Integrating the Energy System – IES

Technical Framework on **Local Energy Communities**

TF-LEC

Vol.1

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Disclaimer: The content of this document is merely informative and does not represent any formal statement from individuals or the Austrian Research Promotion Agency (FFG), the Austrian Climate and Energy Fund (KLIEN), or any official bodies involved. Instead, it is a public document from contributing authors and editors with visionary perspective based on years of experience in their individual disciplines. Opinions, if any, expressed in this document do not necessarily represent those of the entire authors/editors team or any related funding bodies. Any views expressed are those of the contributing person at the time being.

Contents

1 About the Document

The **Technical Framework on Local Energy Communities (TF-LEC)** is a structured compilation of informative and normative specifications compiled according to the IES (Integrating the Energy System – www.iesaustria.at) recommendations and template, as shown in Figure 1.1. The TF-LEC shall enable the normalised use and application of existing standards and practices. Thereby, and in particulare because this document is public, interoperability among cooperative but independently developed products and systems shall be enabled.

1.1 Document structure

This Vol.1 summarises and clarifies the Local Energy Communities Business Case considered henceforth, including environmental constraints and envisioned opportunities to integrate energy consumers and distributed energy resources (DER) in the short term balancing of energy supply and demand. The Vol.1 closes with the informative specification of operational functionalities (*Business Functions*) and the naming of the independent IT systems that interact (*Meta-Actors*). The technical Vol.2 is a dynamic compilation of normative IES Integration Profiles (IIPs).

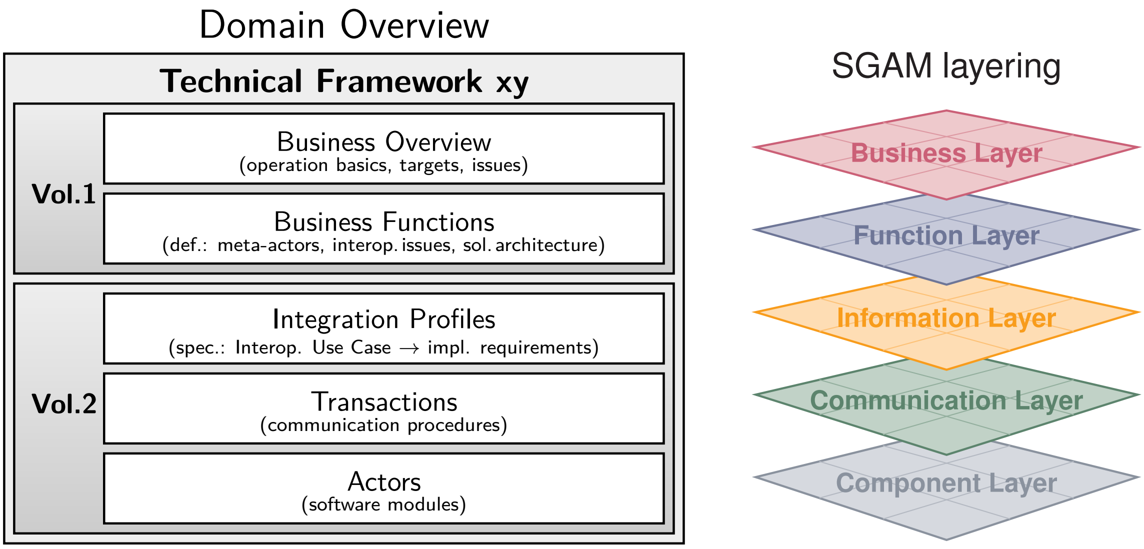

Figure 1.1: The IES Document Structure: roughly incorporating the five SGAM Layers [1].

IIPs state technical constraints and recommendations on how to apply standards and good practice wherever interoperability is at risk. IIPs specify a single feature each, Vol.2 adds a relational table that links the Business Functions from Vol.1 with the IIPs in Vol.2.

The entire Technical Framework shall be embedded in a business domain overview, here on modern energy systems and Smart Grids in general. The concept of Technical Frameworks and Integration Profiles is based on the established IHE (Integrating the Healthcare Enterprise – www.ihe.net) approach to *IT interoperability* in the medical technology sector. The base of the structuring reflects the common approach to complex problems also underlying the V-model. The Smart Grid Architecture Model (SGAM) [2] also uses the common layering approach to handle complexity by multi disciplinary separation.

◊ **Vol.1**

- Business Case Overview (informative)
  - Typical applications
  - Relevant meta-actors

  - ○ Related standards
- Business Functions (informative)
  - ○ Describe interoperability issues (use IEC 62559 Use Case Methodology)
  - ○ Use Case diagrams
  - ○ Actor Transaction diagrams

◊ **Vol.2**

- Business Functions to Integration Profile mapping (normative)
  - ○ Table(s) binding Integration Profiles to Business Functions
- Integration Profiles (normative)
  - ○ Definition of Interoperability issue addressed (Use Case)
  - ○ Definition of needed transactions
  - ○ Definition of involved actors
- Transactions (normative)
  - ○ Specification of individual steps and list of actors involved
  - ○ Specification of used IT standards, options, variants, etc.
  - ○ Specification of communication security and resiliency
- Actors (normative)
  - ○ Specification of actors' interfaces
  - ○ Specification of used IT standards, options, variants, etc.
  - ○ Specification of actor safety and data security measures

↪ The structure of Technical Frameworks follows the *top-down* approach and the informatics tradition to first name items, than define them, and finally specify them. For example: name an algorithm, define what it does, and specify how to implement it, before actually coding it. The terms *"definition"* and *"specification"* are hence used accordingly. Writing a Technical Framework can be done in any order. Commonly, previous parts need amendment whenever later parts become changed or added because the context runs back-to-front.

↪ *Vol.2* starts with assigning Integration Profiles to the Business Functions from Vol.1. In this table also Integration Profiles from other Technical Frameworks may be assigned (*bundled*). Transactions and Actors are specified profile by profile. They may as well be bundled from one Integration Profile into some other. Bundling shall prevent redundant specification. The bundling formalism is specified in [3] and further addressed in Vol.2 (introduced also in Vol.1 Section 6).

1.2 What is *interoperability*

According to dictionary: *"Ability of a system to work with or use the parts or equipment of another system"* [Merriam-Webster] the term *interoperability* refers to the ability of a system to work with parts and features provided by some other system. To do so, information is essential. First, to know how to use which parts, and second, how to address and control the used features of the other system.

To cooperate seamlessly the following five *interoperability levels* need to be considered:[1]

- **Legal:** common compliance with regulatory obligations and standards
- **Semantic:** uniform understanding and interpretation of information and operation means
- **Syntactical:** equal data formats, coding schemes, and encryption methods
- **Technical:** using the same communication means and protocols
- **Operational:** timely reliable provisioning of info/response

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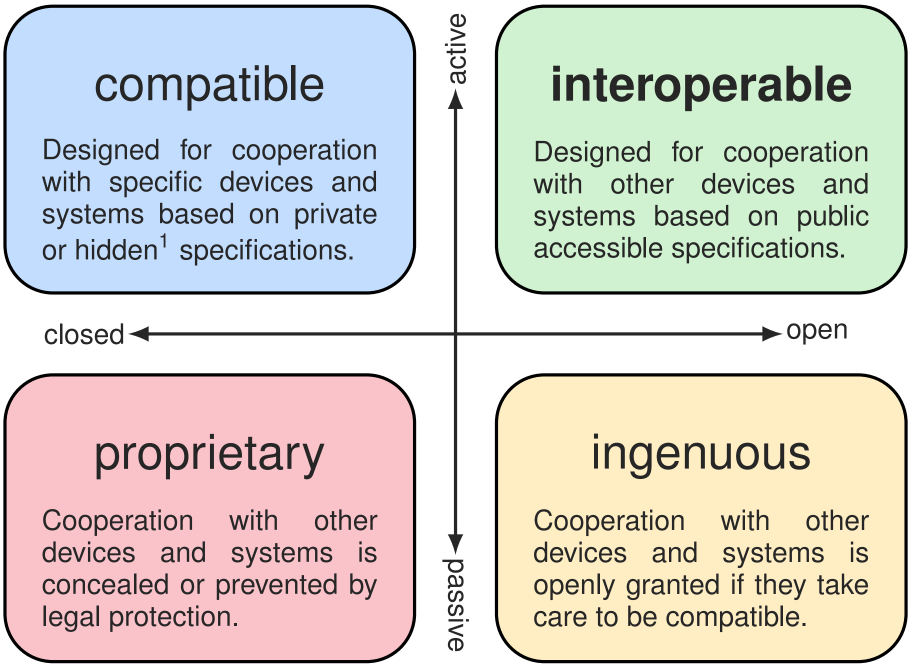
[1] Five layers similar to the SGAM and the Technical Framework structure.

Orderly cooperation of systems is possible where requirements are fulfilled layer by layer, and where all internal components of a device operate correctly, i.e., flawless. Imagine what happens if the unit of a metric differs (semantic issue): cooperation fails. E.g., the mars-lander crashed even though each sub-system worked perfectly to its own specification. Malfunction of cooperation does not necessarily imply faulty sub-system implementation; per se these may work fine. Consequently, *interoperability* cannot be assessed stand-alone without involving independent systems as test peers. Accordingly, INTEROPERABILITY CANNOT BE IMPLEMENTED INDIVIDUALLY.

Ad testing *interoperability* [ITU-T Z.450] says: *”Testing to assess the ability of two or more systems to exchange information and to make mutual use of the information that has been exchanged.”* Here *mutual use* is pronounced, i.e., all involved systems shall benefit. Thus, correct interpretation and trust in the correctness and beneficial use of exchanged information and provided features are likewise essential.

Other references, examples and notes

◊ **wikipedia.org:** *"Interoperability imply Open standards ab-initio, i.e., by definition. When a vendor is forced to adapt its system to a dominant system that is not based on Open standards, it is not interoperability but only compatibility."*



Designed for cooperation with specific devices and systems based on private or hidden[1] specifications.

Designed for cooperation with other devices and systems based on public accessible specifications.

Cooperation with other devices and systems is concealed or prevented by legal protection.

Cooperation with other devices and systems is openly granted if they take care to be compatible.

[1] Getting specs requires licensing or reverse engineering.

Figure 1.2: Matrix of cooperation options

◊ **interoperability-definition.info:** *"Interoperability is a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions."* Sadly this webpage proves itself semantic interoperability failure due to language complexity when definitions become translated. The German differs considerably: *"Interoperabilität ist die Fähigkeit eines Programms oder Systems (dessen Schnittstellen vollständig offengelegt sind) mit anderen gegenwärtigen oder zukünftigen Produkten oder Systemen ohne Einschränkungen hinsichtlich Zugriff oder Implementierung zusammen zu arbeiten bzw. zu interagieren."*

↪ *Only one definition in one language can be binding.* Not two or more, even though all can be valid in their context. Not knowing how to interpret a particular definition, it remains a rather unspecific composition of words, alike given names being composites of letters, basically. TERMS DESCRIBE CONTEXT ⇔ CONTEXT SPECIFIES TERMS.

1.3 Definitions

Active customer is a final electricity customer, or a group of jointly acting final customers, that may produce, use, sell and store electricity, commonly self-generated within their premises (within confined boundaries), for whom these activities do not constitute a primary commercial or professional aim.

Actor is here a functional component of an IT system that executes operational tasks commonly in cooperation and/or coordination with other actors.

Aggregation refers to a function performed by a natural or legal person (an *Aggregator*) that combines multiple customer loads or their generated electricity for sale, purchase or auction in some *electricity market*.

Ancillary service means a service necessary for the operation of a transmission or distribution system, including balancing, steady state voltage control, fast reactive current injection, inertia for local grid stability, short-circuit current, black start capability and island operation capability, but is not including any congestion management.

Business Case is the economic viable application of an idea or technology.

Business Function is a feature required to be realised for a Business Case to work.

Conformance Testing is a standalone process to ensure that the implementation conforms to specified standards and profiles, i.e. the implementations outputs and response are checked against rules and patterns.

Demand response means the change of electricity load by a customer, in respect to the normal or current consumption pattern, in response to market signals, including in response to time-variable electricity prices, incentive payments, or other options for reimbursement.

Distribution refers to the transport of electricity at different voltage levels towards the delivery to customers, but does not include supply.

Distribution System Operator is the legal entity that is responsible for energy grid safety and persistent power supply.

Electricity consumer is a technical asset that consumes electric power when operated. In a market centric view, the natural or legal person that operates electricity consuming assets is often referred to as energy consumer.

Electricity customer is a natural or legal person that purchases electricity service, i.e., the provisioning and on demand delivery of electric energy.

Electricity generation refers to the physical production of electricity.

Electricity markets are markets for electricity, including over-the-counter markets and electricity exchanges, markets for the trading of energy, capacity, balancing and ancillary services, in all time-frames, including forward, day-ahead and intra-day markets.

Electricity producer refers to a natural or legal person that operates assets to generate and sell electricity.

Electricity supply refers to the sale of electricity to customers; i.e., assuring and billing of the supply with the contracted amount of electric power.

