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U2DEMO

Use of open-source P2P energy sharing platforms for energy Democratization

Deliverable D 2.1
P2P MARKET AND ENERGY SHARING DESIGNS AND CONSUMER PARTICIPATION PROCESSES

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Disclaimer

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[1] https://u2demo.eu/

Executive Summary

This report outlines the foundational framework for enabling peer-to-peer (P2P) energy trading and energy sharing within energy communities across Europe. As part of Work Package 2 of the Horizon Europe-funded U2Demo project, this report introduces a set of functional architecture templates designed to support the development and deployment of open-source tools and platforms for energy democratization.

The report identifies and analyses nine *collective energy activities*, interactions of a community as a group within the electricity system, relevant to the U2Demo pilots in the Netherlands, Belgium, Italy, and Portugal. These activities range from managing grid constraints (kW-max) and trading flexibility, to models of energy sharing and community self-balancing. Each pilot demonstrates unique priorities and constraints, offering insights into the diversity of local implementations.

A central theme of the report is the role of coordination mechanisms: processes that align individual member actions within a community. The report categorizes coordination types (e.g., direct control, mediated cooperation, implicit competition) and evaluates their impact on functional architecture design.

The deliverable presents functional templates for each collective energy activity, detailing required tools, algorithms, stakeholder roles, and information flows. These templates are structured around the phases of the Universal Smart Energy Framework [1] (Contract, Plan, Validate, Operate, Settle) and are designed to be adaptable across regulatory and social contexts. It is demonstrated that each coordination type results in another type of information exchange between Energy Community Members and the Energy Community Manager while the information exchange between the Energy Community Manager and Third Parties is determined by the collective energy activity.

The report concludes that all types of coordination mechanisms can be applied in the collective energy activities discussed in this report. However, some activities such as providing flexibility services to a Flexibility Service Provider require the Energy Community manager to have oversight. This need introduces additional information sharing requirements in decentralised (e.g. ‘peer-to-peer’ or ‘price response’) designs.

This deliverable serves as a reference for future development within U2Demo and beyond, supporting energy communities in adopting interoperable, open-source solutions for collective energy activities.

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Acronyms

BRP	Balance Responsible Party
CSP	Congestion Service Provider
DER	Distributed Energy Resource
DSO	Distribution System Operator
EC	Energy Community
FSP	Flexibility Service Provider
ESCO	Energy Service Company
HFCEA	Harmonized framework for community energy activities
P2P	Peer to Peer
PV	Photovoltaic
SGAM	Smart Grid Architecture Model
USEF	Universal Smart Energy Framework
HEMRM	Harmonised Electricity Market Role Model
WP	Work Package

Glossary

Collective energy activity	A set of interactions within the electricity system initiated by an energy collective as a group targeted at achieving joint goals [2].
(energy community) Coordination mechanism	Processes (e.g. auctions, P2P negotiation structures, top-down optimization solutions or static rules) for aligning the behaviour of individual members and sub-processes in the energy community.
Functional architecture	A functional architecture defines the various actions that a system can perform in support of specific goals, and how those actions relate to each other in order to collectively give the system the appropriate capabilities to meet those goals [3].
Reference architecture	A Reference Architecture describes the structure of a system with its element types and their structures, as well as their interaction types(among each other and with their environment). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on it [4].
Direct control architecture	A centralised control architecture where individual units (e.g., households, DERs) relinquish both their data and control capabilities to a central authority. This central entity makes operational decisions such as switching, scheduling, or load adjustments based on full or partial access to system data.
Indirect control architecture	A decentralised control architecture where units are controlled and operated independently from each other, which can be manual or automatic. More than one stakeholder is involved in the control in an indirect control design.
Peer-to-peer coordination	Members of an energy community communicate directly (without relying on a central operator) with each other to decide how energy-related devices should be used or how energy should be divided between them.
Algorithms and tools	In the context of the U2DEMO project, algorithms refer to process or set of rules to be followed in calculations or other problem-solving operations that underpin P2P energy trading and energy-sharing systems. Tools in the U2DEMO project denote the software and platform implementations that realise algorithms, making them usable within the U2DEMO pilots.

Energy flexibility - **Implicit** - **Explicit**	The ability to shift energy use in time, location or form (using another commodity). The ability to shift energy is derived from an initial plan on when and how to use energy. A deviation from this plan can be offered as 'energy flexibility' to parties in need for flexibility in the form of an availability (e.g. kWh reserved) or activation (e.g. kWh delivery). When an individual or a community uses flexibility to optimize his own position this is called 'implicit flexibility'. When an individual or a community offers flexibility to other parties e.g. grid operator or an energy trader this is called 'explicit flexibility'.

1 Introduction

U2DEMO aims to enable widespread participation in energy sharing and peer-to-peer (P2P) trading in energy communities. Work package (WP2) of the U2DEMO project focuses on the fundamental development of a framework, models, and methodologies for P2P trading and energy sharing, and includes, among others, investigating suitable P2P trading architectures and design methods. Task T2.1 aims to conceptually develop P2P trading and energy sharing architectures that enable the activities of energy communities identified in WP1 [2].

1.1 Goal

This report presents functional architecture templates for activities of energy communities related to energy sharing and peer-to-peer trading. In particular, we will describe the role of *coordination mechanisms:* processes (e.g. auctions, P2P negotiation structures, top-down optimization solutions or static rules) for aligning the behaviour of individual members and processes in the energy community.

The templates are designed on the basis of a defined set of use cases, corresponding to collective energy activities in which the U2DEMO pilots are currently involved, or demonstrate an interest in pursuing further development. The intended result is to provide a *reference architecture* for functional design that provides guidance to further tasks in U2DEMO such as the development of algorithms and tools, platform design, and integration of these solutions at the pilot locations. Also, we intend to provide insights on the impact of a choice for a certain coordination mechanism on the design of consumer participation processes.

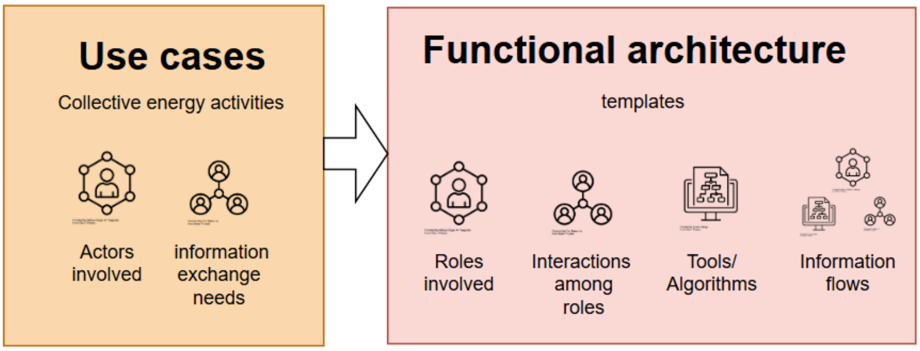


Figure 1-1 - The functional architecture templates are created around a set of use cases

The functional architecture templates are designed according to the in Appendix A presented guidelines for functional harmonization of collective energy activities derived from the Universal Smart Energy Framework [1] and the Harmonized Electricity Market Role Model [5]. These guidelines serve as the foundation for creating reference architectures that support the reuse of (open-source) software tools across different energy communities with minimal local adaptation and implementation efforts. This includes facilitating deployment in various EU Member States by enabling adaptation to different legal, regulatory, and social contexts.

1.2 Scope

The analysis of the use cases and development of the templates is conducted at a level of abstraction focusing on information exchanges and the role of algorithms and tools. Figure 1-2 shows the mapping of the abstraction level on the interoperability layers of the Smart Grid Architecture Model (SGAM) and the exemplary categorization of abstraction levels introduced in the SGAM User Manual [6]. Both the use cases (collective energy activities) as the functional architecture templates cover only the functional layer.

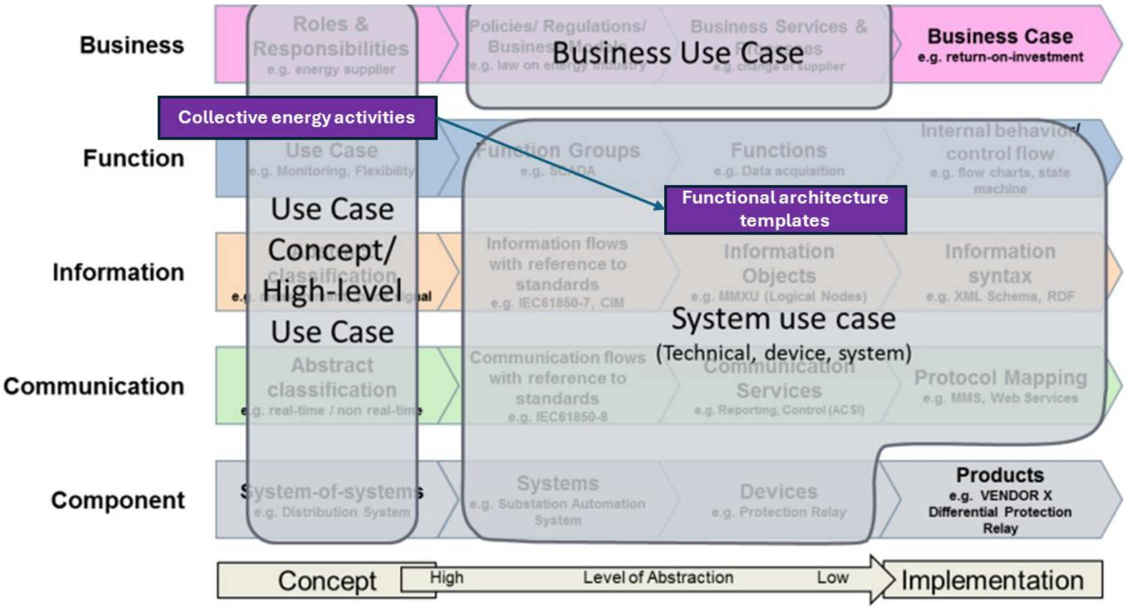


Figure 1-2 - Mapping of abstraction level on the SGAM interoperability layers.

Note: The scope of this report is on the functions. This is illustrated by mapping the 'collective energy activities' and 'functional architecture templates' on the SGAM interoperability layers and abstraction levels introduced in the SGAM user manual [6].

As the focus of our analysis is on the role of actors and tools/algorithms we will not identify the underlying processes of data sharing and data protection into detail. Functions purely in the domain of data acquisition and data processing such as reading measurements are not defined explicitly in this report. For example, in the requirements for a function 'day-ahead forecast of the community load', it will be described that measurements are needed but the function 'meter data collection' will not be described. Specification of data processes will be performed in WP3 of the U2DEMO project.

1.3 Structure

In Chapter 2, we introduce the collective energy activities, the use cases for creating the functional architecture templates. In Chapter 3, we introduce the concept of coordination mechanisms and explain the effect of choosing a different type of coordination mechanism on the functional architecture. Chapter 4 presents the functional architecture templates. Finally, Chapter 5 summarizes the insights from Chapters 2-4 and explains how the templates can be used in the open-source software ecosystem and can support energy communities.

1.4 Relationship with other deliverables

Figure 1-3 shows the role of WP2 in the U2DEMO project. In this report, we present the results of Tasks 2.1. This task builds further on the results of WP1. In particular the *collective energy activities* developed in WP1 (see Deliverable D1.2 [2]) which serve as use cases for the development of the functional architecture templates. Furthermore, the work has been done in parallel tot Task T1.4 where Business Use Cases (BUCs) for the U2DEMO Pilots (see Deliverable D1.4 [7]) were defined.

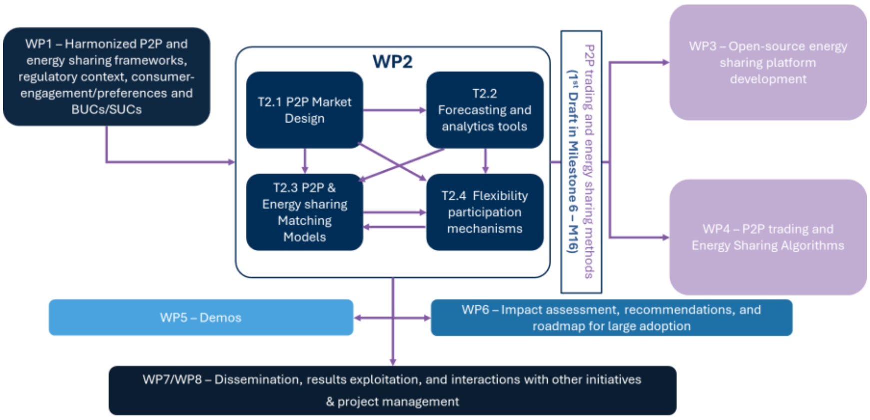


Figure 1-3 - The role of WP2 in the U2DEMO project (image created by WP2 lead VITO).

In the templates presented in Chapter 3, functional requirements for various algorithms to be developed in WP2 and/or WP4 are presented. Finally, to WP3, the functional architecture templates provide insight in the building blocks that the U2DEMO platform should enable and offer access to.

