registers).
- Versatile Time of Use (TOU) module, providing 3 identical and independent contract configurations, with up to 4 rates and 24 rate periods per day, 24 daily profiles, 12 weekly profiles and 12 seasons in a year and up to 30 special days per contract.
- Maximum Demand Recording for each of the programmed tariffs.
- Time synchronization.
- Event and alarm recording with a broad set of manageable events.
- Power Quality recording. Voltage variations outside the established thresholds and long-term voltage interruptions.
- Breaking and reconnection elements for remote switching operations, power control and demand side management.
- Self-diagnostics and monitoring.
- Enhanced anti-tampering protection system, including magnetic field detection and cover and terminal cover opening.
- Internal battery for RTC and tampering events.

Figure 1: Single Phase 5CTM

Figure 2: Three Phase 5CTD

4CCT | Smart Metering Data Concentrator for secondary substations
Product source:
https://www.zivautomation.com/metering-solutions/data-concentrator-units/smart-metering-data-concentrator-for-secondary-substations/
A metering data concentrator unit (DCU) that includes an advanced low voltage supervisor and Powerline Communication (PLC) controller with network monitoring functions, in addition to remote smart meter management functions.
Key Features:

- The 4CCT has an embedded PRIME or G3 base node.
- Ensures high power transmission without distortion and is also optimized for operation over low impedance LV grids, without affecting the line impedance.
- High receiver sensitivity and efficient data transfer provide optimized communications over noisy lines.
- The low voltage supervision function is performed by an internal three-phase energy meter, monitoring the secondary of the distribution transformer.
- Remote firmware upgrade, WEB/CLI configuration, connection to ZIV PRIME AMI Manager debugging tool, NTP synchronization, hardware watchdog, SNMP management, access control.

Figure 3: 4CCT | Smart Metering Data Concentrator for secondary substations

PLC communication gateway: Regesta Smart PLC (Teldat)

Product Source:

https://www.teldat.com/smart-grid/utilities-product/regesta-plc-smart-grid-industrial-utilities-gateway-router-lte-3g-4g-scada-ethernet/

This PLC gateway is ideal for large scale deployments due to its advanced networking protocols and management tools. This gateway is not interoperable with G3-PLC.

Key Features:

- PRIME PLC interface with base and service node operation. It supports up to 2000 PLC smart meters, with topology discovery and firmware updates. Compatible with both 1.3 and 1.4 versions of the protocol.
- Embedded 2G/3G/4G interface with dual SIM card tray for automatic backups. Advanced Teldat system for proactive monitoring and automatic recovery from WWAN incidents.
- The Regesta Smart PLC includes a housing design for optimal heat dissipation and, wall mount and DIN rail mount options, guaranteeing operation between -25 and 70 °C with up to 93 % humidity.
- The Regesta Smart PLC includes state-of-the-art security: ACLs, firewall, 802.1X, IPSEC with hardware encryption, DMVPNs, etc. This allows for safe and scalable deployment in easy to manage smart grid networks.
- The Regesta Smart PLC includes a software stack with the advanced functions required by advanced IP networks, such as QoS, policy routing, DMVPNs, VLANs, and VRF, providing maximum versatility for shared services.

Figure 4: Reguesta Smart PLC

G3-PLC

G3-PLC operates on frequencies from 10kHz to 490 kHz. Its peak data rate reaches up to 300 kbit/s. G3-PLC employs Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is a method for nodes to avoid collisions by listening to the channel and if it is empty, the node can then transmit its signal. The system architecture of G3-PLC consists of a data concentrator and meter nodes and uses mesh routing protocol that determines the best path between the nodes. It uses IPv6 packets to transport data over the powerline channels which can allow internet-based energy management systems and applications. The data is also encrypted with 128-bit AES.

Some of the features that G3-PLC protocol have are:

- Compliant with world regulatory bodies such as CENELEC, ARIB, and FCC (10 kHz - 490 kHz).
- Standards based — pre-standard in IEEE, ITU, IEC/CENELEC and IEC/SAE.
- Two layers of forward error correction (FEC) for robust data communication in harsh channels.
- Adaptive tone mapping for optimal bandwidth utilization.
- Channel estimation to select the optimal modulation scheme between neighbouring nodes.
- "Robust" mode to improve communication under noisy channel conditions.
- 6LoWPAN adaptation layer to transmit IPv6 packets over powerline channels.

G3-PLC Alliance proposes a feature for some G3-PLC devices called a G3-PLC Hybrid PLC & RF. This is a hybrid standard that integrates network communications for wired and wireless media. The benefit of this is to provide interoperable solutions in order to reduce complexity and the cost of installations. Semtech has announced a few years ago that they had developed EV8600 dual modem which uses both LoRa and G3-PLC. However, there are no product pages available for the EV8600 and no other articles mention this modem existence beyond May 2016.

Landis+Gyr E450 | Single/Three Phase PLC Smart Meter

Product Source: https://www.landisgyr.eu/product/landisgyr-e450/

This smart meter can work with both single and three phases. It is a flexible electricity meter, multi-energy data collector, remote two-way communication node and an interface for end user interaction.

Key Features:

- Powerline Carrier Technologies (G3-OFDM, PLAN+)
- Single and polyphase, with and without supply control switch (UC3 rated)
- Remotely updatable firmware
- Standardized and interoperable (IDIS/DLMS/COSEM)
- Optional integrated load switch
- Multi-energy support (wireless & wired M-Bus). DSMR 2.2+ and OMS 4.03 (wireless modes T1, S1, C1)
- Programmable demand-response functions
- Anti-tampering package
- Consumer Interface (OpenHAN Interface); Optical and Mbus wired. OpenHAN is a standard for home networks to standardise powerline networking interoperation from a utility point of view.

Figure 5: Landis+Gyr E450

SGW1050 |Substation Gateway (Siemens)

Product Source:

https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/smart-communications/substation-gateway-sgw1050.html

This substation gateway can be used to connect to not only smart meters but also other low voltage power installations. It can connect to other devices such as power quality meters, charging stations or multifunctional measuring devices in the distribution grid.

Key Features:

- G3-PLC PAN coordinator supporting cenelec A or FCC band including notching capabilities.
- 3x electrical Ethernet RJ45 Ethernet 10/100Base-TX (WAN, Local, Service).
- 4G/LTE CAT4, 3G UMTS/HSPA and 2G/GPRS/EDGE option.
- Integrated power supply.
- Multi-protocol support: DLMS/COSEM (IEC62056), Modbus TCP, OPC UA Pub Sub, HTTPS, TLS, SNMPv3, NTP.
- Zero-touch provisioning. This feature will perform the configuration and connection to the management system. The device may need to be personalised during manufacturing for customer crypto-credentials, customer network configuration, customer identification (e.g. barcode), customer-provided SIM cards for cellular WAN variant.

Figure 6: SGW1050 Substation gateway

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