Energy storage is an electric asset that allows to defer the final use of electricity to a moment later than when it was generated. This may (and often does) include the conversion of electrical energy into a better storable form of energy, its storing, and subsequent reconversion into electrical energy or use as another energy carrier.

Grid Codes are regulations, typically specifying technical requirements that need to be fulfilled to connect devices to the electricity grid or to participate different electricity markets.

Household customer purchase electricity service to operate electric assets within the own household. Non-household customer purchase electricity not for own household use, including producer, industry, small and medium-sized enterprises, general business, and wholesale customer (i.e., energy trader).

Integration Profile is the specification required to realise a part of a Business Function (or combination thereof) in an interoperable fashion (normalised).

Interoperability Level refers to the abstraction level of interoperability requirements. We consider five levels: Legal, Semantic, Syntactic, Technical, and Operational.

Interoperability Testing is a process to check whether the system interacts effectively with foreign systems, i.e. when different vendors meet to test their interfaces against each other (e.g. Connectathon Energy).

Interoperability Use Case is a part of a Business Function that relies on data exchange between different actors according to an Integration Profile (i.e. where interoperability is required).

Meta-Actor joins functional components (actors) in order to fulfil all the functionalities required for a Business Function (IHE grouping). For the Use Case description, it could be a human operator, but typically it is a software component embedded in some device that provides an interface to some communication infrastructure.

Network Codes see *Grid Codes*.

Safety refers to maintaining a proper state of systems such that neither persons operating assets nor the electricity system itself, i.e., the seamless power supply to all customers, is undue endangered.

Security refers to both, security of supply and provision of electricity, and colloquially may also include technical safety. Primarily, security aims at the protection of the system's operation to assure system safety, including restricted physical and digital access to system assets.

Smart Grid Architecture Model (SGAM) refers to the reference architecture model developed by the M/490 for the European Commission [4]. It provides a normative approach to position (locate) the different components, services, and sub-systems of a smart grid, among each other and to identify required interfaces.

Synchronverter – also called virtual synchronous generator – is a power inverter that mimics a synchronous generator to provide "synthetic inertia" as ancillary service.

Transaction is the execution of sending, receiving and reacting to a message or set of messages (1..n) exchanged between a pair or more actors. Transactions realise Use Case specific information exchanges (in one or both directions, in a strict or loose order) as specified by an Integration Profile.

Transmission refers to the (long distance) transport of electricity across the extra high-voltage and high-voltage grid with a view towards delivery to customers or distributors, but does not include supply.

Operational Use Case is a part of a Business Function that describes a task not involving any data exchange between actors. Such internal use cases are mentioned in the IES Technical Framework, but not considered as Integration Profiles because they do not cause interoperability issues.

Use Case is a well defined functionality in a well specified environment. Use Cases can be defined and specified on every SGAM Layer.

This page is intentionally blanc (space for more definitions).

2 Business Overview

Every Technical Framework shall contain a business overview. It shall describe the business, here Local Energy Communities, to enable holistic understanding of the interoperability issues and their solution. Vol.1 shall be a concise textual description including graphics for better understanding. Listing relevant standards including a short note on their use in relation to Local Energy Communities shall provide a link to common practice.

The fundamental intention of a Local Energy Community shall be some voluntary joint achieving of beneficial goals that cannot be reached without the cooperating community members. A Local Energy Community shall constitute a legal entity, self-organised and conjointly managed by the members. Operating a Local Energy Community shall not be a business by itself, Local Energy Communities shall provide benefits to members and/or the local public instead. Section 2.1 on European Commission specifications of Energy Communities is informative and included to provide a holistic view and validate some less evident recommendations stated later on.

Concerning interoperability, the cooperation type within legal entities is in principle not relevant. Cooperation related constraints that need to be implement technically are requirements to consider and mention in IES Integration Profiles. However, other cooperation types that might not be called Energy Community in respect to EC directives may still operate equally, i.e., are welcome to utilise the same specifications.

Local Energy Communities

For this Technical Framework the term *Local Energy Community* shall be used openly, based on the meaning of the individual terms as specified in official dictionaries. Much is going on toward the development of various forms of Local Energy Communities. The European Commission discarded the term in recent directives, there is no clear definition, neither are specific constraints or obligations defined. However, there are specifications for Energy Communities in the Clean Energy Package [5]. As of spring 2020, a plurality of public funded R&D projects refers to Local Energy Communities [`https://cordis.europa.eu/search/en?q=%27Local%20Energy%20Communities`]. At least three carry the term in the project name, and there are many more in national and other funding programs. Try [`https://www.google.at/search?client=opera&q="Research+Project"+%2B"Local+Energy+Communities"`] for an individual search.

In the *Opinion of the European Committee of the Regions on 'Models of local energy ownership and the role of local energy communities in energy transition in Europe'* (2019/C 86/05) [`https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588355257430&uri=CELEX:52018IR2515`] EC document we find hints on the initial idea, among many other specifications including the following:

- Community initiatives based on local collaborative solutions can be set up by individuals or groups of individuals, small businesses, local authorities or households, acting on their own initiative or as part of a coordinated group.
- Local energy communities can shoulder an important role in the energy transition and spur on the development of sustainable energy technologies, for the benefit of local communities and the European Union as a whole.
- There are many possible organisational structures for community energy initiatives, such as partnerships with local authorities (including public-private partnerships – PPPs), cooperatives, community foundations, limited liability companies, non-profit customer-owned enterprises, housing associations or municipal ownership.
- Local energy communities can be an efficient way of managing energy at community level, by generating, distributing and consuming electricity or centralised heating and cooling, whether or not they are connected to local distribution networks.
- Energy cooperatives can contribute to the decentralisation, opening up and democratization of energy systems and thus can have a positive impact on sustainable local economic and social development, and can thus also contribute to tackling energy poverty and promote job creation within the community.

A recommendation for adoption published on-line without date on a company webpage only, states that *'Local Energy Community' means: An association, a cooperative, a partnership, a non-profit organisation or other legal entity which is effectively controlled by local shareholders or members, generally value rather than profit-driven, involved in distributed generation and in performing activities of a distribution system operator, supplier or aggregator at local level, including across borders activities.* Further, that *LEC members shall benefit from a non-discriminatory treatment with regard to their activities, rights and obligations as final customers, generators, distribution system operators, or aggregators* and that *shareholders, or members of a local energy community shall not lose their rights and obligations as household customers or active customers.* These proposals are well considered in the definition of Citizens Energy Communities and Renewable Energy Communities summarised in Section 2.1.

It is also mentioned that *there will be a need for rules on the correct metering, billing etc. of the customer's connection point(s) and rules/regulatory framework upon the use of LEC infrastructure ("lease of last mile").* And a reminder that *all market actors, including customers of Local Energy Communities, should be able to participate in the market in a fair way, but also cover costs they are responsible for in the electricity system.*

Trying to categorise different types of Energy Communities residing in between a single prosumer focusing on maximising self-consumption and an aggregator maximising financial profit on the energy markets, the following archetypes may be identified:

- **Prosumer:** private generation assets reside entirely behind the final meter, single ownership, no community
- **Owners' Association (§16a):** all the generation and load assets reside behind a joint grid connection point
- **Generation Community:** DERs are shared across the local LV grid, proximity is defined by the grid topology
- **Coordination Community:** load coordination with local generation across MV grid across small municipality
- **Citizen Community:** joint DER financing and usage aiming at regional benefits, independent of grid relations
- **Virtual Power Plant:** aggregated generation and selling of remote controlled DER, a business, no community
- **Aggregator:** selling of mostly uncontrolled distributed RES, prediction based, a market player, no community

The ***Owners' Association*** is an Energy Community comprised of property owners that share a common grid connection point. For example, a condominium owners' association where members individually own flats within a typically multi-story building that they own in common (as an association). A building integrated RES and/or DER is therefore also jointly owned and metered independent of the electricity meters per flat, as is the energy required for common appliances, e.g., corridor lighting and elevators. To share the energy produced by the building integrated RES, the metered energy flows need to be balanced within the Owners' Association.

This Energy Community type is in Austria enabled by the §16a of the according law on energy supply and regulations (ElWOG 2010). To clearly separate this special type from more general owners' associations, we use "§16a" as an identifier for this particular type of an Energy Community.

The ***Generation Community*** extends the §16a Owners' Association by enabling participants spread across different grid connection points, still within the same low voltage (LV) grid section. Different connection points cause 'private' power flows across the local LV infrastructure, which needs to be allowed and commonly also controlled by the local DSO. Market position and applicable procedures can be identical to those of §16a Owners' Associations.

Note: If an Energy Community rents or takes over the electricity grid section required to connect its members, that Energy Community turns into a members-owned utility and where membership is voluntary, that Energy Community has to perform as local DSO for the non-members that purchase their energy solely from the supplier of their choice, but happen to be attached to the now Energy Community owned electricity grid. Vice versa, a small utility, i.e., a local grid operator and energy supplier (e.g., "Stadtwerke") may be converted into an Energy Community by delegating ownership and governance to the members of the thereby established Owners' Association, which has several still unique connection points to adjacent grid sections, and likely also has to serve non-members as local DSO.

The ***Coordination Community*** shall include the medium voltage level to allow bigger customers connected at higher levels to be integrated in Energy Communities as well. It adds load and generation prediction with consequential load shifting to optimise self-consumption. The grid load added by actively managed community assets can be a priori assessed and coordinated with the DSO to support local grid stability.

This archetype is henceforth assumed as the typical, most potential, promising and powerful, but also very complex and truly challenging, approach to Energy Communities. It fits the EU directives on Renewable Energy Communities and also addresses DSO's concerns on grid stability and implementation feasibility. However, it also fosters the *Net-Zero Customer* that jeopardises many of the business cases the established energy economy is based upon.

The ***Citizen Community*** is focused on providing new services to the benefit of the community members and their region. Addressing energy poverty and supporting local RES and regional business in general shall be central aims. The prime offer is the opportunity to invest in RES and to use these for the good of the region lived in, aside from a possibly long-term and probably rather indirect return-on-investment. If profit from green business is intended, participation in a virtual power plant or acquiring shares of a RES aggregator appear more appropriate.

The citizen community is not bound to grid relations and therefore more in the realm of energy trading rather than energy sharing. However, in accordance with the EU directive on Citizens Energy Communities, this Energy Community type enables shared private investment in regional solutions and can actively support beneficial regional development by aiming more on the value gained than on the profit momentarily earned.

Figure 2.1 tries to sketch the grid relation, i.e., the location of different Energy Community archetypes. This attempt to categorise is intended for better understanding of potential options, but it is not based on facts in all aspects relevant. Regional legislation and regulation have a strong impact on what is possible, and that may enforce Energy Community types that comprise a mixture of the idealised archetypes listed and sketched here.

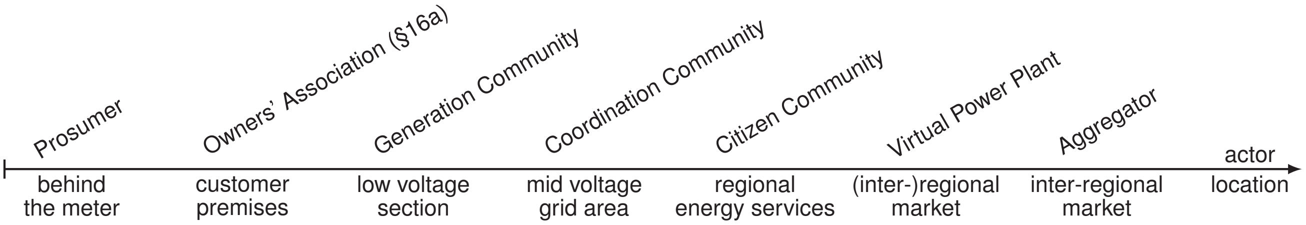


Figure 2.1: Location of archetypical community types within the electricity system

2.1 Energy Communities according to the Clean Energy Package

If the statutes of a cooperation activity conforms with EU directives and has a legal form designated by the Member State, this legal entity is eligible to be entitled as Energy Community. Distinctive characteristics are: *governance, membership/ownership, and primary purpose* of the legal entity.

The REScoop.eu initiative summarises that an Energy Community is "*a way to 'organise' citizens that want to cooperate together in an energy-sector related activity based on open and democratic participation and governance, so that the activity can provide services or other benefits to the members or the local community.*" It is also stated that Energy Communities shall be "*an alternative type of market actor*", and "*a different way/philosophy to do business*", which is in accordance with the Clean Energy Package [5]. Finally, "*the primary purpose of energy communities is to create social innovation, i.e., to engage in an economic activity with non-commercial aims.*"

The aims can include production and sale of energy, but Energy Communities are not limited thereto. Energy services as well as socio-economic benefits to the members and/or the local community are also valid aims, as long as these are achieved self-organise and are energy-related. The Clean Energy Package contains two definitions of energy communities: *'Citizens Energy Communities'* and *'Renewable Energy Communities'*. Both these definitions are framed as a particular way to organise collective action around a particular energy-related activity, i.e., through a legal entity. Energy Communities organise around specific ownership, democratic governance and a non-commercial purpose (as opposed to traditional market actors). For further information on the different organizational forms, see: https://cor.europa.eu/en/engage/studies/Documents/local-energy-ownership.pdf, p. 13 e.v.