2 Use cases: activities of energy communities

As a starting point for the development of the functional architecture templates we take the *collective energy activities* introduced in [2] and summarized in Table 2-1. These activities can be seen as high-level use cases defined with the intention to support the process of creating functional architecture templates that can be used also by other projects. Therefore, the use cases are defined specific enough to identify the required roles, tools/algorithms and information flows and generic enough to cover more than just one bottom-up defined use case.

In this chapter, we analyse the collective energy activities in the context of the U2DEMO pilots in The Netherlands (NL), Belgium (BE), Italy (IT) and Portugal (PT) as shown in Table 2-1. The analysis provides insights in how the high level use cases (collective energy activities) link to concrete use cases (the U2DEMO pilots). As some pilots intend to implement multiple activities we also get insight in how collective energy activities relate to each other.

Table 2-1: The collective energy activities (source:[2])

Collective energy activity		Pilots
Collective kW-max	An energy supplier or grid operator incentivizes the collective to take care of a kWmax constraint. This may be a fixed constraint (e.g. contracted power, time-dependent transport capacity limit) or a constraint that is planned e.g. day-ahead.	NL, BE
Collective flex activation delivery to a flexibility service provider	The collective offers flexibility activation to an aggregator as a whole instead of contracting an aggregator on an individual basis. A certain amount of flexibility is sold by the collective to the aggregator.	NL, PT, IT
Joint self-supply	A collective supplies electricity to its members. None of the members has another primary energy supplier. *This activity has been left out of scope in this report as it does not fall in the main scope of the U2DEMO project (energy sharing and P2P trading) and comes with various additional complexities.*	NL
Collective self-balancing	The collective is seen as a 'balancing group' within a larger portfolio of a BRP. The collective needs to send balancing prognoses and there is an incentive to activate flexibility to meet the schedule.	NL
Joint self sub-supply (energy sharing via sub-supply model)	The community members have a primary supplier but are also supplied from the community. The sub-supply is registered as allocation which means that actual energy is delivered between the members of the community.	NL
Optimization for local sustainability goals	The collective activates flexibility to meet local sustainability goals, e.g. they store solar energy produced in the community to use at a later moment. Often this goal is combined with other incentives.	NL
Energy sharing via adjusted energy bill model	A collective facilitates the sharing of energy from jointly or individual owned assets to individual members. This means the collective communicates	BE

Collective energy activity		Pilots
	the energy sharing to a certain party that results in an adjustment on the energy bill.	
Energy sharing via cash-back model or vouchers	A collective facilitates the sharing of energy from jointly or individual owned assets to individual members. This means the collective communicates the energy sharing to a certain party that results in a cash-back separate from the billing of energy.	IT, PT
Collective control of individually or jointly owned assets	The collective has together a say about how to control assets. These rules are defined in community agreements and should be implemented in other activities where control of assets takes place.	All

P2P trading by means of the sale of renewable energy by automated transactions such as via smart contracts (see D1.1 [8] for interpretations of the concept in regulatory frameworks) can apply to activities such as energy sharing and flexibility trading to Balance Responsible Parties. The use of smart contracts or other form of automation does not change the functional architecture in relation to the tools and algorithms studied in this report.

2.1 The Dutch (NL) pilot

Living Lab Scheveningen is the centrepiece of The Hague's Smart City efforts, focusing on solving environmental, safety, and sustainability challenges in public spaces. One of its key energy projects is located at the beachside near the harbour, where collaboration with the local Distribution System Operator (DSO), Stedin, began last year. This partnership enables more advanced studies on grid dynamics and the testing of flexibility services.

Currently, the lab has to municipal and commercial users. A cooperative has been formed to manage the grid and oversee the value streams of its members, and this cooperative is expected to adopt the future smart energy platform.

Within this community, three beach house owners are connected to a smart grid owned by the Den Haag municipality. The municipality has a contracted grid capacity of 857 kW with the DSO Stedin. Members either already have or are planning to install solar panels, and a neighbouring cooperative is constructing a solar park that will also connect to this grid. Additionally, the community has access to a shared battery, provided on loan by the municipality.

All energy assets—solar installations, battery storage, and future additions—are shared among community members. The cooperative has ambitious plans to integrate more flexible energy resources, including both shared infrastructure and smaller, individually owned assets like boat chargers, wind turbines, and EV charging stations.

The cooperation is already developing a platform for interfacing with the infrastructure and assets in the open source tool Open Remote [9]. Technical partner of the municipality Kerstens Techniek is implementing this software.

2.1.1 Activities, priorities and constraints

The activities the Dutch pilot take already part in or has interest to develop are mentioned in Table 2-2 along with their priority. Earlier prioritized activities result in a constraint to the next activities. The order of priority presented in this report has been defined by the representatives of the Dutch pilot.

First priority is the activity kWmax. The community operates a grid that is connected to the DSO grid.. The community has to adhere to the permanent power constraint imposed at the connection point to the DSO managed grid. Not adhering to it can incur costs or even result in limitations by the grid operator to do experiments in the future and thus has the first priority.

Second priority is the flexibility trading on the Dutch platform for congestion management GOPACS via an independent Flexibility Service Provider. At the moment, the Dutch pilot community trades flexibility at GOPACS at day-ahead. Their ambition is to trade flexibility (also) at intraday. However, trading at the GOPACS intraday flexibility market requires a Transfer of Energy[2] between the independent aggregator and the energy supplier: to ensure the suppliers position is balanced when flexibility is activated in its portfolio by an act of the independent aggregator. In contrast, day-ahead activated flexibility volumes can be taken into account by the energy supplier in the sourcing because the community communicates before day-ahead its expected profile via the activity 'self-balancing'. Trading flexibility via GOPACS at day-ahead is the 'fall-back' activity when the barriers for intraday flexibility trading are not resolved when the demonstrations start.

Table 2-2: List of activities performed at the Dutch pilot

Activity name	Situation pilot	Priority
Collective kW-max	The community operates their own grid. There is a static limitation on the kW consumption and feed-in on the connection point that connects the community grid to the DSO grid.	1
Collective flex activation delivery to a flexibility service provider	Intraday flexibility delivery to a Flexibility Service Provider (FSP) who bids in the flexibility in the GOPACS platform. *Note: in this document we worked out the situation for intraday flexibility. It is possible that this will be replaced or combined with day-ahead flexibility trading on GOPACS.*	2
Collective self-balancing	The community nominates their own energy consumption/feed in profile to the Energy Supplier/Balance Responsible Party(BRP). Deviations from this profile are settled against imbalance market prices. This creates an incentive for the community to activate flexibility in the community to meet the pre-defined schedule.	3

2 Energy volumes transferred between the BRP of the Aggregator and the BRP of the Supplier. Source: [1]

Activity name	Situation pilot	Priority
Joint self sub-supply	Allocation of energy produced by or stored in jointly and individually owned assets to individual members (as consumers).	4
Optimization for local sustainability goals	Optimize the control of flexible assets to contribute to local sustainability goals such as using as much as green electricity as possible, into account.	5
Collective control	Within the community there are shared and individually owned assets. For the shared assets community control rules should be defined in a democratic process. With their individually owned assets members can respond based on their own interest (e.g. price or sustainability).	Take always into account

Third priority is to optimize the activity of self-balancing. This means the schedule sent to the Supplier/BRP should be close to realisation and flexibility is activated to reduce deviations from this schedule.

Fourth priority is the allocation of energy to individual members. At the moment the community is exploring what would be a fair division of energy (benefits) to the members. In the Dutch pilot all members have together a single energy contract. As such the allocation has no effect outside the community. Nevertheless, the activity of energy sharing via day-ahead self-sub-supply was selected because we have the ambition to develop and test a system that is relevant for a large amount of energy communities in the Netherlands in the future. This means that we assume that the members of the energy communities have different energy supply contracts (so individual retail prices may differ) and can have different energy suppliers.

Latest priority is to take into account local sustainability goals defined by the community on a group level. At the moment individual members have the ability to set their energy management system in a mode that optimizes either for best financial or for best sustainability result but there is not a joint optimization goal for sustainability defined yet.

The community has collectively and individually owned assets. The members of the energy community have a say about how to control the collectively owned assets. This can be defined in the form of a mandate e.g. 'The technical operator (at the moment that is Kerstens Techniek) should use these assets to optimize the other activities and given priorities and constraints'. The members can also decide that each member has a proportional right to use a collectively owned asset as if it is owned by themself e.g. 'each member has a pro rata right to share energy from the solar panels'.

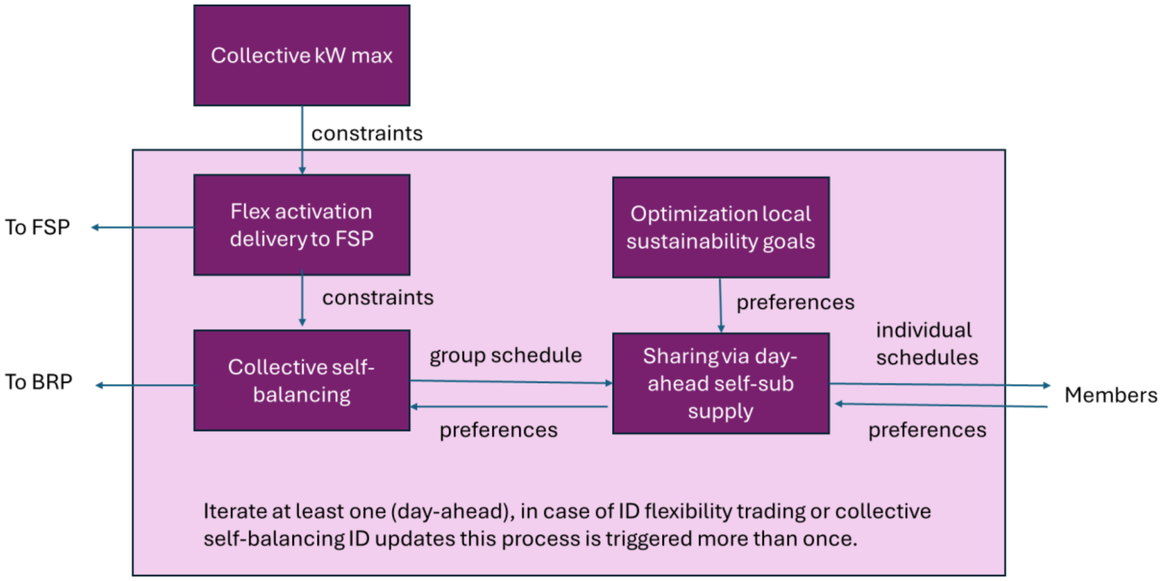
2.1.2 Interplay between activities

Figure 2-1 shows the how the activities identified as relevant for the Dutch pilot influence each other:

- The static kWmax needs to be satisfied within an acceptable risk profile. This can be either a probabilistic risk profile or an N or N-1 constraint that there should always be a resource available that can reduce the load below the kWmax. In both cases this results is a constraint for further activities.

- The same is valid for the explicit flexibility activity, based on the risk profile or rule chosen, a constraint should be taken into account in the next activities. The activity 'community self-balancing' creates a group schedule to be sent to the energy supplier in its role as BRP. This group schedule forms the basis for the allocation on individual level (the energy sharing via sub-supply). As the group is a self-balancing group, changes in individual schedules do not have an effect on the level of the BRP (even if consumers would have different BRPs). However, every consumer has its own supply contract (either dynamic or static) and price conditions. As a result, for some members in the community, receiving shared energy can be more or less beneficial. It is even possible that the energy from the community has a higher price than the energy an individual consumer can buy from its main supplier.

- The individual supply contracts as well as certainties/uncertainties about consumption/production lead to preferences of members to be interested in receiving or providing 'shared energy'. These preferences should be taken into account in the activity of community self-balancing such that the group schedule is optimized. Preferences can also come from optimizing local sustainability goals. For example, when there is no financial benefit of consuming shared energy, local sustainability goals can add another argument. At the moment, these local sustainability goals are not prioritized above the optimization of sharing energy so members will not take off 'locally produced energy' when the price is higher than the feed-in tariff of their own supplier.



Note: The arrow indicates what output of the higher prioritised activity should be taken into account in the next activity. The activities in the light pink box are iterate one or multiple times depending on how many times the flexibility provision to the Flexibility Service Provider is trigged. In the fallback scenario it is daily process, in the envisioned intraday (ID) scenario it might be more than once.

Figure 2-1 - Interplay between activities as the Dutch pilot.

At the moment the interaction between group level control and individual control is implemented by sending price signals. This illustrates that group level constraints and schedules are translated into price incentives that result in a response that support the result on group level. In Chapter 3 this and other ways of coordination will be discussed in detail.

2.2 The Belgian (BE) pilot

The demo is located in the province of Antwerp, in Flanders, Belgium. The site is located in Mechelen, a medium sized Belgian city of approx. 87.000 inhabitants. Klimaan is the local citizen cooperation for renewable energy and operates a Citizen Energy Community (CEC) based on PV electricity production in the social housing neighbourhood Otterbeek.

The current setup results in a lot of excess solar power production, for which no immediate consumption is found in the social context. Most tenants take advantage of direct self-consumption, and the general acceptance rate to novel concepts among social tenants is low. Possible extensions of the CEC currently under investigation are charging infrastructure for EVs and adding batteries in three households.