2.1.1 Citizens Energy Communities

The "DIRECTIVE (EU) 2019/944 on common rules for the internal market for electricity and amending Directive 2012/27/EU" defines in Article 2 (11) that **‘citizen energy community’** means a legal entity that:[2]

(a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises;

(b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and

(c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders.

and in (12): **‘supply’** means the sale, including the resale, of electricity to customers.

In **Article 16** on citizen energy communities the DIRECTIVE (EU) 2019/944 state that:

1. Member States shall provide an enabling regulatory framework for citizen energy communities ensuring that:
    (a) participation in a citizen energy community is open and voluntary;
    (b) members or shareholders of a citizen energy community are entitled to leave the community, in which case Article 12 applies;
    (c) members or shareholders of a citizen energy community do not lose their rights and obligations as household customers or active customers;
    (d) subject to fair compensation as assessed by the regulatory authority, relevant distribution system operators cooperate with citizen energy communities to facilitate electricity transfers within citizen energy communities;
    (e) citizen energy communities are subject to non-discriminatory, fair, proportionate and transparent procedures and charges, including with respect to registration and licensing, and to transparent, non-discriminatory and cost-reflective network charges in accordance with Article 18 of Regulation (EU) 2019/943, ensuring that they contribute in an adequate and balanced way to the overall cost sharing of the system.
2. Member States may provide in the enabling regulatory framework that citizen energy communities:
    (a) are open to cross-border participation;
    (b) are entitled to own, establish, purchase or lease distribution networks and to autonomously manage them subject to conditions set out in paragraph 4 of this Article;
    (c) are subject to the exemptions provided for in Article 38(2).
3. Member States shall ensure that citizen energy communities:
    (a) are able to access all electricity markets, either directly or through aggregation, in a non-discriminatory manner;
    (b) are treated in a non-discriminatory and proportionate manner with regard to their activities, rights and obligations as final customers, producers, suppliers, distribution system operators or market participants engaged in aggregation;
    (c) are financially responsible for the imbalances they cause in the electricity system; to that extent they shall be balance responsible parties or shall delegate their balancing responsibility in accordance with Article 5 of Regulation (EU) 2019/943;
    (d) with regard to consumption of self-generated electricity, citizen energy communities are treated like active customers in accordance with point (e) of Article 15(2);

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[2] Blue text indicates cites taken 1:1 from the official EU directives.

(e) are entitled to arrange within the citizen energy community the sharing of electricity that is produced by the production units owned by the community, subject to other requirements laid down in this Article and subject to the community members retaining their rights and obligations as final customers.

For the purposes of point (e) of the first subparagraph, where electricity is shared, this shall be without prejudice to applicable network charges, tariffs and levies, in accordance with a transparent cost-benefit analysis of distributed energy resources developed by the competent national authority.

4. Member States may decide to grant citizen energy communities the right to manage distribution networks in their area of operation and establish the relevant procedures, without prejudice to Chapter IV or to other rules and regulations applying to distribution system operators. If such a right is granted, Member States shall ensure that citizen energy communities:

   (a) are entitled to conclude an agreement on the operation of their network with the relevant distribution system operator or transmission system operator to which their network is connected;
   (b) are subject to appropriate network charges at the connection points between their network and the distribution network outside the citizen energy community and that such network charges account separately for the electricity fed into the distribution network and the electricity consumed from the distribution network outside the citizen energy community in accordance with Article 59(7);
   (c) do not discriminate or harm customers who remain connected to the distribution system.

◊ **What shall Citizens Energy Communities achieve?**

(a) Active participation of end-users in the energy transition, fostering private investment and social revenues;
(b) access to novel energy services and sources including measures to reduce energy poverty;
(c) increase the number, capabilities and utilisation of Distributed Energy Resources particularly addressing flexibility and novel business models and markets.

2.1.2 Renewable Energy Communities

The "DIRECTIVE (EU) 2018/2001 on the promotion of the use of energy from renewable sources" defines in Article 2 (16) that **‘renewable energy community’** means a legal entity:

(a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;

(b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;

(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.

In **Article 22** on renewable energy communities the DIRECTIVE (EU) 2018/2001 state that:

1. Member States shall ensure that final customers, in particular household customers, are entitled to participate in a renewable energy community while maintaining their rights or obligations as final customers, and without being subject to unjustified or discriminatory conditions or procedures that would prevent their participation in a renewable energy community, provided that for private undertakings, their participation does not constitute their primary commercial or professional activity.

2. Member States shall ensure that renewable energy communities are entitled to:

   (a) produce, consume, store and sell renewable energy, including through renewable power purchase agreements;

   (b) share, within the renewable energy community, renewable energy that is produced by the production units owned by that renewable energy community, subject to the other requirements laid down in this Article and to maintaining the rights and obligations of the renewable energy community members as customers;
   (c) access all suitable energy markets both directly or through aggregation in a non-discriminatory manner.

3. Member States shall carry out an assessment of the existing barriers and potential of development of renewable energy communities in their territories.

4. Member States shall provide an enabling framework to promote and facilitate the development of renewable energy communities. That framework shall ensure, inter alia, that:

   (a) unjustified regulatory and administrative barriers to renewable energy communities are removed;
   (b) renewable energy communities that supply energy or provide aggregation or other commercial energy services are subject to the provisions relevant for such activities;
   (c) the relevant distribution system operator cooperates with renewable energy communities to facilitate energy transfers within renewable energy communities;
   (d) renewable energy communities are subject to fair, proportionate and transparent procedures, including registration and licensing procedures, and cost-reflective network charges, as well as relevant charges, levies and taxes, ensuring that they contribute, in an adequate, fair and balanced way, to the overall cost sharing of the system in line with a transparent cost-benefit analysis of distributed energy sources developed by the national competent authorities;
   (e) renewable energy communities are not subject to discriminatory treatment with regard to their activities, rights and obligations as final customers, producers, suppliers, distribution system operators, or as other market participants;
   (f) the participation in the renewable energy communities is accessible to all consumers, including those in low-income or vulnerable households;
   (g) tools to facilitate access to finance and information are available;
   (h) regulatory and capacity-building support is provided to public authorities in enabling and setting up renewable energy communities, and in helping authorities to participate directly;
   (i) rules to secure the equal and non-discriminatory treatment of consumers that participate in the renewable energy community are in place.

5. The main elements of the enabling framework referred to in paragraph 4, and of its implementation, shall be part of the updates of the Member States' integrated national energy and climate plans and progress reports pursuant to Regulation (EU) 2018/1999.

6. Member States may provide for renewable energy communities to be open to cross-border participation.

7. Without prejudice to Articles 107 and 108 TFEU, Member States shall take into account specificities of renewable energy communities when designing support schemes in order to allow them to compete for support on an equal footing with other market participants.

◊ What shall Renewable Energy Communities achieve?

(a) Provide local entities fair and affordable access to local, clean renewable energy resources and other energy-related services, including vulnerable and energy poor households;
(b) offer the choice to take control and responsibility for local self-provisioning of energy needs, furthering *energy democracy* and public acceptance of renewable and other clean energy technologies by allowing citizens and local businesses to invest and participate in the decision making;
(c) create participation opportunities that generate revenue within the local economy and address energy efficiency as well as local socio-economic needs.

2.2 Energy Community operation schemes & hierarchies

Henceforth it is assumed that an Energy Community intends to jointly utilise resources and provide services by coordinating the operation of members' energy appliances. Whether self-consumption is prioritized or not has no impact on the interoperability of coordinated systems.[3]

A characteristic that differentiates most Energy Communities from Virtual Power Plants and their operators, the aggregators, is commonly the proximity to members and the joint decision making. The characteristic that separates Energy Communities from Micro Grids is the lack of a private electricity grid infrastructure that connects all the components the Micro Grid is composed of. Energy Communities rely on the local distribution grid infrastructure to electrically connect their member's energy appliances.[4] Another differentiation is that the Energy Community will not, or not entirely, substitute the contracts of community participants with major energy suppliers.

Frankly, Energy Communities may be considered Micro-Grids composed of components that are owned and governed in total or in parts by the participating parties and that organisationally operate not behind meters but across meters using the public distribution grid to transport energy flows among the parts and participants an Energy Community is composed of.

The relations of Energy Communities with Energy System stakeholders is sketched in Figure 2.2, showing the most relevant relations, where *control*[5] evidently implies a contractual relation. Open questions are the relation of Energy Communities as legal entities with energy suppliers, aggregators, energy markets and other entities. That community members need contracts with energy suppliers appears necessary because most Energy Communities will be too small to always balance all demands within the community. If they can, with or without substitution from energy markets, and balancing is their prime business, than their role is that of a local energy supplier and artificial renaming is not indicated. Whether Energy Communities may and can participate in a reserve energy market depends on their size and regional regulations. Some time in the near future a novel flexibility market may evolve to cover small scale flexibility trading, or the entire energy trading will be based on small scale end-to-end trading, i.e., transactive energy systems where highly volatile energy prices are used to balance demand and supply [6, 7, 8].

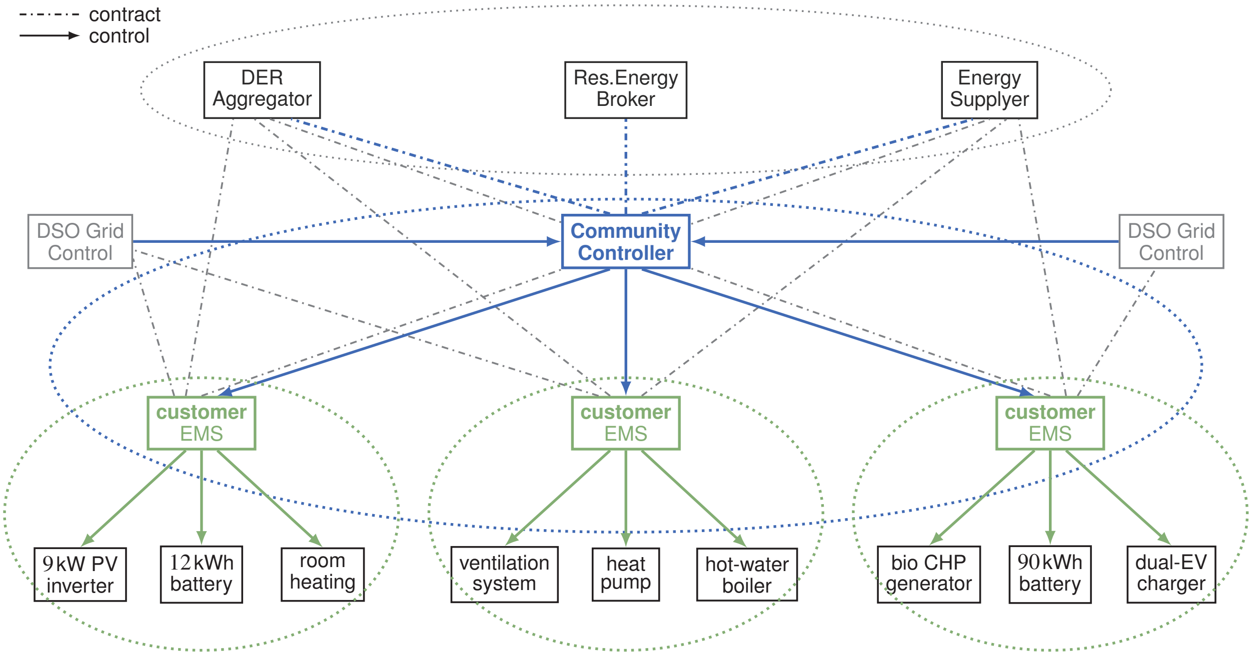

Figure 2.2: Energy Community Relations

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[3] As of 2020, maximising self-consumption is in many regions the most economic aim attracting participants to invest and share excess.

[4] Integrating the local grid operator in any Energy Community endeavour would be wise, but possibly hard to sell (see Section 2.1).

[5] The term 'control' in the context of coordinating energy appliances means operational control of energy flows rather than controlling community decision-making. Later shall be termed *community management* henceforth.

For now, we assume such grid stabilisation means and activities (i.e., *ancillary services*) feasible among Energy Communities and the local Distribution System Operators (DSOs).

The actual management and control of Energy Communities is not defined by EC directives. A vast plurality of options can be imagined. From cooperation in financing DER and RES equipment with fair sharing of generated energy and gained revenues, to coordinated operation of energy appliances with internal balancing of demand and supply. Latter seems to be the most stringent cooperation requiring both, Energy Community internal metering and concerted control. Other Energy Community cooperation schemes need a subset of the features only. The most challenging cooperation is used to identify and specify required features, i.e., Meta Use Cases (*Business Functions*).