Considering the high capacity of the PV systems, there is excess electricity production during several periods. In this pilot, Klimaan wants to apply different matching approaches in order to get the running energy sharing schemes optimized, while upholding the social aspects of the setup. At the same time, Klimaan wants to implement an efficient management of its highly fragmented income streams. Through gamification, the pilot wants to raise the tenant involvement and reinforce the business case.

The Belgian pilot consists of a residential social housing building with multiple apartments. There are 197 PV installations, all installed behind household connection points but owned and operated by Klimaan. Building's consumption from the PV accounts for about 20% of its total energy consumption with the rest being met by an energy supplier. There are minor congestion problems in summer, the community foresees as future activity to limit injection.

2.2.1 Activities, priorities, and constraints

Table 2-3 lists the activities relevant to the Belgian pilot:

Table 2-3: List of activities performed at the Belgian pilot

Activity name	Explanation	Priority
Support members to optimize individual self-consumption	Klimaan supports the members to optimize for individual self-consumption.	1
Energy sharing via adjusted bill model	Members of the community consume energy from the energy community and with from their main supplier. During settlement, they get an adjusted bill which takes into account the shared energy.	2
Collective kW-max	Static limitation on the kW feed-in to the DSO grid.	3
Collective control	Klimaan takes care of the prioritization of individual self-consumption over the collective goals. The EC should agree with this approach.	Take always into account

As a first priority Klimaan supports individual members to optimize their individual self-consumption as that results in more value than sharing energy. Klimaan supports individual members directly so this is not a 'collective energy activity'. Second, the collective self-consumption optimization is prioritized that is incentivised by the activity energy sharing via adjusted energy bill.

In the settlement phase the amount of energy shared is calculated by the DSO using predefined energy sharing allocation rules (e.g. 'static' or 'optimal'). The community chooses a certain 'allocation method' in the contract phase and cannot influence the amount of energy that is allocated at specific members.

The collective kW-max has been identified as a future activity when more PV or (flexible) load is installed in the community. At the moment this activity is not feasible, but it is expected that injection reduction could contribute to the integration of renewables in distribution grids.

When flexibility in the community is used to increase the collective self-consumption energy sharing decreases already the peak production and consumption of the community. Therefore, it is prioritized before taking care of the kWmax. It is a research question whether the kWmax incentive is still needed in this use case when people have the incentive to optimize self-consumption.

The community has a Power Purchase Agreement with the municipality. As this activity does not require tools or algorithms, it was not included as an activity of the energy community. In the future, Klimaan, is planning on having more activities and to facilitate P2P energy sharing along with building assets for the community to aid in this direction.

2.2.2 Interplay between activities

The individual self-consumption is prioritized over optimization of energy sharing. This means only the excess renewable generation should be taken into account in the energy sharing activity. When flexibility is activated to increase the collective self-consumption volume, the energy sharing activity results already in a lower maximum load. If there is in total more excess of generation than the kWmax, the community can activate flexibility to increase local demand or choose to curtail.

2.3 The Italian (IT) Pilot

The demo is located in the central part of the Italian peninsula, in Abruzzo region. The site is placed in Vallevignale, a small town in the municipality of Notaresco, Teramo. An operative Renewable Energy Community (REC) in Vallevignale is fully managed by EnGreen. The REC currently involves 10 buildings: 5 of these buildings can be considered prosumers (as they produce, self-consume and share their renewable energy production) and the remaining 5 are consumers (which can use the low-cost energy produced by the other members of the REC).

The demo starts from the installed capacity of 42 kW of photovoltaic and 105 kWh of lithium battery storage, and the already installed 5 Electric Vehicles (EV) charging stations and 5 heat pumps. As per the interviews performed in the WP1 of U2DEMO with the members of the pilot, the main sources of energy are gas (70,000kWh annual), electricity (40,000kWh annual) and biomass (40,000 kWh annual) and installed PV gives an estimated output of 50,000 kWh annually. All assets in the community are individually owned and shared with the members of the community. For example, the EV charger is on private property but is made accessible to the community.

2.3.1 Activities, priorities, and constraints

Table 2-4 presents the activities that were identified as relevant for the Italian pilot:

Table 2-4: List of activities performed at the Italian pilot

Activity name	Explanation	Priority
Energy sharing via cashback model	In Italy, energy communities receive an cash-back via the renewable energy support program for shared energy. This incentive is transferred to the bank account of the community.	1
Community flex activation delivery to an FSP	Offering long-term flexibility (before day ahead) and Intraday congestion management offers via the Piclo platform [11] are identified as future activities.	2
Collective control	The assets in the Italy pilot are managed by the EC Members. To improve joint optimization collective control rules can be established.	Take always into account

2.3.2 Interplay between activities

Not applicable at the moment. When the community provides flexibility to the FSP the relation between the two activities (constraint, priorities) should be defined.

2.4 The Portuguese (PT) Pilot

The Portuguese Pilot in Valverde, Évora, is an energy initiative focused on testing peer-to-peer (P2P) energy trading within a Renewable Energy Community (REC). The pilot is managed by E-REDES as the Distribution System Operator (DSO) and EDP Commercial is the Energy Supplier of the households involved. At the moment the households have same energy supplier, but they are allowed to switch.

The U2Demo pilot involves 10 individually owned homes, each equipped with 1.5 kWp photovoltaic (PV) systems and second-life batteries (10 kWh each). PV is the primary renewable energy source, covering approximately 30% of total consumption. At present, only the batteries serve as flexible loads, but future plans include adding smart plugs to electric boilers and washing machines to expand flexibility. This pilot builds on the infrastructure established by previous EU projects like DOMINOES, InteGrid, SENSIBLE, and POCITYF.

2.4.1 Activities, priorities, and constraints

Table 2-5 introduces the activities that were identified as relevant for the Portuguese pilot:

Table 2-5: List of activities performed at the Portuguese pilot

Activity name	Explanation	Priority
Energy sharing via energy bill adjustment	Energy sharing using a dynamic sharing coefficients mechanism in Portugal. The DSO takes care of the adjustments in energy production/consumption according to the sharing coefficients indicated by the EC manager.	1
Energy sharing via cashback model or vouchers	The community is incentivised via vouchers to improve the collective self-consumption. In the proposed voucher system dynamic sharing coefficients are possible.	2
Community flex activation delivery to an FSP [10]	Community flex activation delivery to an FSP was identified as a future activity. Both the provision of ancillary services (manual Frequency Restoration Reserve) as well as the provision of flexibility for congestion management via the Piclo Flex platform [11] were identified as options to be tested in the project.	Undecided
Collective control	The assets in the PT pilot are owned by the EC Members. To improve joint optimization collective control rules can be established.	NA

At the time of writing of this deliverable the characteristics of this activity Community flex activation delivery to an FSP were not known and so no further information about these activities is provided.

2.4.2 Interplay between activities

At the moment not enough information is available about the activity Community flex activation delivery to an FSP’. When the community provides flexibility to the FSP the relation between this activity and energy sharing activities should be defined in terms of constraints and priorities. Furthermore, the feasibility and added value of the combination of the two energy sharing activities should be further researched.

3 Coordination mechanisms

In this section we discuss the need for coordination in collective energy activities and present an analysis on how different coordination mechanism designs influence the functional architecture and so way the members of the energy community interact with each other and the outside world.

3.1 The need for coordination in collective energy activities

Coordination is a key aspect for energy communities engaging in collective energy activities, as it is sometimes necessary to align members' actions and can also lead to optimal outcomes. A pragmatic definition of coordination refers to "*the act of gluing together different sources of behaviour so that the resulting ensemble shows some desired characteristics and functionalities* [12]." This 'act of gluing together' requires a predefined process that integrates the sources of behaviour in the energy community relevant for a collective energy activity: a coordination mechanism.

In the table below we explain the need for coordination in the collective energy activities:

Table 3-1: Coordination needs in collective energy activities.

Collective energy activity	Coordination needed
Collective kW-max	To ensure that the net consumption and production in the community does not exceed the limit.
Collective flex activation delivery to a flexibility service provider	To deliver a joint flexibility response as agreed with the Flexibility Service Provider.
Collective self-balancing	1. To provide a joint planning to the Balance Responsible Party that minimizes the expected cost at the stage of real time control (see next bullet). 2. To minimize at real-time the deviation from the scheduled load.
Joint self sub-supply	Optimize the division of energy among the members while taking into account the uncertainty of production and consumption and the terms and conditions of the supply (and balancing) contracts of the members. The division should align (if applicable) with regulated energy sharing rules.
Optimization for local sustainability goals	Optimize the match of renewable production in the community with consumption.
Energy sharing via adjusted energy bill model	Optimize the total amount of shared energy in the community given the sharing calculation rules defined in the sharing model and the terms and conditions of the supply contracts of the members.
Energy sharing via cash-back model or vouchers	Optimize the total amount of shared energy in the community while taking into account the sharing calculation rules defined in the sharing model / voucher system.
Collective control of individually or jointly owned assets	The community needs to agree with the members on how to control these collectively controlled assets as the members have a say about how to control these assets.

Collective energy activity	Coordination needed
	We assume that this 'coordination' takes place offline e.g. in a democratic process at a general assembly and results in static rules that should be taken into account in other collective energy activities.

The term *coordination mechanism* is introduced by Charbonnier et al. in a literature review study on grid-edge coordination [13]. This term refers to a broad range of solutions including auctions, p2p negotiation structures, top-down optimization solutions or sets of static rules. These solutions are described in technical literature using terms such as *peer-to-peer market*, *community-based market*, or *transactive local control*.

Using the term *coordination mechanism* in the report has three benefits:

- The term covers a broad range of technical solutions. This ensures that no approaches are unintentionally excluded. Other terms like *peer-to-peer trading* are in technical literature associated with certain architectures and techniques[3].
- The term covers a broad range of applications and as such can be applied to all collective energy activities we discuss in this report.
- The term *coordination mechanism* offers a neutral perspective focussing only on the procedure to coordinate. It allows describing the functional requirements of implementing collective energy activities clearly separate from the regulatory, social and business context.

3.2 A taxonomy of coordination mechanisms

Charbonnier et al. [13] proposed a taxonomy to distinguish grid-edge coordination mechanisms based on three aspects as illustrated in Figure 3-1:

1. Layer 1- Agency: are assets directly controlled by a central management system or should the central system interact with other (member or process - e.g. EV charging -level) energy management systems?
2. Layer 2- Information: is information from individual assets and processes shared at all and if yes, between individual members or processes (bilateral) or via a mediator?
3. Layer 3- Game: is the coordination between the individual members/processes established via a competitive or cooperative approach?

[3] Terms like P2P trading are associated with certain architectures and techniques [16] but there is no consensus on the definition [13].

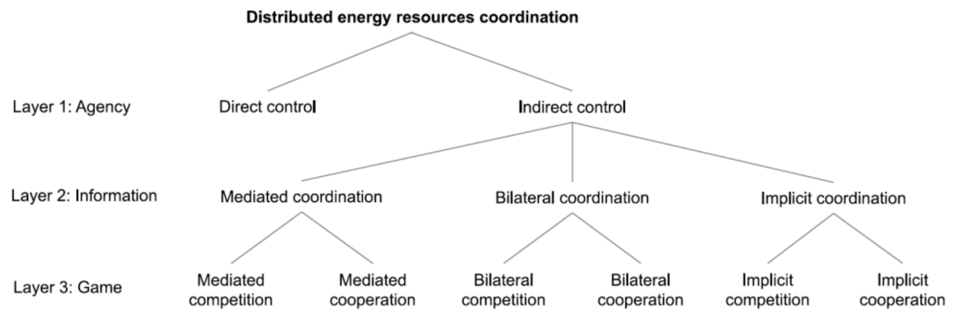


Figure 3-1 - The distributed energy resource coordination taxonomy [13]

The taxonomy of Charbonnier et al. resolves ambiguity in the terminology by synthesising the categories of coordination strategies in an exhaustive, mutually exclusive taxonomy. For the evaluation of the impact of the coordination mechanisms on the functional architecture it is useful to have a mutually exclusive taxonomy that covers a large and diverse amount of solutions.

3.3 Impact of coordination approach on the functional architecture

In this section we describe the coordination mechanism types identified in the Charbonnier et al. [13] taxonomy when implemented at the level of energy communities in terms of interactions between key roles defined in Appendix A: the Energy Community Manager (EC Manager), the Energy Community Members (EC Members) and Third Parties the EC Manager communicates with.

The descriptions of the coordination mechanisms are defined agnostic from the specific coordination need that is defined by the collective energy activity. As such we refer in general to Third Parties instead of mentioning the role the EC Manager communicates with in a specific collective energy activity. The function of a coordination mechanism in each activity and so the specific details of interactions in the context of an activity will be described in Chapter 4.

3.3.1 Direct control

In a direct control design all assets are controlled by a central energy management system according to predefined community rules. No control decisions are made by individual energy management systems of members (or other more granular levels, e.g. EV charging station). This means individual members need to share their preferences and constraint directly to the EC Manager and the EC Manager has direct access to all data that is needed to coordinate. This design is illustrated in Figure 3-2.