Three macro operations are evident to manage and control energy demand and supply within an Energy Community:

- Prediction and scheduling of power demand and supply
- Reliable monitoring and control of energy flows
- Fair sharing and compensation of energy supplies

A causal chain of actions would for example be:

1. Collect asset & env. conditions
2. Predict demand & generation
3. Distribute planned schedules
4. Monitor power & energy flow
5. Calculate deviation from plan
6. Trigger schedule corrections
7. Accumulate energy budgets
8. Adjust fulfilment weighting
9. Distr. benefits & compensation

The three columns show the features (*IES Business Functions*) that result from the three above derived operation demands respectively. Commonly, the features within a column may be repeated (*cycled*) independent and asynchronous to those listed in other columns. The resultant coordination, monitoring and control cycles are depicted in Figure 2.3. Steps **3** to **8** constitute the main *"on-air"* control cycle. Steps 2, 5, 7, and basically also 9, are Community Energy Management System internal actions not depicted. Note also, that *Member Behaviour* and *Cooperation Policy* represent intrinsic parts of the *Community Energy Management System*, only shown explicitly because for their implementation artificial intelligence, neuronal networks, or machine learning is likely applied.

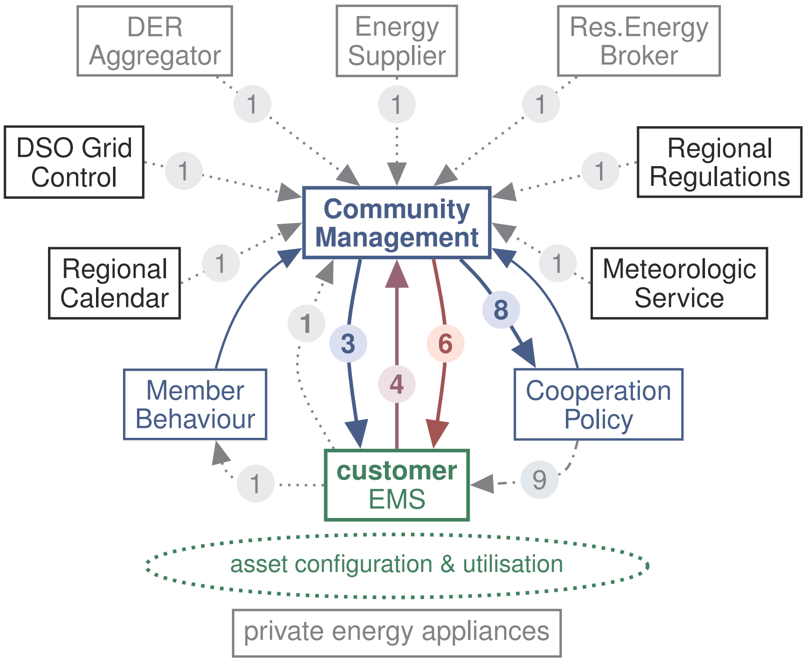


Figure 2.3: Management and control cycles within Energy Communities [9]

Next a short informative overview of established cooperation schemes before Energy Community centric approaches integrating individual customer behaviour prediction and dynamic grid constraints consideration are sketched and introduced in Section 2.3.

2.2.1 Demand Response

For Energy Communities the Demand Response principle applies twofold. First, as power system entity an Energy Community can participate in a Demand Response scheme to achieve financial benefits from utilising aggregated flexibility. Second, an Energy Community can establish an internal Demand Response scheme to coordinate the Energy Community members. These options become linked when external demand signals are directly forwarded to Energy Community members.

Typical Demand Response schemes are based on *voluntary response* and implement one-way communication only. The operator of the Demand Response system requests a load change by addressing a group of customers that is sufficiently big to approximately achieve the intended change. This approach is entirely based on stochastic modelling and gathered experience with contributing customers (e.g., applying machine learning).

The most common signalling already implemented are intra-day energy price changes. To be effective, these need to be significant, at least during the early-adoption phase. People need to change their energy usage behaviour, which is not easily achieved. Vice versa, intra-day price variation of sufficient magnitude can render private battery storage economic. The availability of private battery storage improves the efficiency of Demand Response schemes. Batteries are perfectly shift-able loads and the clients owning batteries are keen to load their batteries at low intra-day prices, thereby tackling the problem of too much power inserted locally, given that price signals are geographically correct targeted.

A social drawback of Demand Response is potential unfairness. Poor households may not afford equipment to shift load or use battery storage, even though that could save them money. Secondly, geographically targeted intra-day prices cause significant dependence of the yearly energy bill on the customer's geographic location.

For a Local Energy Community geographic proximity is natural, and investments can be shared in the community. Systemic unfairness within an Energy Community is marginal and can be mitigated by Energy Community governance. However, monetary signals may not be eligible. Other bonification of the flexibility offered needs to be democratically defined and jointly executed. A virtual inter-day price may still be used to compatibly realise the demand signalling within an Energy Community. Compensation may be based on energy budgets and tokens.

2.2.2 Demand Side Management

Direct Load Control (DLC) is the opposite of Demand Response. Members of such an Energy Community would hand over the control of their individual energy consumption pattern to the Energy Community management system. In its purest from this scheme is unrealistic, at least for human customers. Only in emergency situations unrestricted control of customer appliances is applicable, i.e., to prevent worse situations.

However, if influencing customer appliances is strictly confined to an amount commonly accepted by customers and an option to easily overrule community intervention is provided, some Demand Side Management (DSM) becomes viable. Compared to Demand Response the control is far less stochastic if overruling by customers can be assumed rare exceptions.

Energy appliances that fit this scheme quite well are room heating and cooling, hot water provisioning, and other appliances, in particular at industry customers, where huge energy buffering is involved. For example, if the room heating is interrupted for a short while, the temperature in the room drops insignificantly due to the amount of heat stored in the building's walls. Still, if due to some reason the customer vents the rooms on a cold day, overruling may be necessary. Similar situation occurs with hot water if a sufficiently over-sized boiler is installed. Again, overruling may still be required if for example an unusual number of people enjoy a hot shower within short time.

An example where DSM is perfectly common are variable loads integrated in virtual power plants where a central VPP controller manages the individual loads. Not inserting power has no negative effect on the customer's living quality. For production DLC is widely accepted if in the long term the gained benefits from being remote controlled are acceptable. However, self-consumption priority is required where consumption tariffs exceed insertion reimbursement.

2.3 Integrating the local grid in the Energy Community management & control aim

Members of Energy Communities will commonly emerge from within a limited region and are most likely attached to the same regional distribution grid, some even to the same supply strand, as shown in Figure 2.4. Note that according to the SGAM shown in Figure 2.5, the grid-hierarchy is roughly aligned with the *Domains-axis*, whereas the control-hierarchy is aligned with the *Zones-axis*. This traditional alignment reflects the centralised management model widely assumed to cover the complexity of reality, where the component layer power control is implemented mostly distributed, i.e., based on local frequency, $\cos\phi$, voltage and current. Many power plants do not insert the produced power in the highest grid level, such that upward energy flows are not uncommon in the higher grid levels. However, they are managed unisonous as if all produced power would be inserted at the highest grid level to assure fail-safe capacity provisioning.

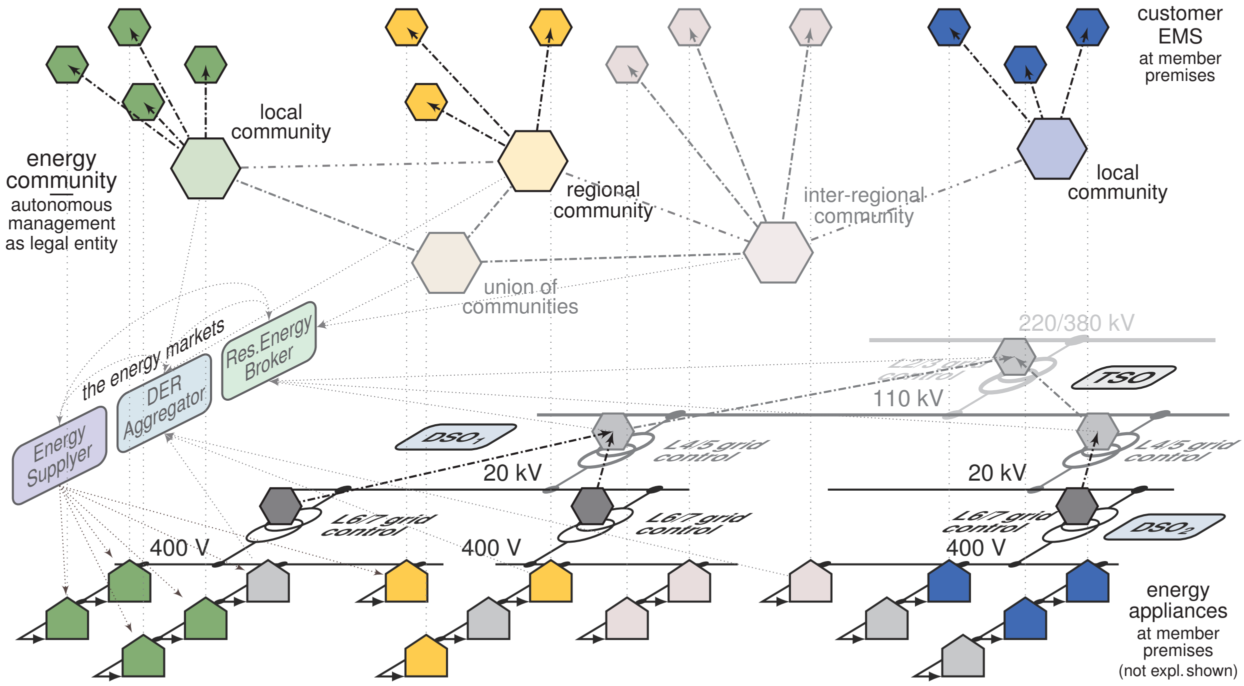


Figure 2.4: Energy Communities reside above distribution system and constitute an energy management domain

Figure 2.4 shows several variants of imaginable Energy Communities. The outermost (green and blue) reside behind the low voltage transformer, here referred to as grid level 7. Customers directly connected to the transformer station not sharing lines with others are considered as level 6 clients, customers connect to a mid-voltage strand, e.g., at 20 kV, are level 5 clients, those directly connected to the high-to-mid voltage transformer as level 4 clients, and so on. Accordingly, we might call the regional Energy Community (yellow) a level 4/5 community because energy flows between some members need to pass through grid level 5, but not across the high-to-mid voltage transformer at level 4. The third Energy Community (pale) includes flows across the high voltage level (L3), which commonly is required for long distances only. Therefore, such a community shall not be considered being a Local Energy Community. This might be a wide spread Citizens Energy Community, operating on the same level as aggregators, just not focused on gaining profit on the energy markets. Another option sketched is a virtual *union of communities* that might manage flexibilities across different Energy Communities, kind of private *Flexibility Marketplace*, possibly based on a blockchain backed ledger and soft contracts.

Energy Community participants are at the lowest possible end of the power grid, i.e., behind the meter, just in front of their own energy appliances, which they manage. Joining possibilities, flexibilities and aims in an Energy Community does not relate into the traditional control hierarchy, also because participation is voluntary such that in general not all grid clients are covered. Instead, Energy Communities are customer groups that themselves may be cascaded and thereby define an independent control dimension (hierarchy). As Energy Communities integrate Distributed Energy Resources, this new hierarchy falls in between Resources (DER) and Distribution (the DSOs' grids) on the SGAM Domain-axis, as shown in Figure 2.5. However, Energy Communities may as well be seen as energy system entities that reside in behind *Customer* and *Resources*, joining them in the *Field* and *Station* zones (e.g., Local Energy Communities), and providing them cooperation in *Operation* means and *Market* access (e.g., Citizens Energy Communities).

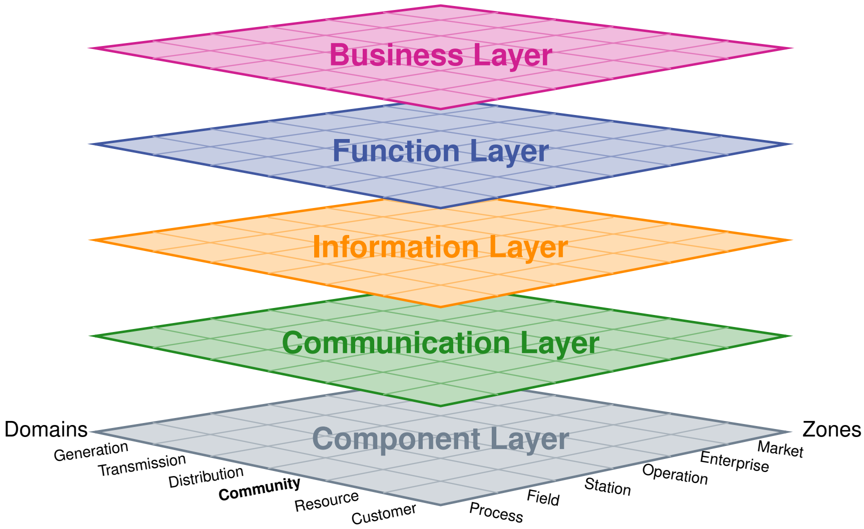


Figure 2.5: The SGAM [4] extended by Energy Communities on Domain-axis

With smart grids, i.e., the deployment of distributed intelligent energy devices, the centralised energy management constraint shall be abolished and distributed management enabled, reaching from regional cells and swarm behaviour to a purely edge managed *transactive energy* system [6]. Energy Communities are a most granular approach envisaged to achieve horizontal energy management among customers and related entities on a peer-to-peer cooperation basis. How this can be achieved technically and which modules need to interact will be defined in Section 3. Here, the environmental and technical issues relating to Energy Community business opportunities are elaborated first.

2.3.1 Increase the utilisation of the local grid capacity

To fully exploit the available capacity of the electricity grid connecting the members of an Energy Community it is necessary to know the current utilisation of grid components and sections, i.e., at transformers and along individual supply lines. Figure 2.6 shows a snapshot of the power levels along a simple supply line. Commonly, the power drops with the distance of the access point from the feeder point, where commonly a transformer is located (P_0). In the example we see a rise in the power level at P_4 where power is inserted. Actually, also P_2 and P_5 insert a little bit of power.

With no local power insertion, the power drop would be perfectly concave along a power line with constant resistance per distance unit because in that case the electric current decreases from client access point to client access point as clients continue to drain current from the line.

The example also shows how a local, *grid aware energy management* can considerably improve the low voltage grid utilisation. If P_4 would not insert power, the curve drops below the lower limit at P_5 and P_6. Poor supply quality and potential problems with sensitive appliances at customers P_5 and P_6 might result.

Conservative distribution grid planning does not consider local power insertion. It is assume far too unreliable over time, i.e., the DSO has to assume that at some time (a) all local load needs to be served from higher grid levels, and vice versa (b) all local production needs to be forwarded to higher grid levels.

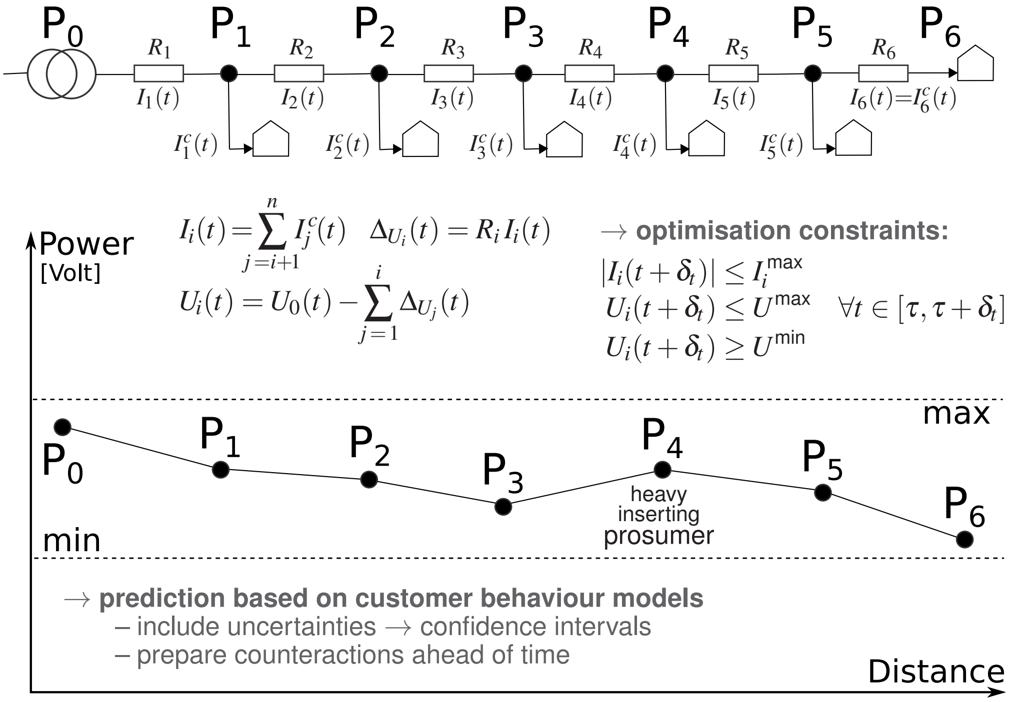


Figure 2.6: Power drop along an electricity feeder line

Consequently, the access capacity granted to connected customers is assigned such that the curve shown in Figure 2.6 never drops below the minimum. Seem to be save, but the local fuse is the only device that limits how much current a customers can actually draw from the grid. Fuses respond rather slow, allowing customers to exceed their maximum access capacity for quite a while.

This timing tolerance allows the Energy Community control to operate asynchronous, without strict synchronisation and deterministic delays as required for real-time control common with operations technology (e.g., grid control). Response times up to some minutes appear acceptable. To realise this Energy Community control, the components sketched next, the so called Meta-Actors, are introduced, foreseen, and defined in section 4, and finally specified via their modules and required interaction in the according TF-LEC Integration Profiles.

2.3.2 Gain benefit from reduced grid tariffs for local flows

The traditional management of energy flows is hierarchically organised top down along grid levels shown in Figure 2.7, i.e., EHV → HV → MV → LV, and so are the grid tariffs. Grid operation and maintenance costs from higher grid levels are spread across all grid levels below, but not vice versa. The lower a customer is attached, the costlier are the grid tariffs.

The most costly grid level in terms of CAPEX is layer 7 due to the grid density required to reach every L7-customer and the costly underground cabling commonly used in densely populated areas (in Europe). Also the transformers connecting grid levels are expensive and increased energy demand in lower grid levels requires higher capacity transformers, traditionally. For example, integrating widespread EV charging at 22 kW per station likely requires transformation capacities not present because today private households commonly have an access capacity of only 3 to 6 kW. However, if a local Distributed Energy Resource connected to the same grid section can provide the required energy, changing the transformer to a bigger one would not be necessary.

In that respect, Energy Communities can actively reduce the cost for grid adaptation. An approach to compensate these cost savings is to drop grid tariff shares resulting from grid levels not affected by local energy flows. For the energy shares a customer consumes for which the Community Energy Management System approves that no higher grid levels have been required to transfer it from a local source to this community member, the DSO may skip

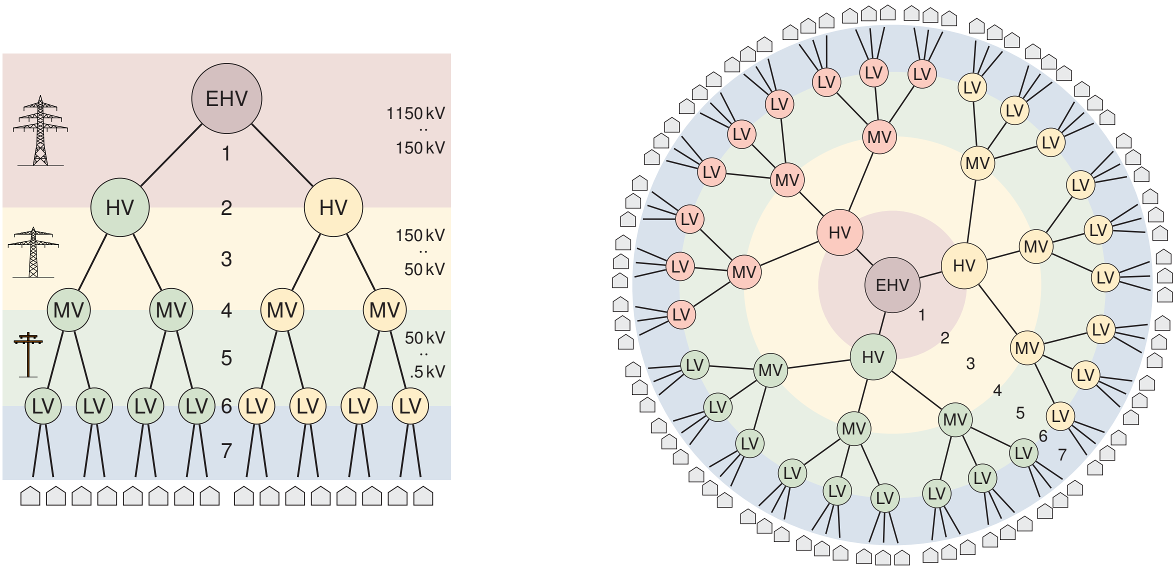


Figure 2.7: The tree topology of the electricity grid shown from the top results in concentric circles similar to the onion model of modern software solutions implementing a concentric systems architecture – a two-dimensional cooperation architecture – where horizontal (left/right) means cooperation within the same level/shell, whereas vertical refers to level linking, i.e., cooperation with a level/shell above (north/inward) or below (south/outward).

the cost shares of higher grid levels included in the regular grid tariff. This is a clear benefit, in addition to the cheap renewable energy provided by fellow community members.

Looking far into the future, assuming net-zero energy regions on all scales and that most energy flows are managed, meaning that the majority of flows no more occurs randomly, the current grid tariff model may be queried in total. In case Distributed Energy Resources provide most of the energy transported by TSOs and distributed to industries that cannot get all their energy from local sources, the cost aggregation logic somewhat flips and the tariff aggregation occurs partly bottom up. In this future the TSOs transport reserve and balancing energy, which commonly is required in demand aliquot shares by nearly all customers, evenly distributed across all grid levels, such that a flat grid tariff charged on any reserve and balancing energy flows, independent on the level the power resides from and to which it is delivered to, would be adequate. Of course in addition to the local tariffs on the local pre-planned energy flows where the grid levels actually used are known on a per flow basis.

2.3.3 Offer flexibility to support local grid stability

The proximity of Energy Community members provides the potential to actively act toward local grid stabilisation. Either autonomously for the greater good (i.e., non-monetary benefits), or by offering ancillary services to the local DSO at some fair (regulated) price (tariff) or for some other means of beneficial compensation or indirect reward. Latter may for example be reduced grid tariffs for energy flows that do not leave the regional distribution grid toward higher (voltage) grid levels as discussed in Section 2.3.2.

Ancillary Services potentially provided and sold by Energy Communities may include for example [10]:

- Ability to ramp power up and down quickly
- Contribution to local voltage regulation
- Standby reserve power
- Black-start capability
- ...

A more casual ancillary service that may be required by regulation is the *traffic light system* presented in 5.6.4, as good practice example for a rather minimalistic approach to grid courtesy.

2.4 Sharing of energy within an Energy Community

In the end, any energy community is in some way a consortium of members that in a way intend to profit from cooperation. Some Energy Communities will be based on shared financing of resources, others on sharing excess energy. How energy and gained revenues shall be distributed is to be decided by the members. So far the directives are clear; national law and regulations might currently differ, but will converge over time.

In case of shared financing, the distribution key may be the contributed investment over time. Initial shares become adjusted by yearly contributed member fees as well as follow up investment contributions:

$$\text{share}(\text{member},t)[\%] = 100 \cdot \frac{\text{investments}(\text{member}) + \text{member-fees}}{\text{investments}(\text{all members}) + \text{all member-fees}}$$

This scheme assures persistent financing and fair shares, members that could not invest much upfront catch up via the member fees they pay, and members that want more energy shares more quickly can achieve this by providing financial sources to improve the efficiency of the Energy Community.

In case of excess sharing, the distribution equation shall also include the contributed energy kWh^{+} actually shared. The energy amount (kWh) has to be multiplied by some price factor to get sum-able units. The price could for example be the *spot price* for the current time interval to attract contribution at peak demand times:

$$\text{share}(\text{member},t)[\%] = 100 \cdot \frac{\text{investments}(\text{member}) + \text{member-fees} + \text{price-factor} \cdot \text{kWh}^{+}(\text{member},T)}{\text{investments}(\text{all members}) + \text{all member-fees} + \text{price-factor} \cdot \text{kWh}^{+}(\text{all members},T)}$$

If the energy sharing is dynamically adjusted by this distribution key, those that contribute more at one time within T get more at other times, fostering effective load shifting if the members get a signal that tells them if their share is rising or falling. The time interval for balancing the energy actually shared shall span sufficiently many metering intervals to be effective; e.g., T could be a day, a week, months or an entire year. Unsettled energy shares need to be converted into money for remuneration eventually.

2.4.1 "Gemeinschaftliche Erzeugungsanlagen" (ElWOG § 16a)

A solution to the peer-to-peer sharing problem exists for communities living in an apartment building (block of flats) sharing for example a common PV system on their roof. See exemplary scenarios at http://pv-gemeinschaft.at/ or the legal text of *Elektrizitätswirtschafts- und –organisationsgesetz (ELWOG) § 16a*.