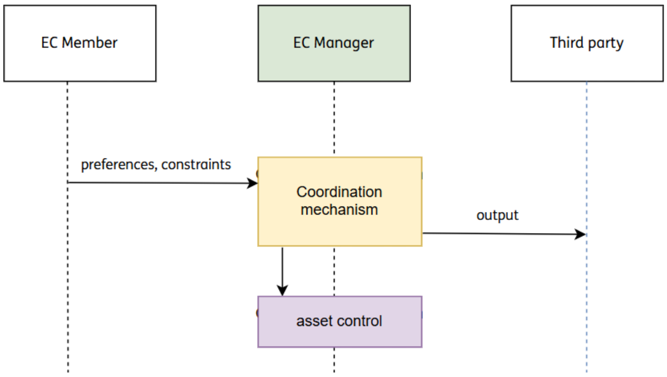


Figure 3-2 - Coordination via a direct control mechanism

The implications of a direct control design are that EC Members can have only a say about the control decisions via offline democratic processes (the Contract phase).

3.3.2 Mediated cooperation

Mediated cooperation is an approach of indirect coordination via a central coordinator. Control happens at the level of individual energy management systems of members, but a central entity provides the control plans and commands. To what extent the member has to follow these commands depends on the community agreements on what 'cooperation' means. For example, a community can decide that sharing certain information is mandatory or that costs are charged for not following commands.

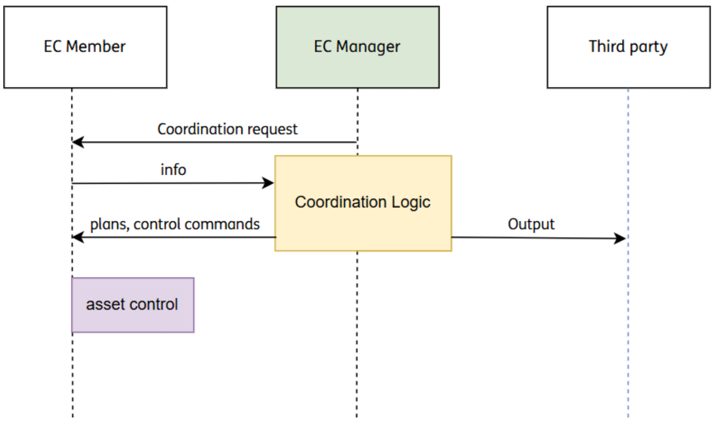


Figure 3-3 - Coordination by a mediated cooperation approach.

As shown in Figure 3-3 mediated cooperation requires two-way communication between EC manager and EC members. EC Members share information about their options and preferences to control assets. They share also data the EC Manager needs to create a (an optimal) plan such as the state of a battery or expected use of energy. The EC Manager shares plans and requests to control assets. The control of assets is in the hands of the EC Member.

3.3.3 Mediated competition

The coordination approach 'mediated competition' (see Figure 3-4) has similarities to the approach 'mediated cooperation' on the level of agency (indirect) and information (via mediator). The main difference is the type of information that is shared. In a mediated competition design parties communicate in terms of bids and asks. Forecasts, needs, and preferences are all translated into 'transactive' terms. This type of coordination includes process where the mediator proposes a price, and parties respond to this price with a volume offer.

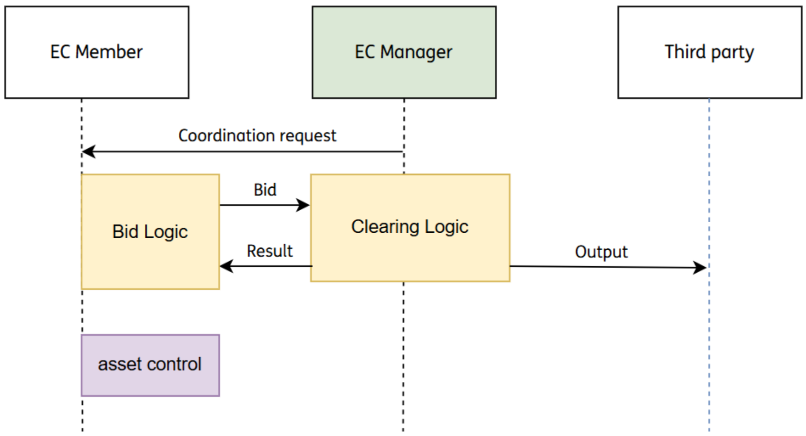


Figure 3-4 - Coordination by a mediated competition approach.

A key difference with the mediated cooperation design that a bid logic is required at the level of the EC Member. A bid logic generates bids in the form the clearing logic requests them such as price-volume pairs. To define a bid logic the EC Member should know what kind of bidding behavior is expected from them by the energy community. For example, a community can decide that bids reflect marginal prices, opportunity costs or cost price plus offers.

3.3.4 Implicit competition

Implicit competition (Figure 3-5) is another competitive approach. The difference between the 'mediated' variant is that the EC manager communicates via a one-way connection with the EC Members. Via this one-way connection the EC Manager provides signals such as a single price for taking of or feeding in energy or a conditional (e.g. volume dependent) price scheme. EC Members need to implement logic that responds to such price signals.

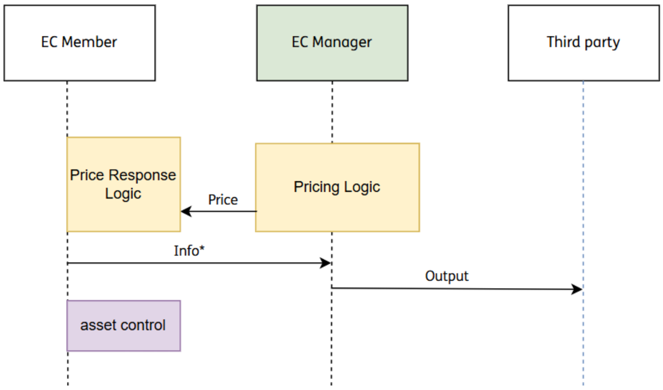


Figure 3-5 - Coordination by an implicit competition approach

In the context of collective energy activities implicit competition has a drawback that it does – when implemented strictly – not provide any feedback to EC Manager. For activities requiring the EC Manager to provide offers or schedules to a Third Party it might be required that the EC Members provide information on their response. The EC Manager might not be able to estimate the price responses precisely enough. In such case an additional information sharing process (see arrow indicated with info* in Figure 3-5) might be required.

3.3.5 Implicit cooperation

Implicit cooperation (Figure 3-6) is an approach that has according to Charbonnier et al. [13] less attention than other coordination approaches. In the context of an energy community represented by an EC Manager this approach can be best represented as follows: the EC Manager shares information (he receives from Third Parties or aggregated insights that individual EC Members cannot receive) with EC Members and gives them the task to respond in the best way to the situation. No further communication with the EC Manager of other EC Members takes place.

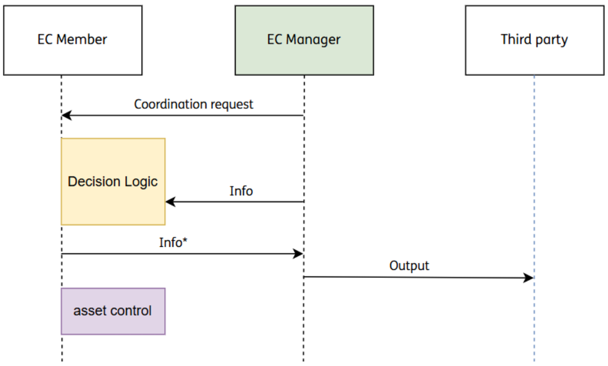


Figure 3-6 - Coordination by an implicit cooperation approach

This approach enables also a route to coordinate without any interaction within the community. For example, EC Members measure the active voltage and respond to undervoltage by reducing load. Such no or low communication is for example beneficial when coordination when there is no fit for purpose ICT infrastructure (e.g. real time communication equipment) available. After or before this 'real-time' phase it might be needed to share information with the EC Manager (see arrow Info* in Figure 3-6).

3.3.6 Bilateral cooperation

A variation on the implicit cooperation approach is the bilateral cooperation approach (Figure 3-7). The EC Manager is assumed to provide information including goals for the EC Members but leave it to the EC Members to find an appropriate solution to the coordination problem. In the bilateral cooperation design EC Members interact with each other: peer-to-peer so without a mediator.

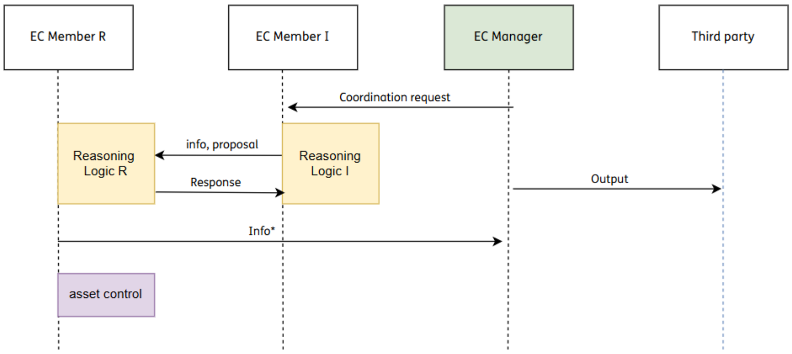


Figure 3-7 - Coordination by a bilateral cooperation approach

In this design, EC Members have two different roles in the functional architecture. They act as initiators (EC Member I in Figure 3-7) of the bilateral coordination or as responding agents (EC Member R in Figure 3-7). EC Members control assets in their role as responding agent. As the coordination happens outside the view of the EC Manager an additional information flow from EC Member R to EC Manager might be needed for activities where the EC Manager has to provide information to a Third Party (arrow Info* in Figure 3-7).

3.3.7 Bilateral competition

In a bilateral competition design (Figure 3-8), the EC Members try to solve the coordination problem by talking to each other (peer-to-peer). In contrast to the bilateral cooperation design members (both in their role of Initiating and Responding agent) interact with each other via transactive messages (bids, asks, prices and price responds, etc.).

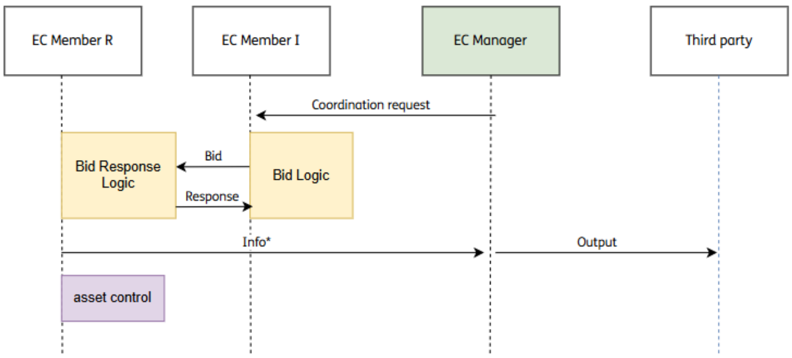


Figure 3-8 - Coordination by a bilateral competition approach

3.4 Conclusions

The selection of a specific coordination mechanism results in a distinct functional architecture, which is reflected in differentiated roles and patterns of information exchange. As a result, the type of information available to individual EC members changes, along with what type and amount of data they are expected to share and communicate. Choosing a coordination mechanism (in pilots) should be done carefully as the effectiveness of coordination decreases if members are not able or not willing to share the type of information required in a certain design.

4 Functional architecture templates

This chapter presents the functional architectures templates for implementing collective energy activities introduced in Chapter 3 (Table 4-1). For each activity, we present the necessary tools, and the requirements for a coordination mechanism. Additionally, we provide an information flow diagram that outlines the different phases of execution, illustrating how the activity is carried out step by step by one of the roles described in Table 4-1.

Figure 4-1 - The phase of the USEF market coordination mechanism [1]

Interactions are defined along the USEF phases[4] illustrated in Figure 4-1 which are Contract, Plan, Validate, Operate, and Settle. The rough timelines are:

- Contract is ~Year (s) to Week ahead. The actions described in the Contract phase are needed to do the collective energy activities (prerequisites). We assume these actions happen offline. Identification of supporting tools and platforms for this phase is left out of scope.
- Plan is ~Week to Intraday, often planning happens around Day Ahead.
- Operate is within the Imbalance Time Settlement period, typically 15 minutes,
- Settle is Hours to Months after.

The correct timelines should be configured for each local situation.

Table 4-1: List of roles identified as relevant for the collective energy activities (see Appendix A)

Actor	Source	Phases	Role
EC Member	Appendix A	All	This is an active consumer in the Energy Community that can act in activities as consumer but also as producers, storage facility provider etc.
EC Manager	Appendix A	All	The Energy Community Manager is the entity which has the authority to act on behalf of the community and is responsible for its actions.
Incentive provider	Appendix A	Contract	This is the party responsible for providing incentives to the community to activate its flexibility like shifting schedule for consumption of the locally produced electricity, shifting production schedules, or

[4] See Appendix A for the motivation to use this part of the Universal Smart Energy Framework.