In theory any sharing strategy can be negotiated among participants. However, the self-production shares are assigned via meter data accessible to the metering system operator only, e.g., the local DSO. Sharing schemes not supported by the metering system operator need to be contracted and implemented a posterior among the participants based on civil contracts. The two established yet not everywhere available sharing schemes are:

(a) fixed energy shares per member (static quota)

$$\text{energy-share}(\text{member},t) = \text{fixed-share}(\text{member}) \cdot \text{production}(t) \tag{1}$$

(b) demand proportional energy shares (dynamic)

$$\text{energy-share}(\text{member},t) = \frac{\text{demand}(\text{member},t)}{\text{demand}(\text{all members},t)} \cdot \text{production}(t) \tag{2}$$

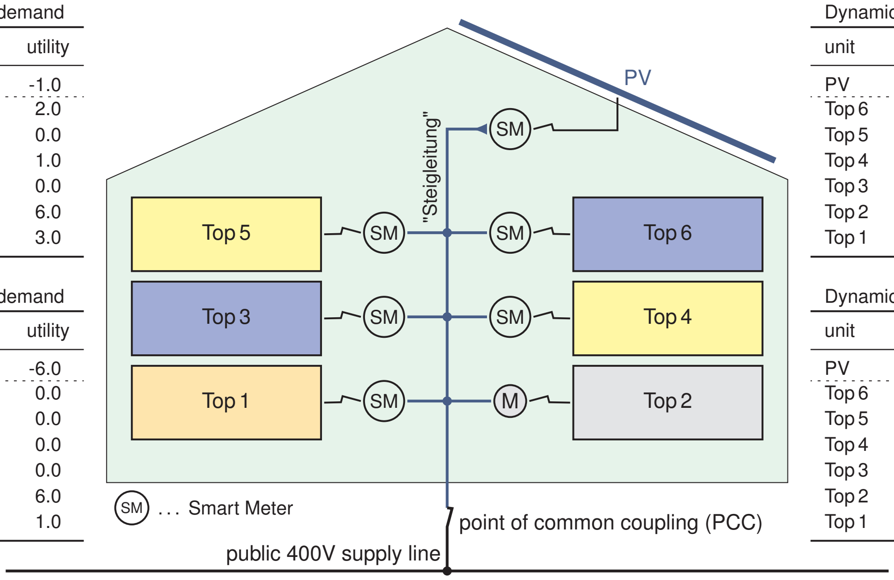
Note that the equations are simplified: the share a participant actually gets is evidently upper bound by the current demand, i.e., $min[\text{energy-share}(\text{member},t), \text{demand}(\text{member},t)]$. An exemplary setting is shown in figure 2.8, together with tables showing the scheme dependently assigned shares for exemplary situations [11].

Static (a 20%): PV < demand

unit	load	share	utility
PV	-10	9.0	-1.0
Top 6	4	-2.0	2.0
Top 5	1	-1.0	0.0
Top 4	3	-2.0	1.0
Top 3	2	-2.0	0.0
Top 2	6	- -	6.0
Top 1	5	-2.0	3.0

Static (a 20%): PV > demand

unit	load	share	utility
PV	-20	14.0	-6.0
Top 6	4	-4.0	0.0
Top 5	1	-1.0	0.0
Top 4	3	-3.0	0.0
Top 3	2	-2.0	0.0
Top 2	6	- -	6.0
Top 1	5	-4.0	1.0



Dynamic: PV < demand

unit	load	share	utility
PV	-10	10.0	-0.0
Top 6	4	-2.7	1.3
Top 5	1	-0.7	0.3
Top 4	3	-2.0	1.0
Top 3	2	-1.3	0.7
Top 2	6	- -	6.0
Top 1	5	-3.3	1.7

Dynamic: PV > demand

unit	load	share	utility
PV	-20	15.0	-5.0
Top 6	4	-4.0	0.0
Top 5	1	-1.0	0.0
Top 4	3	-3.0	0.0
Top 3	2	-2.0	0.0
Top 2	6	- -	6.0
Top 1	5	-5.0	0.0

Figure 2.8: Sharing of collective power generation

First of all, the community needs a feed-in contract with some utility to get rid of the excess power when momentarily more power is generated than can be assigned to the participants. Depending on regulation and/or participant governance, the gained revenues from selling excess energy shall be used for maintenance and/or forwarded to participants; evenly, shares aliquotely, share utilisation based, or any combination and variation thereof.

To be most accurate, balancing and shares distribution shall be performed on the shortest time interval feasible, e.g., the 15 min intervals provided by smart meters. Every participant and every electricity generation unit needs a distinct smart meter to enable a realistic, still smoothed, shares balancing. Participation is not possible without a capable meter; e.g., Top 2 in Figure 2.8 would first need a smart meter installed before being able to participate. The balancing is best performed by implementing equation (1) and/or (2) at the metering system operator. The calculated figures for internally distributed energy-shares become subtracted from the metered consumption figures prior forwarding latter to the individual energy suppliers of the participants[6].

The according tables in Figure 2.8 reveal that with static sharing quota (shown on the left) there remains excess power to be sold at low feed-in tariffs when the current demand is below the assigned share in a per participant regime. Better utilisation of the self-generated electricity is achieved with dynamic sharing (shown on the right) because the power is shared based on the current demand, such that the available power is used to fulfil all demands prior selling excess energy at low tariffs.

2.4.2 Generation sharing within Local Energy Communities based on § 16a

In general, privately distributing energy to peers across a public infrastructure is legally prevented for public safety reasons. If a privately owned grid infrastructure cannot be used, some existing, legalised, and regulatory approved energy sharing scheme needs to be implemented. If we apply the methods presented in section 2.4.1 as used for systems behind the point of common coupling now for Local Energy Communities, we get sharing as shown in Figure 2.9. In this example we consider a transfer of energy from one low voltage grid to an adjacent low voltage grid utilising the mid-voltage level, which here, on the right side of this example, causes a temporarily upward oriented energy flow. Organisationally, the smart meters of community members record the energy drawn and the energy inserted independently, and forward both these values, possibly among other grid quality parameters metered, to the grid, or more precisely, the metering system operator that runs the relevant advanced metering infrastructure.

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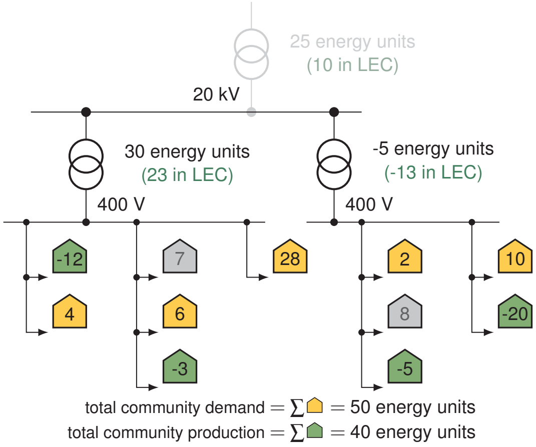
[6] Local power generation is commonly assumed not to provide the power required at all times. Therefore, and because of the legally enforced free choice of the energy supplier, participants need individual supply contracts in parallel.

Quota driven sharing

load	quota	community	supplier	excess
-12	10%	-4.0	0.0	-4.0
4	10%	-4.0	0.0	-0.0
7	- - -	- - -	7.0	- - -
6	10%	-4.0	2.0	-0.0
-3	10%	-4.0	0.0	-4.0
28	20%	-8.0	20.0	-0.0
30		-24.0	29.0	-8.0
2	10%	-4.0	0.0	-2.0
8	- - -	- - -	8.0	- - -
-5	10%	-4.0	0.0	-4.0
10	10%	-4.0	6.0	-0.0
-20	10%	-4.0	0.0	-4.0
-5		-16.0	14.0	-10.0
25		-40.0	43.0	-18.0
10	100%	-40.0	**28.0**	**-18.0**



Demand driven sharing

load	community	supplier	excess
-12	0.0	0.0	-0.0
4	-3.2	0.8	-0.0
7	- - -	7.0	- - -
6	-4.8	1.2	-0.0
-3	-0.0	0.0	-0.0
28	-22.4	5.6	-0.0
30	-30.4	14.6	-0.0
2	-1.6	0.4	-0.0
8	- - -	8.0	- - -
-5	-0.0	0.0	-0.0
10	-8.0	2.0	-0.0
-20	-0.0	0.0	-0.0
-5	-9.6	10.4	-0.0
25	-40.0	25.0	-0.0
10	-40.0	**10.0**	**-0.0**

Figure 2.9: Sharing of collective power generation

The only difference in calculating shares compared to the equations presented in section 2.4.1 is that the community $\text{production}(t) = \sum \text{production}(\text{member}, t)$, such that the equations become:

(a) fixed energy quota per member (static sharing)

$$\text{energy-share}(\text{member}, t) = \text{quota}(\text{member}) \cdot \sum_{\text{members}} \text{production}(\text{member}, t) \tag{3}$$

(b) demand proportional energy shares (dynamic)

$$\text{energy-share}(\text{member}, t) = \frac{\text{demand}(\text{member}, t)}{\text{demand}(\text{all members}, t)} \cdot \sum_{\text{members}} \text{production}(\text{member}, t) \tag{4}$$

That static sharing is not the best choice is clearly shown by the community sums in the last row of the left table in Figure 2.9. With static sharing the members (or the community as a whole) need to sell 18 energy units at the low feed-in tariff while at the same time the members buy in total 28 energy units at their commonly much higher purchase tariffs. With dynamic sharing, all the community internal provided power is used within the community, only the 10 units that actually are not available within the community are bought at purchase tariffs. The purchasing burden is load adequately distributed among the members that in average drained power in the current time interval.

Note, for example simplicity the community members either feed or drain power to or from the grid within the shown 15 min time interval. In practice, a prosumer's smart meter will record both, a positive purchase and a feed-in figure, for every 15 min interval. Both these figures shall be accordingly considered when calculating shares and not simply accumulated into a single load figure per member as in the example given.

Aside from potential physical layer issues (i.e., no implicit consideration of grid constraints), these sharing schemes can be very well applied. If the metering system operator can implement the summation of feed-in figures in addition to the already present shares calculation and consequential meter figures adjustment prior forwarding purchase and feed-in figures to the individual utilities of the community members, energy sharing across public infrastructures could be realised instantly.

2.4.3 Fair Energy Sharing

The sharing schemes specified in section 2.4.1 and 2.4.2 have a disadvantage: the shares distributed to individual members can diverge over time. The more power a member drains, the more cheap energy shares that member will in average get. A poor behaviour that shall be systematically prevented where feasible[7] to minimise the potentially a posterior required monetary compensation of unbalanced energy distribution[8].

However, any alternative accounting scheme needs to be implemented by the AMI operator prior it can be used. An alternative are schemes implemented within the Community Energy Management System, operating on top of the accounting scheme. These may for example cause recurring adjustment of the quotae per member to achieve more accurate balancing of shares assignment over time.

Please suggest additions required to exemplarily grasp common principles and general demands. Feel free to recommend sources to be summarised or referred to. You are welcome to contribute paragraphs or subsections alike.[9]

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[7] On one hand it is good to utilise clean power, on the other shall no power be wasted. The only exception to latter is clean power that would not be generated. For example, the capacity of distributed renewable energy sources that cannot be fed into the distribution grid due to grid curtailment. Wasting such power shares locally has no effect when strictly restricted to the truly surplus, in no other way usable share.

[8] If a member is dedicated to power generation, e.g., a regional operator of a small power plant, than monetary compensation is intentional, as is monetary contribution from members that do not generate power at all. The issue to address is unintended distribution divergence.

[9] Note that not all contributions can be included, and that some copy editing and shortening may occur version by version. Exemplary outlining of potential solutions is welcome, plain advertising and any confinement intended to promote a specific product (software, platform, hardware, or standard) will be generously neglected. Also exemplary solutions applicable for a minority of users that might misleadingly suggest common need or contradict common intentions shall not be included.

3 Business Functions

The business overview contains at least one initial business function. More IES Business Functions can be added in the course of amending the Technical Framework. The overview shall primarily be provided by Figure 3.0.1. Where business is complex, a selection of defined IES Business Functions is shown in Figure 3.0.1 for clarity reasons. In addition, the Smart Grid Architecture Model (SGAM) can be used to position IES Business Functions in the Functions plane along the Domains (conversion chain) and Zones (management) of this organisational architecture.

In the following subsections IES Business Functions are defined. Each starts on a new page[10] and includes at least a textual description of the functionality and an UML Use Case diagram[11] to show involved actors and meta-actors, their relations to each other, and their role in the Local Energy Communities business.