Actor	Source	Phases	Role
			any other flexibility actions. This party is for example the energy supplier or the DSO.
Flexibility Service provider (FSP)	HEMRM	All	A party that offers flexibility services based on acquired (aggregated) Resources. (Source: HEMRM)
Balance Responsible Party (BRP)	HEMRM	All	A party financially accountable for its imbalances. (Source: HEMRM)
Energy Supplier	HEMRM	All	An Energy Supplier delivers energy to or takes energy from a Party Connected to the Grid at an Accounting Point. (Source: HEMRM)
Sharing Result Administrator	ENTEC	All	The role in charge of registering the energy shared.

We present the functional architecture templates for a single mechanism combined with insights into barriers to apply other type of coordination mechanisms. We chose mediated cooperation as this single mechanism as it provides a simplistic and clean view of the requirements needed to enable an activity in the other indirect control design.

4.1 kWmax

The collective energy activity kW-max refers to a coordinated effort within energy communities to collectively stay within a predefined maximum power consumption limit. This limit expressed in kilowatts (kW) can be established via a group-level/dependent connection contract or via a separate contract e.g. capacity limiting contract that the group has with the DSO. It may be a fixed threshold or announced in advance, such as a day ahead or even just a few hours prior.

To successfully adhere to this group-level constraint, the community must implement a system for real-time monitoring and adopt a collaborative coordination strategy. These mechanisms enable members to adjust their energy usage dynamically and ensure that the total consumption remains within the agreed-upon limit. Crucially, this activity relies on effective internal communication to align individual actions with the collective goal.

4.1.1 Tools/Algorithms/Mechanisms

To carry out this activity, a coordination mechanism (Table 4-2) and a peak forecasting algorithm (see Table 4-3) are required. A secondary billing tool is needed if the community likes to incentivise community members for their positive or negative contribution to meeting the goal.

Table 4-2: Coordination mechanism for kW-Max

Coordination mechanism for kW-Max	
Function	The function of this mechanism is to come to a solution to stay under the communicated kW limit.
Requirements/ preconditions	○ It must find at all times a solution that is acceptable given the terms and conditions of the incentive provider. ○ If penalties apply for kWmax exceedance the communities has to take these risks into account.
Coordination mechanisms	No barriers found in the functional architecture to apply a certain mechanism.
Inputs	○ Forecasted peak generation and consumption of each EC member ○ Availability of flexible assets (for instance, a battery can lower kW-requested).
Outputs	Control signal to flexible assets.

Table 4-3: Peak forecasting algorithm

Peak forecasting algorithm	
Function	The forecast algorithm predicts the peak consumption and/or production profile for each asset or on an aggregated level (Member, Community).
Requirements/ preconditions	Relevant data should be available.
Dependency on coordination mechanism	In direct control there is only a centralised forecasting algorithm. In mediated coordination approaches the forecasting algorithm can be (partly) centralised. EC Members need also a forecasting algorithm to optimise their response in implicit competition. In the other designs the forecasting takes place at the level of the EC Member.
Inputs	Relevant data e.g.: ○ Weather predictions ○ Historical production/consumption values ○ Standard load profile ○ Relevant events Parameters: - Risk profile (what risk is accepted when calculating the peak).
Outputs	Estimated peak consumption/production per member/asset.

4.1.2 Interactions between stakeholders

Figure 4-2 provides the information flow diagram. Below we describe the steps.

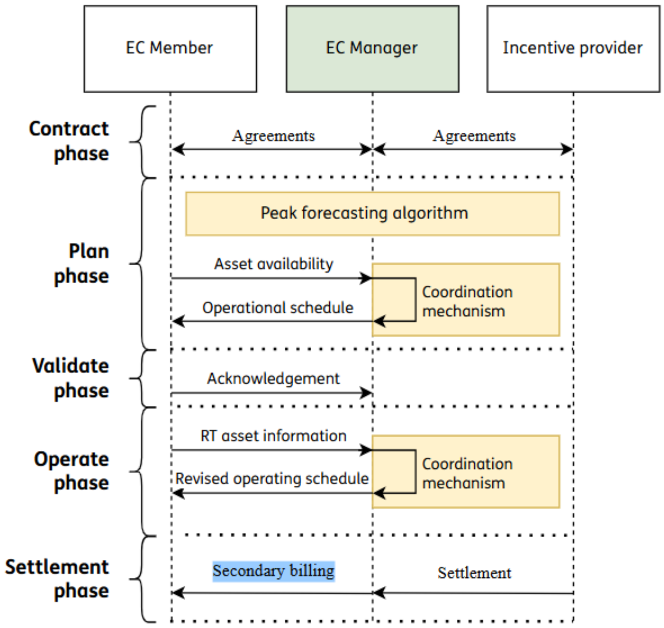


Figure 4-2 - Information flow diagram for collective kWmax

1. Contract phase:
    - EC Member and EC Manager: In these agreements the members agree for the manager to be their representative and act on their behalf. Other terms and conditions to ensure execution of this activity are also a part of these contracts/agreements. There might also be some renumeration schemes mentioned in the contracts for invoicing purposes.
    - EC Manager and Incentive provider: An agreement between them covers the terms and conditions for adhering to an incentive. This agreement can be part of a 'grid connection contract' with the DSO or an 'energy supply contract' with an Energy Supplier.

2. Plan phase: In the plan phase, a peak forecasting algorithm is executed to know the expected peak production and consumption of members or on the level of individual assets. A coordination mechanism is executed to create a schedule that ensures (by taking into account probabilistic risks or an N-1 constraint) the community stays within its assigned limits. The final running schedule is sent to the respective EC Members to make them aware of the actions they have to take to ensure that the community does not exceed its limit.

3. Validation phase: In this phase, the EC Member sends an acknowledgement of receiving the operational schedule.

4. Operate phase: This happens in real time and assets are scheduled to ensure adhering to the incentive, in this case, staying under the limit. The situation can change during the day of execution and there is a chance of deviation from the prognosis. In these cases, a real time optimization can be executed to ensure staying within the kW max limit.

5. Settlement phase: If there are any transactional incentives associated with staying within the kWmax limit, or penalties for going over the limit, they are settled with the EC Manager. These might be further distributed among the members of the community using the secondary billing tool.

4.2 Community flex activation delivery to a flexibility service provider

In this activity, the community uses its assets and the flexibility to respond to flexibility requests from a third party. These third parties are called Flexibility Service Providers (FSP) and are interacting with parties in need for flexibility such as grid operators or energy traders. Depending on the market the community is participating in, the FSP is qualified as a e.g. Balance Responsible Party (wholesale market), Balance Service Provider (balancing market) ,Congestion Service Provider (local flexibility market) or Capacity Service Provider (e.g. reactive power markets). A community can act on different markets via one or even multiple FSPs.

4.2.1 Tools/Algorithms/Mechanisms

To carry out this activity, a dual coordination mechanism (Table 4-4) is required. Furthermore, a flexibility forecasting algorithm (Table 4-5) is required to estimate the flexibility available in resources such as heat pumps and EV. If baselines or (drop-to) limits are defined on connection or community level, it is needed to predict uncontrollable load and production (e.g. using a profile or peak forecasting algorithm such as defined in Table 4-7 or Table 4-3) as well. A secondary billing tool is needed if the community likes to attribute the costs and benefits of the flexibility activity to the members who contributed by providing flexibility.

Table 4-4: Coordination mechanism for flexibility service provision

Coordination mechanism for flexibility service provision	
Function	a. Respond to a flexibility request of the FSP with an offer that can be delivered with a certainty level that fits the terms and conditions of the contract between the EC and the FSP. For some products it might be needed that the EC sends the FSP a baseline against which the flexibility activation can be checked. (step a) b. If a flexibility offer is accepted by the FSP, try to deliver this flexibility while taking care of the constraints, preferences, and priorities of members of the community. (step b)

Coordination mechanism for flexibility service provision	
Requirements/ preconditions	a. Agreement with the FSP about the terms and conditions of the flexibility offerings. Prequalification of flexibility resources might be needed. b. A communication interface between FSP and EC Manager.
Coordination mechanisms	Implicit and bilateral coordination designs make it challenging for the EC Manager to create offers as it has no oversight. Especially when the FSP requires a lot of certainty that an offer will be delivered. As such for function step a, Additional information sharing processes might be needed.
Inputs	○ Forecasted generation and consumption of each EC member ○ Availability of the assets for flexibility activation ○ Characteristics of flexibility resources.
Outputs	a. Flexibility offer and where needed: a baseline b. Plans for control of assets / control commands.

Table 4-5: Flexibility forecasting algorithm

Flexibility forecasting algorithm	
Function	Predict the flexibility each asset (or aggregated level) can provide with a certain confidence level or risk acceptance profile.
Requirements/ preconditions	Relevant data should be available.
Dependency on coordination mechanism	In implicit and bilateral coordination designs a central forecast or forecast aggregation process might be required to ensure the EC Member can provide a plan with enough ‘trust’ or to comply with requirements such as providing a baseline and/or flexibility activation plan per asset/member. In all designs it is possible to have an individual, central and or dual level forecasting process.
Inputs	Relevant data e.g.: ○ Weather predictions ○ Operational historical data e.g. respond rate, ramp rate, etc.
Outputs	An estimate of the flexibility that can be provided per asset (or aggregated level).

4.2.2 Interactions between stakeholders

Figure 4-3 provides the information flow diagram. Below we describe the steps:

1. Contract phase:
    - EC Member and EC Manager: These agreements define the terms and conditions under which the member’s flexibility will be activated as well as how jointly owned assets should be controlled.
    - EC Manager and FSP: An agreement is needed about responsibilities and terms and conditions for providing flexibility when requested.

2. Plan phase: In this phase, the EC Manager receives the information about the need for flexibility via a flexibility request. Coordination mechanism (step a) is used to align the flexibility sources in an optimal way (e.g. fair, economically optimal). The result of a flexibility forecasting algorithm is used as input to this optimization. A resulting flexibility offer (or multiple) is sent to FSP. Depending on the requirements of the market the FSP operates in the EC Member should send also a baseline. The FSP may need a baseline to quantify the delivered flexibility to his customer (a grid operator or energy trader) or to establish a Transfer of Energy with the Balance Responsible Parties of the EC Members.

3. Validation phase: When the flexibility offer is accepted by the FSP, the flex offer gets transformed into a flex order for the EC Manager. EC Members are also informed of the actions/flexibility to be performed on an individual level.

4. Operate phase: The agreed upon operational schedule is carried out. If applicable (for example for balancing products) low granularity set points will be provided by the FSP. There can be an update from the EC member about availability of the assets or expected deviations from earlier forecasts (especially when used as baseline for the flexibility product delivery); this might trigger a real time coordination mechanism.

5. Settlement phase: The FSP settles with the EC Manager for the flexibility provided. Further, to distribute the invoice among the EC Members, the manager uses the secondary billing tool.

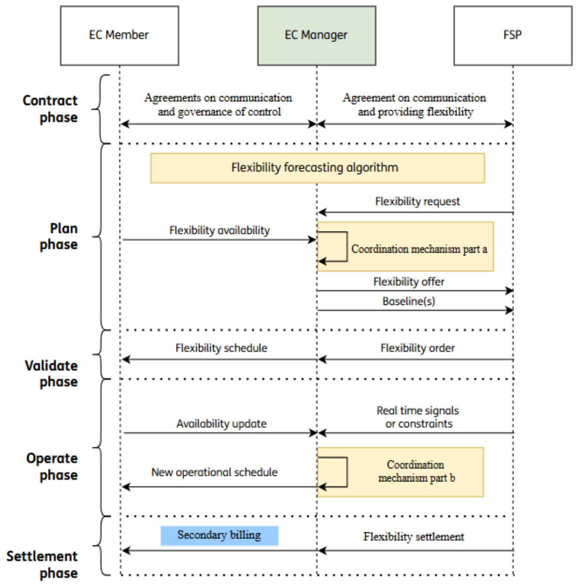


Figure 4-3 - Information flow diagram for community flex activation (delivery to a flexibility service provider)

4.3 Community self-balancing

In the activity self-balancing the members use the flexibility of their assets to ensure their realised energy consumption and production matches the planned load. Defining the planned load is also part of this activity.

4.3.1 Tools/Algorithms/Mechanisms

To carry out this activity, a coordination mechanism (Table 4-6), a profile forecasting algorithm (Table 4-7) and flexibility forecasting algorithm (Table 4-5) are required. A secondary billing tool is needed if the community likes to allocate balancing costs to individual members.

Table 4-6: Coordination mechanism for self-balancing

Coordination mechanism for self-balancing	
Function	a. To provide a joint planning to the Balance Responsible Party. (step a) The planning should be optimized against the expected costs (financial or comfort impact) of rescheduling (coordination mechanism part b) and/or expected imbalance costs left after applying 'step b.' b. To minimize at real-time the deviation from the scheduled load and/or minimize the expected imbalance costs (step b).
Requirements/ preconditions	The EC Manager can provide the joint nomination for the EC Members as a group to a single BRP.
Possible coordination mechanisms	For creating a joint planning (mechanism part a) additional information flows should be introduced to give the EC Manager enough insight.
Inputs	Step a: forecasts of the consumption/production Step a: *(optional)* flexibility availability estimates Step b: now-casting of production, consumption, and flexibility availability Step b: *(optional)* real-time imbalance prices.
Outputs	a. Nomination on group level + optional: flexibility availability plan (e.g. ensure battery is available to ramp up and down) b. Flexibility activation plans/commands.

Table 4-7: Profile forecasting algorithm

Profile forecasting algorithm	
Function	The forecast algorithm predicts the consumption and/or production profile for each asset or on member level.
Requirements/ preconditions	Relevant data should be available.
Dependency on coordination mechanism	See peak forecasting algorithm in Table 4-3.
Inputs	Relevant data e.g.: - Weather predictions - Historical production/consumption values - Standard load profile.
Outputs	Estimated consumption/production per asset or member.

4.3.2 Interactions between stakeholders

Figure 4-4 shows the interaction between the stakeholders for the activity community self-balancing.

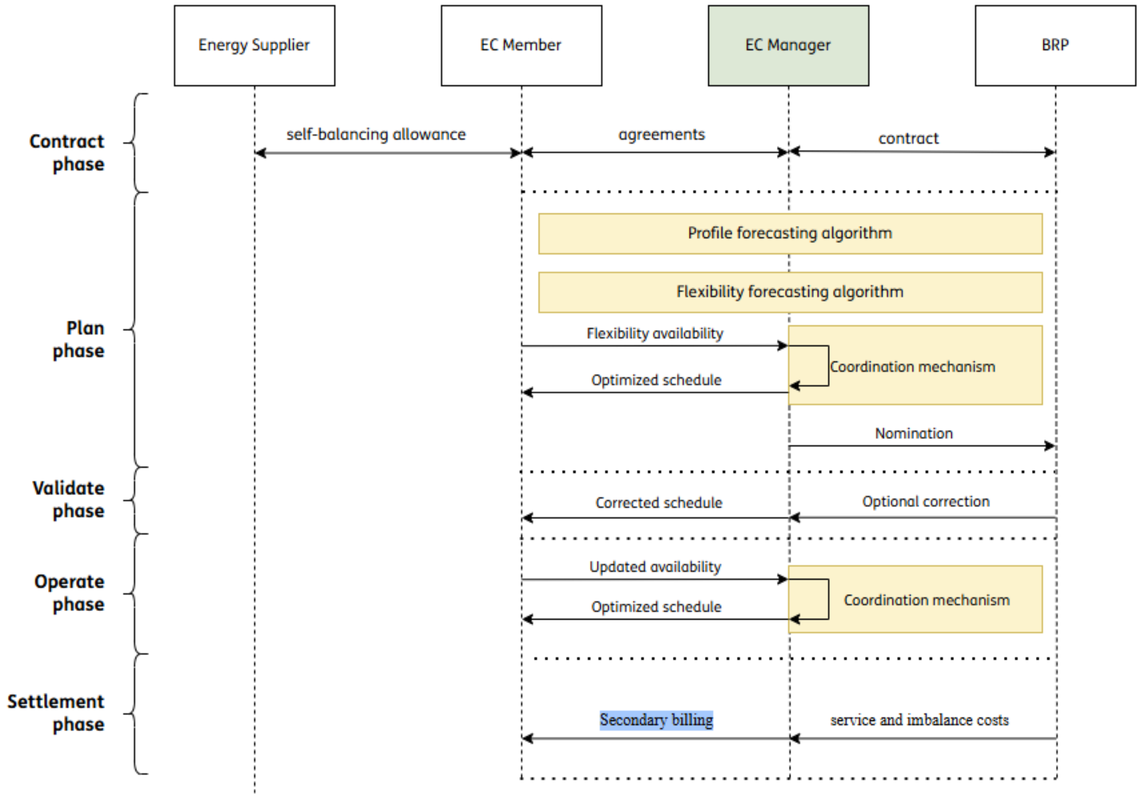


Figure 4-4 - Information flow for community self-balancing

1. Contract phase:
    a. EC Member and its own energy supplier (who by default takes care of the BRP role): members needs to have a supply contract in which is defined that their balance position will be taken care of via a group balancing contract.
    b. EC Manager and BRP: The EC manager contracts one party (the BRP or an intermediate party) that take care of the balancing the group. The EC manager and BRP agree on the communication interface.
    c. EC Member and EC Manager: The community needs to agree on the terms and conditions on how to perform this activity.

2. Plan phase: The forecasts of load/feed-in and flexibility as well as resource availability information is used as an input to a coordination mechanism. The coordination mechanism is used to find schedule that will be send as the nomination to the BRP.

3. Validation phase: The BRP checks the nomination, and the EC manager needs to communicate any corrections to the level of the members and/or individual assets.

4. Operate phase: The community tries to minimize at real-time the deviation from the scheduled load and/or minimize the expected imbalance costs by activating flexibility resources.

5. Settlement phase: Between the EC manager and the BRP there will be a settlement for energy against imbalance costs. The EC manager pays the BRP also for its service. The community can use a secondary billing tool to distribute imbalance costs or incentive members who contributed to a reduction of costs.

4.4 Energy sharing via cash-back model or vouchers

The activity energy sharing via cash-back model or vouchers is defined by an ex post registration of shared energy. The registration of shared energy takes place after realisation of energy consumption and feed-in and results in a cash-back or provision of vouchers. The cash-back / vouchers provision creates an incentive for the community to optimise its collective self-consumption.

In the template it is assumed that no limitations apply to allocate volumes to certain EC Members. Restrictions in the sharing (e.g. static sharing keys, restricted dynamic optimization, or calculation of shared volumes by the Sharing Result Administrator without input from the community) result in a more straightforward implementation: some interactions are not needed. Furthermore, we assume that further steps in the sharing registration (e.g. check against measurements and rules) is taken care by the Sharing Result Administrator.

4.4.1 Tools/Algorithms/Mechanisms

To carry out this activity, a coordination mechanism (Table 4-8), a profile forecasting algorithm (Table 4-7) and a flexibility forecasting algorithm (Table 4-5) are required. A secondary billing tool is needed to distribute the cash-back/vouchers to the members.

Table 4-8: Coordination mechanism for collective self-consumption maximization

Coordination mechanism for collective self-consumption maximization	
Function	a. Prepare for maximizing the collective self-consumption by making flexible resources available. (step a) b. Maximize the collective self-consumption volume in the community. (step b)
Requirements/ preconditions	Limitations to sharing (e.g. sharing key rules) should be taken into account.
Possible coordination mechanisms	No restrictions found to apply a certain coordination mechanism design.
Inputs	Estimated consumption and production Flexibility forecasts Availability of assets.
Outputs	Control plan/commands of flexible resources.

4.4.2 Interactions between stakeholders

Figure 4-5 shows the interaction between the stakeholders for the activity energy sharing via cash-back model or vouchers.

1. Contract phase: The EC manager registers the community via a Sharing Result Administrator such that the community can take part in the cash back or voucher program. The EC members agree on the terms and conditions of the sharing optimization within the community.

2. Plan phase: Forecasts of consumption/production and flexibility availability provide the starting point for the coordination. The coordination mechanism optimizes the matching of demand and supply at every time window by planning the activation of flexible assets.

3. Validation phase: The members validate the plan that was the result of the coordination mechanism.

4. Operate phase: When EC member identify deviations from the forecasted load or feed-in or the scheduled flexibility activation a coordination mechanism is called to provide a new schedule.

5. Settlement phase: The community may provide input to the Sharing Result Administrator such as the volumes to be shared or parameters indicating preferences. It is also possible that there is no possibility from the EC Manager to influence the sharing result and no communication to the Sharing Result Administrator is required. The community receives from the Sharing Result Administrator the cash-back / vouchers and needs a secondary billing to divide the benefits among the members of the community.

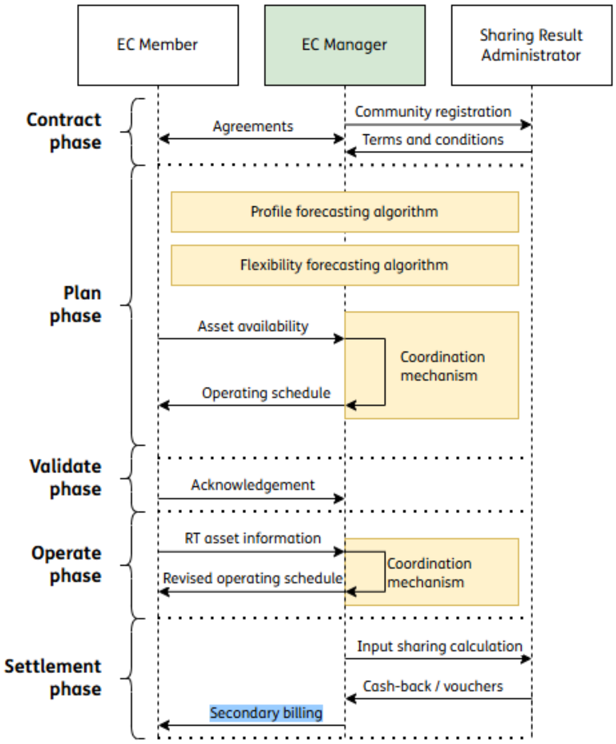


Figure 4-5 - Information flow diagram for energy sharing via cashback model or vouchers

4.5 Energy sharing via adjusted energy bill model

The EC manager communicates the energy sharing to a Sharing Result Administrator that results in an adjustment on the energy bill. This means consumers are not charged for the energy shared, however service fees, balancing costs and taxes may still apply to volumes shared. This adjustment due to self-consumption can be included in the primary bill of energy consumption from the energy supplier or can be a provided in separate bill indicating a reduction in the primary bill. How this process takes places falls outside the scope of the energy community: it is taken care of by the Energy Sharing Administrator. Similar to the cash-back / voucher model, we assume in the templates no limitations apply to allocate volumes to certain EC Members. If that is the case the 'input sharing calculation' information exchange might not be needed.

It is possible that energy sharing has no economic benefits for the community members. The retail tariffs can be competitive to the offering from the community. When the community offering is competitive, energy sharing results in an incentive to optimize the allocation of energy to members. The differences in the energy retail prices that member have agreed with their energy suppliers provide input for the optimization. The community needs to decide how the individual preferences should be balanced in relation to the community goals.

Energy sharing via adjusted energy bill model has similarities with the cash-back/voucher model, but the following differences introduce differences in functional requirements:

- The Energy Suppliers of the individual members are added as additional stakeholders. However, the amount of energy shared is registered 'ex post' the activity has consequences for the sourcing/trading strategy of the Energy Supplier. When the energy the Energy Supplier has sourced for the consumer via long term contracts is settled via a regulated price (e.g. day ahead price) the Energy Supplier wins or loses the price difference. As a consequence of the additional risk of losing money Suppliers may charge additional costs to consumers taking part in energy sharing. By provide in the contracts and plan/validate phase information to the Energy Supplier the transparency to this stakeholder can be increased so he can optimize trading. Note: at the moment energy suppliers don't have information exchange processes implemented for such interactions with the consequence that additional charges apply.

- The retail contracts of the members are an additional factor in this model. Not only the self-consumption should be optimised but also individual retail price differences can be optimized. This introduces additional complexity to the coordination algorithm but also introduces questions about how to divide the benefits of sharing energy over the members. In the cash-back model the group receives a total benefit while in the adjusted energy bill model individual choices for retail contracts have an effect on the benefits.

4.5.1 Tools/Algorithms/Mechanisms

To carry out this activity, a coordination mechanism (Table 4-9[5]), a profile forecasting algorithm (Table 4-7) and a flexibility forecasting algorithm (Table 4-5) are required. In case consumers have dynamic price contracts their energy suppliers provide at day-ahead the prices. It might be beneficial to forecasts these prices support pre-day ahead planning e.g. empty storage buffers to prepare for a day with low day-ahead prices. A secondary billing tool is needed to send invoices for the consumption of energy from the community or individual members. It is also possible to use this tool to redistribute individual benefits within the community.

Table 4-9: Coordination mechanism energy sharing with bill adjustment

Coordination mechanism energy sharing with bill adjustment	
Function	Optimize the benefit of sharing energy within the rules defined by the community.
Requirements/ preconditions	The coordination mechanism assumes members have different energy retail prices.
Possible coordination mechanisms	No restrictions found to apply a certain coordination mechanism.
Inputs	Forecasts of production/consumption Flexibility resources availability info and forecasts Energy retail tariffs of individual members (for consumption and feed-in, including dynamic prices)
Outputs	a. Schedules for activation of flexibility resource (plan phase) b. Control plans/commands for flexibility resources c. Allocation of shared energy to individual members

[5] In case there is no difference in retail tariffs mechanism that is used for the activity the mechanism in Table 4-8 is sufficient.

4.5.2 Interactions between stakeholders

Figure 4-6 shows the interaction between the stakeholders for the activity energy sharing with bill adjustment. Below the information exchanges per phase are described.

Contract phase: The members of the community have a contract with an energy supplier. The energy supplier has defined terms and conditions for sharing energy in their contract with consumers. Some of these terms are regulated. The EC Manager registers the community for taking part in sharing and sets up the interfaces to the Sharing Result Administrator.