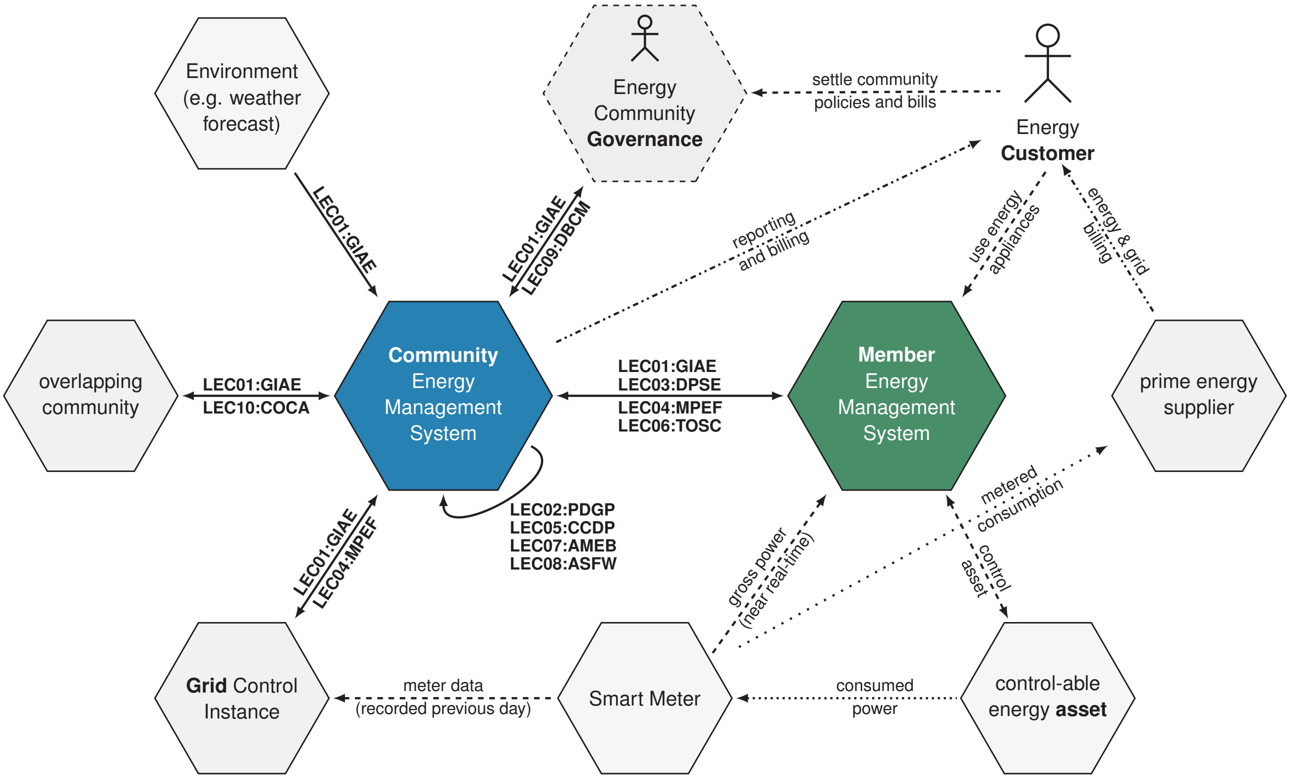

Figure 3.0.1: Business-Functions Overview (meta Actors-Transactions-Diagram)

Note that several of the identified business functions are executed within the Community Energy Management System not directly involving cooperation with other systems. These business functions cannot cause interoperability issues per se. No IES Integration Profiles need to be considered when implementing these, and therefore, no related IES Integration Profiles shall be specified in Vol.2 of the Technical Framework. For a holistic systems understanding, their core functionality shall be sketched in the following subsections but not further elaborated.

For a holistic understanding of the vicinity, figure 3.0.1 also shows some environmental energy system relations. These are dashed where a direct technical link exists, doted where connectivity is more or less indirectly realised, and dash-dotted where it is a contractual link.

IES Business Functions represent rather abstract meta use cases. In general, use cases cover feature-sets and can be defined at different detailing levels. Thus, a rather abstract use case can be split into more detailed use

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[10] Enable insertion of pdf-documents from whichever tool used. I.e., IES Business Functions shall be described in detail with the IEC 62559 Use Case Template using an external file or created with a Use Case Management Repository (UCMR) and embedded in the Technical Framework as imported subsections. The complete definition should be stored in a UCMR and in the following subsections only description and Use Case Diagram included. Where a UCMR is not available, the complete Use Case definition shall be included.

[11] Geri Schneider and Jason P. Winters: *Applying Use Cases, Second Edition – A Practical Guide*, Addison-Wesley, ISBN: 0-201-70853-1, 2001

cases. Vice versa, use cases can be combined to achieve easy understanding at reduced description complexity. Implementation requirements and constraints can be defined on different abstraction levels likewise.

In Vol.2, requirements are assigned to the *atomic* use cases, i.e., use cases that cover procedures that for consistency reasons shall not be split into smaller use cases. These are often referred to as features. See Vol.2 introduction on how to identify and confine such features. Commonly, features are realised using standardised functionality. However, the requirements and therefore the usage of these features can be dependent on the higher level use case, i.e., the IES Business Function they serve.

In addition to the Actors-Transactions-Diagram shown in 3.0.1, the generic Community Energy Management System operation can be depicted as a *Super-Use-Case* shown in 3.0.2. The connectivity show here is exemplary and assumes a rather complex community management approach. In practice the connectivity may differ, depending on community environment and management focus/policy. With some effort the previously identified IES Business Functions can be assigned to the shown use cases and actors. In general, they depend on more than a single use case and use cases are involved in multiple business functions. Therefore, this representation is not very utile to discuss them in detail.

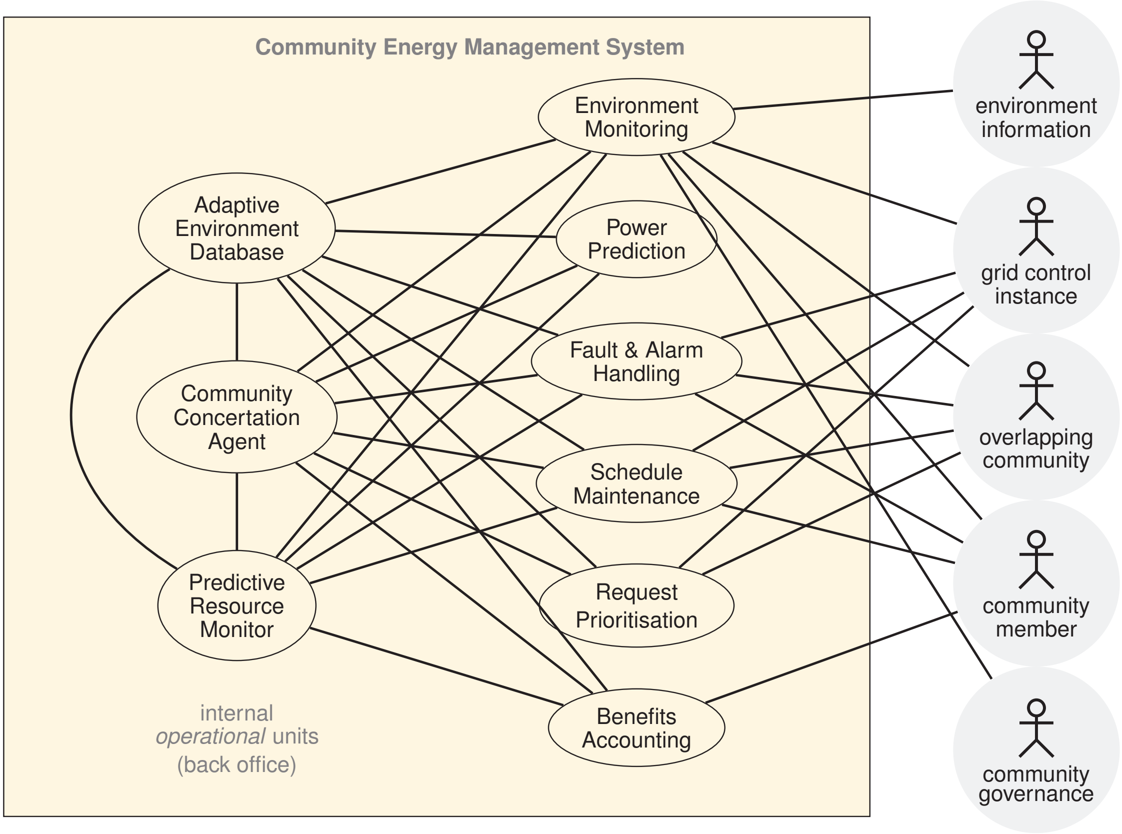

Figure 3.0.2: Super-Use-Case representation of a Community Energy Management System

Next, the high level description is itemised. Business functions and software components are individually defined in the following and in section 4 respectively.

Without loss of generality, internal sub-systems, i.e., back office software tools, which often are realised using generic software packages, are henceforth considered as internal actors. Where all functionality is realised using ready made software packages, the implementation reduces to selecting a viable set of packages that jointly supports all requirements and is integrable at feasible costs. The integration effort may by reduced to configuring the interfaces among the software packages. However, intermediate message parsers need to be developed or purchased and integrated where interoperability is not offered out-of-the-box (e.g., to integrate legacy systems).

3.1 Business Function LEC-1: Get Info from Assets and Environment (GIAE)

This Business Function includes both, a priori information gathering and continuous information updates. As Energy Communities operate in a real, physical, time continuous, mostly analogous environment, the parameters thereof can change any time without warning. Therefore, an Adaptive Environment Database is required to always provide any required information (historic and actual) as accurate and timely as possible.

LEC-BF1 requires a collection of procedures to gather all the data required to operate an energy community. Depending on the available sources, and the extent, scope and complexity of the intended community management, different compositions of mechanisms and information sources are required. The methods reach from manual entry of for example community governance information (e.g., policy parameters) to fully automated retrieval of for example weather forecasts from multiple sources and push notifications on power grid states.

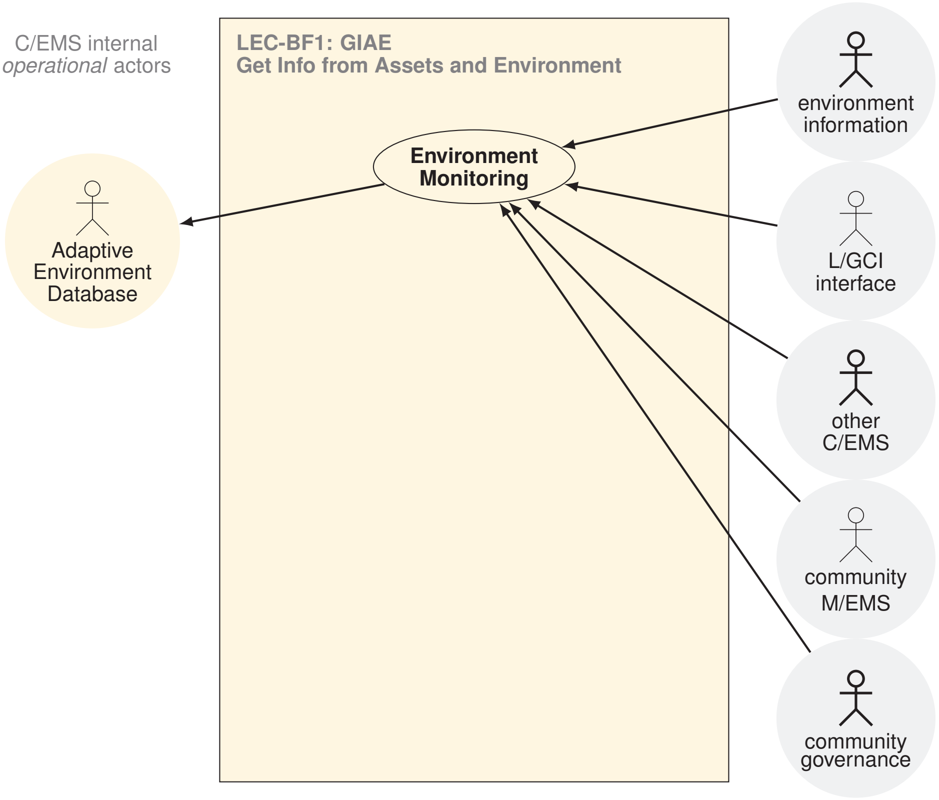

Figure 3.1.1: LEC-BF1-GIAE: Use Case diagram

All information, received off-line as well as on-line, shall be stored in an Adaptive Environment Database.[12] This database is the foundation of Energy Community management and shall contain all the information required to operate the Energy Community.

The multitude of possible interfaces to connect the different sources required may be a problem. However, digital platforms that translate all the different request and response formats offering a unified interface may be a viable solution.[13] Also the Member Energy Management System communicating with the different assets at member premises shall translate the different responses into a unified format to harmonise the communication with the Community Energy Management System.

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[12] The database shall be adaptive in the sense that new data sources and information contents can be added and obsolete or no more available are removed. In particular machine learning based on the correlation of many different information streams improves the more independent sources are available. Given the short life-cycle of IT services and the fast development of interfaces we recognise that adaptation is essential. But also basic information that might be considered static alike the power grid topology can change and becomes dynamic when automated switchover is deployed.

[13] Data security, confidentiality and timeliness need to be evaluated. Safety critical information might demand native interfaces to prevent third party involvement.

3.2 Business Function LEC-2: Predict Demand and Generation Profiles[14] (PDGP)

This Business Function is required within a Community Energy Management System if prediction based load shifting shall be performed. It uses the data available in the Adaptive Environment Database to predict individual energy demands and expected production schedules, e.g., on a daily basis, one day in advance.