Plan phase: Forecasts of consumption/production and flexibility availability provide the starting point for the coordination. Furthermore, information about the supply prices that apply to the individual the community members is required. It is possible that community members have dynamic pricing schemes. Such prices typically depend on the day-ahead clearing and are not known at the moment the sharing volumes should be defined (before day-ahead). The coordination mechanism optimizes the matching of demand and supply at every time window by planning the activation of flexible assets.

Validation phase: The EC members acknowledge the schedules for activation of flexible assets and/or verify the forecasts of consumption and production. The EC Members can also notify their energy suppliers about the scheduled energy sharing to optimize day-ahead and intraday trading processes.

Operate phase: During operation, the It might be beneficial to notify the energy supplier about this activation as this unforeseen flexibility can increase the energy supplier's/BRP's trading or balancing costs.

Settlement phase: The community may provide input to the Sharing Result Administrator such as the volumes to be shared or parameters indicating preferences. With this information the Sharing Result Administrator determines the shared volumes and requests a change in the energy bill at the energy suppliers of the members of the community. The community members receive an adjusted energy bill. Afterwards the community can use a secondary billing tool to settle internal trade and/or redistribute benefits.

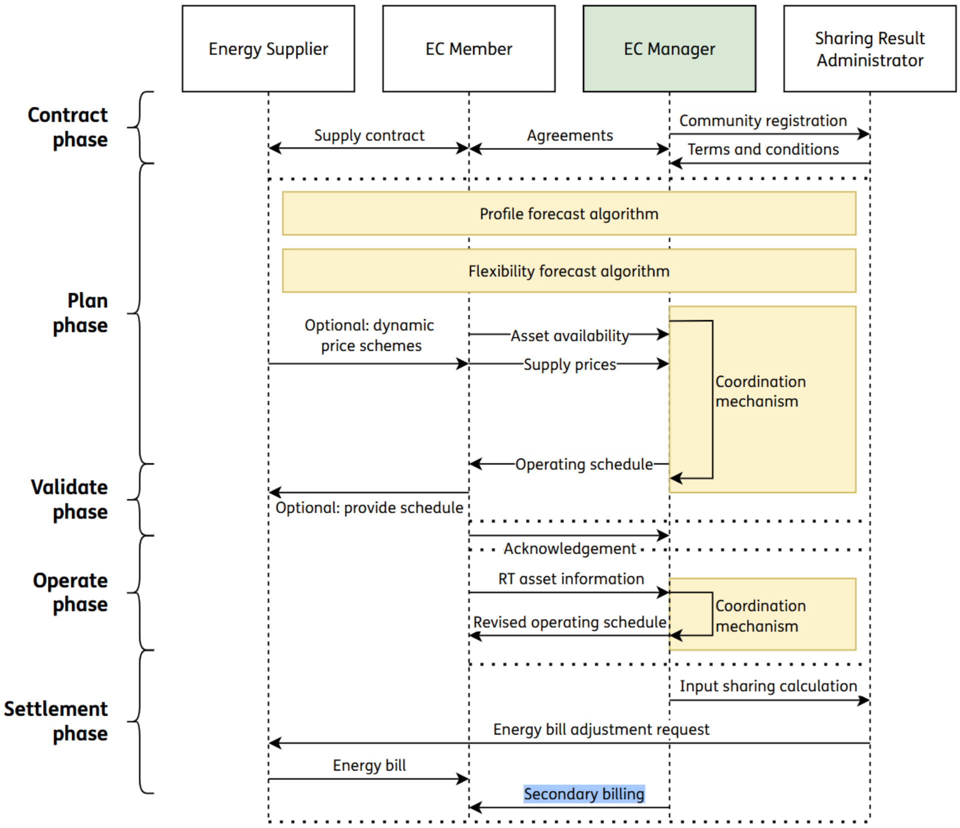


Figure 4-6 - Information flow diagram for energy sharing via adjusted bill

4.6 Energy sharing via joint self-sub-supply

In the activity joint self-sub supply community members have a primary supplier but are also supplied from the community. The sub-supply is registered as allocation which means that actual energy is delivered between the members of the community. The community communicates the amount of energy to sub-supply to the Energy Sharing Administrator. This party communicates the sub-supply to the energy supplier and BRP such that they can take that into account in the energy trading and balancing strategy.

The sub-supply results in a change on the energy bill of individual members as their energy suppliers do not supply (consumption) or take off (production) the energy that is shared. For the shared volumes, the supplier might still invoice administration costs and taxes (this depends on regulation). When sharing energy is competitive to the supply price offering from the energy retail, the community has as objective to optimize the energy sharing. As consumer may have different supply prices individual benefits should be considered in relation to community level benefits.

4.6.1 Tools/Algorithms/mechanisms

To carry out this activity, a coordination mechanism (Table 4-10), a profile forecasting algorithm (Table 4-7) and a flexibility forecasting algorithm (Table 4-5) are required. Also, a price forecasting algorithm might be needed. A secondary billing tool is needed to invoice the members for the energy shared (as producer or consumer).

Table 4-10: Coordination mechanism for joint self sub-supply

Coordination mechanism joint self sub-supply	
Function	Maximize the benefit of energy exchange within the community.
Requirements/ preconditions	The volume to be shared at what allocation point should be defined ahead (planning phase).
Possible coordination mechanisms	The EC Manager needs insights in the plans to share energy. In implicit and bilateral coordination mechanisms this requires an additional information stream.
Inputs	Forecasts of production/consumption Flexibility resources availability information and forecasts Energy supply tariffs of individual members (for consumption and feed-in, including dynamic prices).
Outputs	a. Energy sharing allocation schedule (day-ahead) b. Control plans/commands for flexible assets.

4.6.2 Interactions between stakeholders

Contract phase: The members of the community have a contract with an energy supplier. The energy supplier has defined terms and conditions for sub-supply which includes requirements for notification of sub-supply and costs associated with sub-supply (administration costs and possibly taxes and levies). The EC Manager registers the community for taking part in sharing and sets up the interfaces to the Sharing Result Administrator. Also, the community needs to agree on how to coordination in relation to this activity. In particular the community needs to define how to balance individual interests and community objectives.

Plan phase: Given the forecasted consumption/production, (forecasted) flexibility availability, and supply prices the coordination mechanism determine an optimal schedule for sharing energy and related planning of flexible resources. This plan is shared with the Energy Sharing Administrator who notifies the Energy Supplier and/or BRP (often this is the same party) about the sub-supply such that they can take it into account in the day-ahead trading.

Validation phase: There is an acknowledgement from the EC Members after receiving the schedule.

Operate phase: In the operate phase, there can be sharing of real time information about assets and if necessary, a real time coordination mechanism is run to provide a revised operating schedule to ensure the shared energy is actually consumed and does not result in any unplanned loads that needs to be supplied – for a higher costs - by the energy supplier/BRP of the members.

Settlement phase: The Energy Supplier sends the EC members a bill in which the sub-supply has been processed. The energy community can use a secondary billing tool to invoice the shared energy and redistribute costs and benefits among the members.

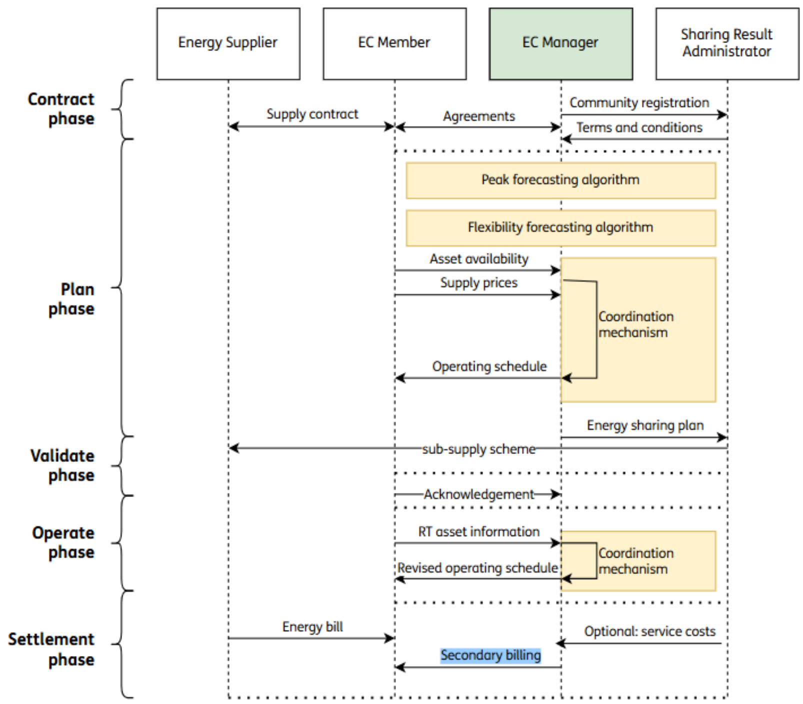


Figure 4-7 - Information flow diagram for energy sharing via sub supply

5 Conclusions

This report presents a set of functional architecture templates for activities of energy communities related to energy sharing and peer-to-peer trading. The templates provide as a reference architecture guidance on the development and integration of algorithms and tools:

- Overview of functional building blocks and the relation between them
- Role of coordination mechanisms and related functional requirements
- Role of tools and algorithms and related functional requirements

Furthermore, this report provides an overview of the coordination mechanism designs that can be used. We demonstrated that each design type results in another type of information exchange between EC Member and EC Manager while the relation between the EC Manager and Third Parties is determined by the collective energy activity.

In theory all types of coordination mechanisms can be applied to all the collective energy activities discussed in this report. However, some activities such as providing flexibility services to a Flexibility Service Provider require the EC manager to have oversight. This need introduces additional information sharing requirements in decentralised designs.

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APPENDIX A: GUIDELINES FOR HARMONIZATION OF COLLECTIVE ENERGY ACTIVITIES

In this Appendix, we present a set of guidelines for the harmonization of collective energy activities. These guidelines are the result of our efforts to establish a way to describe activities of energy communities across social, business, and legal contexts at a functional level required for software development: what concepts, framework and terms should be used?

The harmonization of activities was explored analyzing the *collective energy activities* identified as relevant for the U2DEMO pilots in WP1, from the perspective of the development of functional architectures in Task 2.1. The guidelines are intended to be used by Task 2.1.

A.1 Need for functional harmonization

To enable energy communities to adopt open-source software effectively, it is essential that such software can support diverse regulatory, business, and social contexts with reasonable effort. This means that implementation of an open-source tool[6] or platform within a specific energy community must be achievable within a timeframe and budget that aligns with its business case. From the perspective of developers of tools and algorithms, a harmonized reference is crucial to support these needs.

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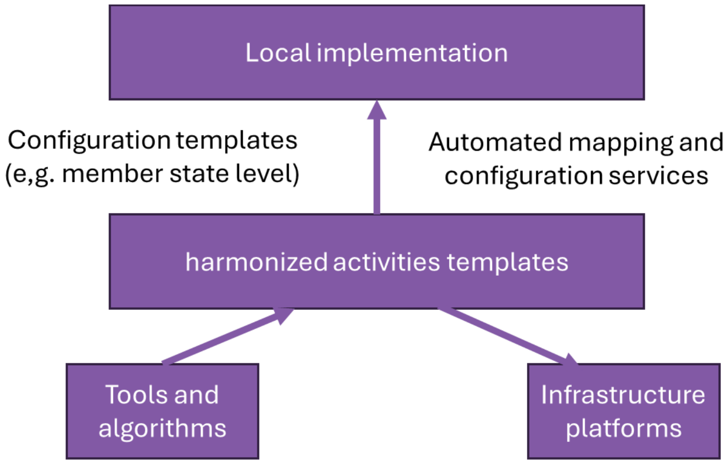

Figure A.1 - Vision on the harmonization of collective energy activities. Templates of functionally harmonized activities support the mapping of a local situation to a tools, algorithms, and platforms. Automated mapping and configuration services can be built on the templates speeding up local implementations

Figure A.1 explains our vision on the harmonization of collective energy activities. Energy communities can find and implement templates of functionally harmonized activities created by developers of other local implementations (e.g. in other member state) or specific tools, algorithms or platforms. These templates offer information exchange structure and provide placeholders for tools and algorithms. The templates have the function of a reference

[6] For an overview of existing open-source solutions see U2DEMO Deliverable T1.3: Mapping and Interoperability Assessment of existing Open Source Solutions for Active Consumers

architecture[7] lowering the barriers of implementing of open source tools and algorithms in a specific implementation (concrete architecture) by providing a universal structure for implementing certain activities.

Additionally, configuration templates can support communities with setting up connections to relevant platforms (e.g. local energy markets) and parties (e.g. energy suppliers or aggregators). Finally, automatic mapping and configuration services can be developed. These tools can help energy communities to find and implement templates at even a greater speed.

In order to achieve this future vision, we need a framework to structure a description of the functional aspects of activities of energy communities.

A.2 Method

Two existing frameworks were used to explore the harmonization of collective energy activities from the perspective of functional architecture development:

1. Harmonised Electricity Market Role Model (HEMRM) developed by ENTSO-E, EFET and ebIX [5]. The HEMRM is a model for analysing roles in information exchange processes within the domain of electricity markets.
2. The Universal Smart Energy Framework [1] developed by the USEF foundation USEF is a framework providing guidelines for the harmonization and development of distributed flexibility mechanisms. USEF focuses in particular on harmonizing information processes between the retail market and wholesale/balancing market.

HEMRM and USEF offer a view on the information exchange between roles involved agnostic from who are the parties that fulfil this role. The models are also agnostic to architectural (e.g. centralised or decentralised control or data sharing approach), or technical (e.g. using blockchain) choices made. Both frameworks can be used as a shared reference for different business, legal and technical contexts. The differences between these contexts are brought back to a single level of abstraction that covers the aspects needed to create functional architectures.

HEMRM and USEF were not made as a reference for the development of tools for energy communities. We explore their ability to serve as a reference in this domain by studying collective energy activities identified in WP1 using a tailored set of questions covering elements of both HEMRM and USEF:

1. **Who is the subject of the activity? What is the related HEMRM role?**

   In USEF, the subject of the activity is always the aggregator. In the HEMRM, the subject of an information flow task is a harmonized role. We ask this question to find out what viewpoint would be appropriate to adopt when functionally harmonizing the activities of energy collectives: a single perspective on the energy community like USEF or a role-based perspective on the role the energy community has in a certain activity?

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[7] '*A Reference Architecture describes the structure of a system with its element types and their structures, as well as their interaction types, among each other and with their environment. A Reference Architecture defines restrictions for an instantiation (concrete architecture). Through abstraction from individual details, a Reference Architecture is universally valid within a specific domain. Further architectures with the same functional requirements can be constructed based on the reference architecture.'* Source: 2_sgcg_methodology_overview.pdf

2. **What is delivered by the subject? Is it energy or energy flexibility?**

In USEF, flexibility is always the delivered good/service, but USEF distinguishes:

1) What is delivered by 'delivering flexibility'? Is it a direct provision of something (activation), is it an option made available under certain conditions (availability)? Is the flexibility delivered with or without an energy transaction?
2) What is the subject remunerated for? For the delivery of availability or activation in terms of kWs/kWs or is there also a punishment for non-compliance such as response rate or ramp rate?

What is delivered is not made explicit in the HEMRM but can be derived from the description of roles and relationships between the roles. This difference between HEMRM and USEF raises the question whether the type of delivery should be stated centrally in a reference architecture (such as flexibility in USEF) or in a more implicit way (HEMRM).

3. **Who is the recipient of the activity? What is the related HEMRM role?**

In USEF, the recipient of flexibility is either the prosumer himself (in case of implicit flexibility) or a Flexibility Requestion Party such as a grid operator or a market participant (explicit flexibility). In the USEF *White Paper Energy and Flexibility Services for Citizens Energy Communities* [14] it was identified that in energy communities other types of delivery interactions apply. In the HEMRM these relations are modelled as interactions of one party (in a certain harmonized role) with another harmonized role. We like to explore if the relations identified in the activities of energy communities are covered in the HEMRM and if it makes sense to represent the recipient explicitly as done in USEF.

4. **Towards which other roles does the subject have responsibilities? And what is the role of this party according to the HEMRM?**

To what other parties does the activity have impact on and as such should the subject inform, settle or in another way interact with? In USEF the interactions with other stakeholders such as the Energy Supplier and Balance Responsible Party are defined. With this question we explore what type of other parties play a role in the activities of energy collectives such that information exchanges to parties outside the community can be identified. The HEMRM does not provide guidance on what interactions are required. We explore if it includes the interfaces required to align with other stakeholders in the collective energy activities

A.3 Results

The results of our exploration to map collective energy activities to HEMRM and USEF can be found in Table A.1. This mapping gives insights into what aspects of information exchange in energy collectives are covered by HEMRM and USEF.

Table A.1: Mapping HEMRM and USEF to the collective energy activities identified as relevant for the U2DEMO pilots

Activity	Subject	Delivery of energy or flexibility	Recipient	Other stakeholders
Collective kW-max	In terms of both USEF and HEMRM the energy community fulfils in this activity the role of an Energy Service Company (ESCO). contracted by multiple Prosumers (USEF) / Party Connected to the Grid (HEMRM).	There is no explicit delivery of energy or flexibility. There is only an implicit activation of energy flexibility.	NA	In USEF, the DSO and energy supplier are identified as parties who can provide implicit flexibility incentives such as constraints and time-of-used tariffs but there is after contracting no communication required with these parties to do this activity: the interactions (e.g. settlement) are already included in other processes.
Optimization for local sustainability goals	The energy community acts as ESCO.	idem	NA	Not applicable. The local sustainability goal is an internal goal of the energy community.
Collective flex activation delivery to a flexibility service provider	The energy community acts as a 'sub-aggregator'. In the HEMRM the EC is seen as a Resource Aggregator (HEMRM) providing (flexibility) resources to another Resource Aggregator (the Flexibility Service Provider) – here the EC is a kind of sub/secondary aggregator. In USEF, the community acts on behalf of the prosumers who contract together an Aggregator.	Energy flexibility is activated.	The recipient is a Flexibility Service Provider (HEMRM) / Aggregator (USEF).	The roles Energy Supplier and BRP are affected. USEF provides a framework to implement the interactions with these stakeholders e.g. notifications, Transfer of Energy. In the HEMRM these kinds of interactions are not explicitly modelled.

Activity	Subject	Delivery of energy or flexibility	Recipient	Other stakeholders
Collective self-balancing	The energy communities role can be seen as a Resource Provider (HEMRM), providing schedules to another market participant: the Energy Supplier. In USEF, the role of the community would be described as ESCO supporting with ‘self-balancing’. USEF focuses mainly on the delivery of the flexibility energy, the act of sending schedules in not explicitly described.	There is no explicit delivery of energy or flexibility. By sending the schedule the community buys or sells implicitly energy from the energy supplier. When flexibility is activated for the purpose of self-balancing this should be seen as an implicit activation of energy flexibility.	NA	The recipient of the energy schedule is the Energy Supplier in the BRP role (HEMRM and USEF).
Energy sharing via day-ahead sub-supply	The energy community as a group initiates this activity by registration of shared energy directly at the energy supplier or via a mediator assigned by regulator. The role the energy community fulfils (e.g. Energy Sharing Organizer) is not (yet) defined in the HEMRM.	Energy is delivered.	The recipient of the energy is another member of the community. The member of the community can be identified as a Party Connected to the Grid in the HEMRM.	The roles Energy Supplier and BRP are affected. Both USEF and HEMRM do not cover interactions required to manage this.

Activity	Subject	Delivery of energy or flexibility	Recipient	Other stakeholders
Energy sharing via adjusted energy bill model	The energy community as a group initiates this activity by registration of shared energy (volume or methodology) to a party assigned by a Member State to arrange the adjustment. Such a role (e.g. Energy Sharing Organize) is not (yet) defined in the HEMRM.	In this energy sharing model no energy is delivered. If the community responds with flexibility to optimize the energy sharing results this is implicit flexibility activation: no delivery of flex or energy.	NA	The adjustment on the energy bill affects causes a change at the Energy Supplier.
Energy sharing via cash-back model	idem	Idem	NA	In this energy sharing model no other stakeholders are affected.

Below we reflect on the results along the questions we defined ahead of the exploration:

What viewpoint would be appropriate to adopt when functionally harmonizing the activities of energy collectives: a single perspective on the energy community like USEF or a role-based perspective on the role the energy community has in a certain activity?

We identified a mismatch in the scope of the HEMRM and the domain of energy communities. The HEMRM provides a view on electricity market roles. When matching the role of the EC to these roles we find a match with terms as Energy Service Company (ESCO) or Resource Aggregator. In the domain of the electricity market it makes sense to represent the EC as such, but these terms do not make sense when describing software in the domain of energy communities as these terms hide an important part of what a party representing the energy community does in terms of information exchange: it communicates with HEMRM roles on behalf of its members, who are in the HEMRM identified as Parties Connected To the Grid. Also, the interaction between the EC (or a party representing the EC as group) and the members of the community are not covered in HEMRM.

We do not think that extending the HEMRM with a role for energy collectives, e.g. a role for jointly acting Parties Connected To the Grid will solve this issue because the energy collective fulfils in every activity a unique role in the communication to other HEMRM roles. Standardising all roles energy communities is also not feasible: it doesn't make sense to differentiate a 'community Resource Aggregator' from another Resource Aggregator as both have the same role in the information exchange to other roles. Furthermore, some roles like the 'sub-aggregator' (the EC acts as Resource Aggregator communicating with a market participants who is also Resource Aggregator) can be mapped on the HEMRM but seem to fall beyond the scope of domain 'electricity market' and so the HEMRM.

The approach used in USEF where interactions are mainly defined from the perspective of the key role (in the domain of USEF, the Aggregator) offers a more scalable solution when describing the role of the EC as initiator and manager of collective energy activities. To refer to this role we advise to use a term such as Energy Community Manager (EC Manager) that clearly indicates the role of this party as a mediator between the group and the 'rest of the world'. This is not a HEMRM type of role: an EC Manager can fulfil different role in information exchange process depending on the activity.

Should the type of delivery be stated centrally in a reference architecture (such as flexibility in USEF) or in a more implicit way (HEMRM)?

The type of delivery differs per activity and in various activities (e.g. collective kWmax, energy sharing via adjustment of energy bill) there is not a delivery of energy or flexibility. Because of the diversity of activities it does not make sense to state 'energy' or 'energy flexibility' as central concepts in a reference architecture.

Does it make sense to represent the recipient explicitly?

In the majority of activities there is not a recipient. In one activity the recipient can be identified by a role in the HEMRM such as the Flexibility Service Provider (FSP). For the activity 'Energy sharing via day-ahead sub-supply' it does not make sense to identify the EC member as consumer of shared energy as the recipient as they are not necessarily playing an active role in the information exchange process.

Does the HEMRM include the information interfaces required to align with other stakeholders (not subject or recipient) in collective energy activities?

Not all information interfaces are mentioned in the HEMRM. Interactions included in USEF such as Transfer of Energy and notification of activation are not explicitly represented in HEMRM.

Table A.2: Roles in energy sharing identified by [15]

Roles defined for the purpose of this study	Definition
Energy Sharing Group	A group of Consumers and Producers that share energy between their members (e.g. an energy community or the owners association of a multi-apartment building.
Energy Sharing Group Representative	A party or person representing the Energy Sharing Group (single point of contact for other stakeholders).
Sharing Request Validator	The role in charge of the validation of a sharing arrangement.
Sharing Result Calculator	The role in charge of calculating the result of the energy sharing.
Sharing Result Administrator	The role in charge of registering the amount of energy shared.

Furthermore, interactions (see Table A.2) around the registration of energy sharing such as the registration and processing of shared energy are not included (yet) in the HEMRM. When generalizing activities a challenging is that communities work with third parties to take care of the interactions with other parties and some interactions are taken care of by regulated parties. Therefore, the activities can be best, when harmonized for such differences, indicate the final responsible party the community has to interact with.

A.4 Conclusions

At some point in time business, social and legal context need to be translated into information exchanges. Harmonizing the latter has potential to reduce the efforts of communities to implement activities.

We explored how the Harmonized Electricity Market Role Model (HEMRM) and the Universal Smart Energy Framework (USEF) can support this functional harmonization. We identified that both frameworks provide useful elements for harmonization of the domain of energy communities but don't provide a full perspective for guiding the development of (open source) tooling and platforms.

The type of guidance the USEF framework offers (information flow diagrams per 'phase', guidance on interactions with other stakeholders) are useful but USEF targets only the sub-domain of energy flexibility and provides barely any guidance on how consumers/producers as a group can act.

The HEMRM provides standardized roles for information exchange actions in the domain of the electricity market but does not cover the type interactions we are mainly interested in: interactions between energy communities and their members, third parties, and the interactions with tools (e.g. for forecasting, control, etc.).

Given the above observations we identified the following guidelines for describing collective energy activities on a functional harmonized level:

1. Collective energy activities should be described from the perspective of the energy community. Only interactions between the energy community and the members of the community AND the direct communication between the community and other stakeholders are described. Tasks done behind the view of the energy community should not be described, they are the concern of parties in the value chain.

2. Collective energy activities should be defined as if the energy community interacts with stakeholders with final responsibility in European regulation such as the Energy Supplier, Balance Responsible Party or Balance Service Provider. Other parties can pick up this role in the activity and ensure that the responsibility is taken care of.

3. Describe the interaction between the energy community (in the role of EC Manager), the EC members and external stakeholders in the form of information exchanges. From the description of an activity the input and output of software implementing the activity can be defined.

4. Collective energy activities describe the role of a tools (this includes algorithms inside a tool). From the description of an activity the functional requirements for tools should be clear.

5. Define interactions along the USEF phases (Contract, Plan, Validate, Operate, Settle).

6. Relevant roles from the HEMRM – to refer to parties the EC interacts with:
    a. Flexibility Service Provider
    b. Balance Responsible Party
    c. Energy Supplier

7. Suggestions for new roles:
    a. EC Manager: A party representing the Energy Community as a group.
    b. EC Member: An individual Member of the Energy Community that interacts with the energy system via an EC Manager.

These guidelines can be used when making a functional architecture. It ensures that parties outside the energy community are referred to in terms of the HEMRM where possible and provides a relevant perspective on the domain of energy communities.