LEC-BF02 relies on information assumed available, i.e., accumulated in a data-base prior doing predictions, and therefore requires no direct interaction with external systems. There are no external accessible interfaces required that might cause interoperability issues in the field.[15]

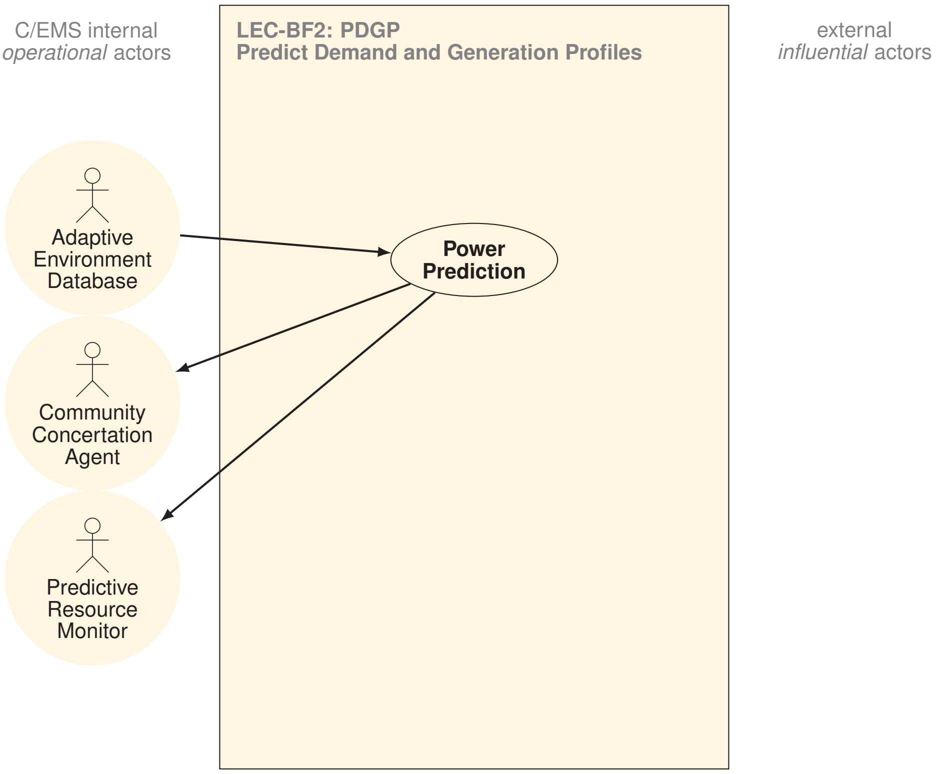

Figure 3.2.1: LEC-BF2-PDGP: Use Case diagram

The prediction results are forwarded to the Community Concertation Agent, where in cooperation with the Predictive Resource Monitor the schedules of all community assets are adjusted (Schedule Maintenance) in a way that optimises self-consumption on the individual and on the community level, and at the same time maximises the minimum gap to the local grid bounds over all community members, which in general results in maximally similar headrooms for unexpected deviations from the planned grid utilisation.[16]

Finally, LEC-BF03 takes over and forwards the planned schedules to the Member Energy Management Systems of the community members for execution, and optionally to the Local Grid Control Instance (and other Community Energy Management Systems) where this information is required for proper grid operation.

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[14] The expected change of the power demand/generation over some time interval, commonly one day, is often called 'profile', in particular if expectable variation is included. To be not easily mistaken with Integration Profiles, we prefer to use the term 'schedule' when referring to simple power over time, and 'power profile' only where deviation intervals are actually included and considered essential.

[15] Business functions that cause no interoperability issues are only briefly sketched for holistic system understanding. No potential for issues to be solved means also that no Integration Profiles are needed, and therefore no further consideration in Vol.2.

[16] How the asset concertation is performed is irrelevant for interoperability as long as the resultant schedules are produced in good faith not to contradict the objectives of peer systems, i.e., Local Grid Control Instance, Member Energy Management Systems, and other Community Energy Management Systems.

3.3 Business Function LEC-3: Distribute Planned Schedules for Execution (DPSE)

This Business Function is responsible for sending any kind of schedule from the Community Energy Management System to any other entity. It distributes planned schedules done by the Community Concertation Agent to the Member Energy Management Systems of the community members, and optionally to the Local Grid Control Instance (and other Community Energy Management System) where this information is required for proper grid operation.

In general, LEC-BF03 simply transfers a power schedule calculated by the Community Energy Management System within its Community Concertation Engine to the destined Member Energy Management System for scheduled execution. How a schedule is specified depends on the profile used, i.e., the capabilities available. At least, a schedule has a start-time, a duration, and power levels. If only a single power level is supported, a new schedule needs to be defined for every power change and executed until the next schedule succeeds.[17] Commonly, it is a sequence of power levels,[18] either specified with individual start-times for each level (event based) or via a constant time-interval in between levels (clocked).[19]

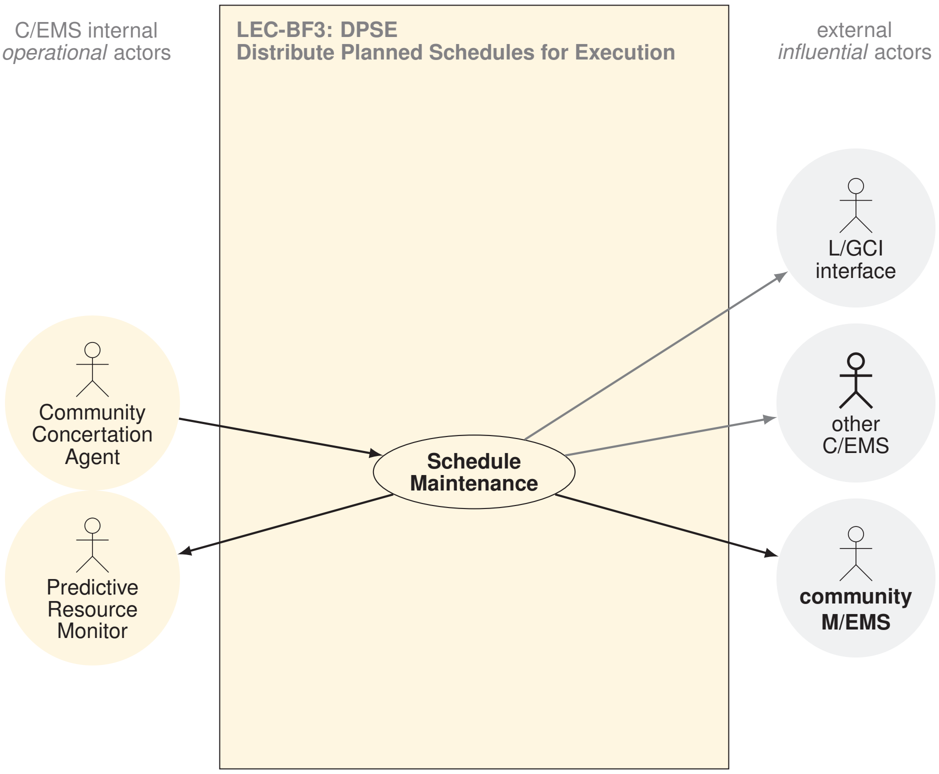

Figure 3.3.1: LEC-BF3-DPSE: Use Case diagram

After receiving a planned schedule, the receiving Member Energy Management System is expected to check the validity of the schedule, i.e., if at least theoretically it can be executed within safety limits. If latter is true, the receiver acknowledges the schedule,[20] else it rejects it and thereby triggers the Community Concertation Agent to redo the optimisation and send a different planned schedule. Planned schedules can be altered any time by receiving and acknowledging a newer schedule for the same or an overlapping time interval. During execution, local events (e.g., a cloud passing over the PV) may cause deviation from the planned schedule at any time, which the Community Energy Management System shall in general detect and respond to on its own (BF-LEC04, BF-LEC05, BF-LEC06).

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[17] Optionally, a schedule may include ramp constraints to shape the transition from one to the next power level. More important might be frequency holding and power angle control (adjustable inertia). However, simple and cheap assets may not support such features.

[18] If a simple asset can be controlled in-time only, e.g., cannot handle timed power setting, the planned schedule needs to be decomposed into a sequence of power settings that are transmitted to the asset just-in-time for execution (i.e., sent ahead of the set time with an offset that equals the transmission and processing delay).

[19] Based on 15-minute intervals we need 96 power levels per day, 92 when shifting to daylight saving time, and 100 when shifting back. Schedules may be generally specified a little longer to slightly overlap, e.g., to hold for example 128 15-minute intervals to mitigate gaps in case the execution of the succeeding schedule is somehow delayed.

[20] Depending on the used profile a more sophisticated procedure may be required to assure that only authorised entities can trigger the execution of a schedule. On the other hand may very simple assets (actors) not provide a return channel at all.

3.4 Business Function LEC-4: Monitor Power and Energy Flows (MPEF)

This Business Function is responsible for continuous awareness of the instantaneous power levels and energy flows. The primary source to perform this are meters (sensors) available at member premises forwarded to the Community Energy Management System via the connected Member Energy Management System. A secondary source can be information from the local grid operator (Local Grid Control Instance) and information shared by other communities. In contrast to LEC-BF1 is manual entry of data not an option; LEC-BF4 shall provide accurate sensor data and provide that in a timely and intrinsically reliable manner.

If the density of the metering locations across the local grid is sufficient, the grid state can be assessed, at least roughly. Where no connection with the Local Grid Control Instance is possible, this assessment is required to maintain grid safety (as good as possible) when actively utilising grid resources to exchange energy among members exceeding the basic (by the DSO guaranteed) access capacities.

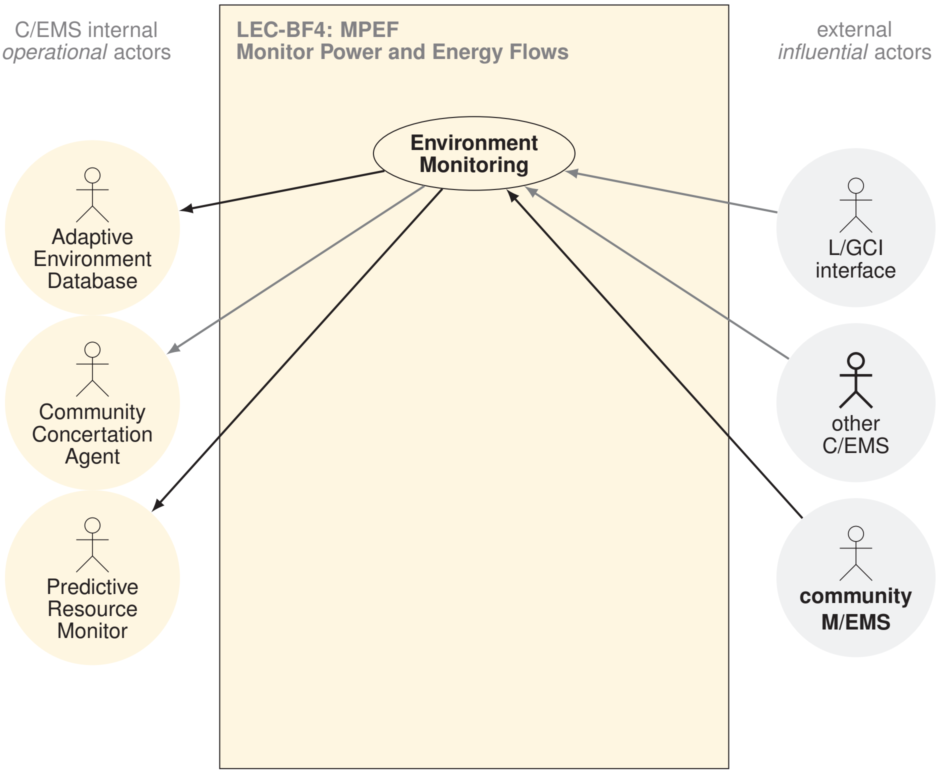

Figure 3.4.1: LEC-BF4-MPEF: Use Case diagram

The prime objective of LEC-BF4 is to collect the data required for LEC-BF5, i.e., calculating the deviation from planned schedules, and the subsequent LEC-BF6 that triggers on-demand schedule adjustment to counteract critical deviation from the planned grid load. It is important to note the difference between power (kW) and energy (kWh): power is instantaneous and important for safely operating appliances and utilising public grid resources, whereas energy is the integration of power over time, which yields what can be accounted, shared and also traded.[21]

The data collected by LEC-BF4 may also be used for LEC-BF7 to calculate the contributed and consumed energy shares per member, which is used in LEC-BF8 to trigger adjustments that intend to improve fairness, and LEC-BF9, where compensation and benefits are distributed to members according to community policy.[22]

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[21] Power is planned and recorded via the Resource Monitor (where deviations become apparent), whereas energy shares are recorded in the Environment Database (or within Community Concertation in case the agents include data storage).

[22] In case the Energy Community does not get data from the AMI operator on the shares assigned per member, the energy flow monitoring is the only basis for LEC-BF7, LEC-BF8, LEC-BF9. Anyway, monitored data will be more accurate and responsive (i.e., provides information close to real-time and not delayed via a monthly or yearly balancing report or energy bill).

3.5 Business Function LEC-5: Calculate Current Deviation from Plan (CCDP)

The planned and the actually monitored power levels produced and consumed by the community assets will in general not match perfectly. Small deviations can be neglected, but for large deviations, in particular where trends toward critical situations become apparent, the deviation from planned power levels needs to be analysed to identify the possible source(s) and to calculate measures to counteract any upcoming critical situation.

The Business Function LEC-BF5 is introduced to explicitly mention the non-trivial effort that backtracking and mitigating deviations via adjacent resources causes.[23] Alike LEC-BF3, this task is performed entirely Community Energy Management System internal and raises no directly related interoperability issues.

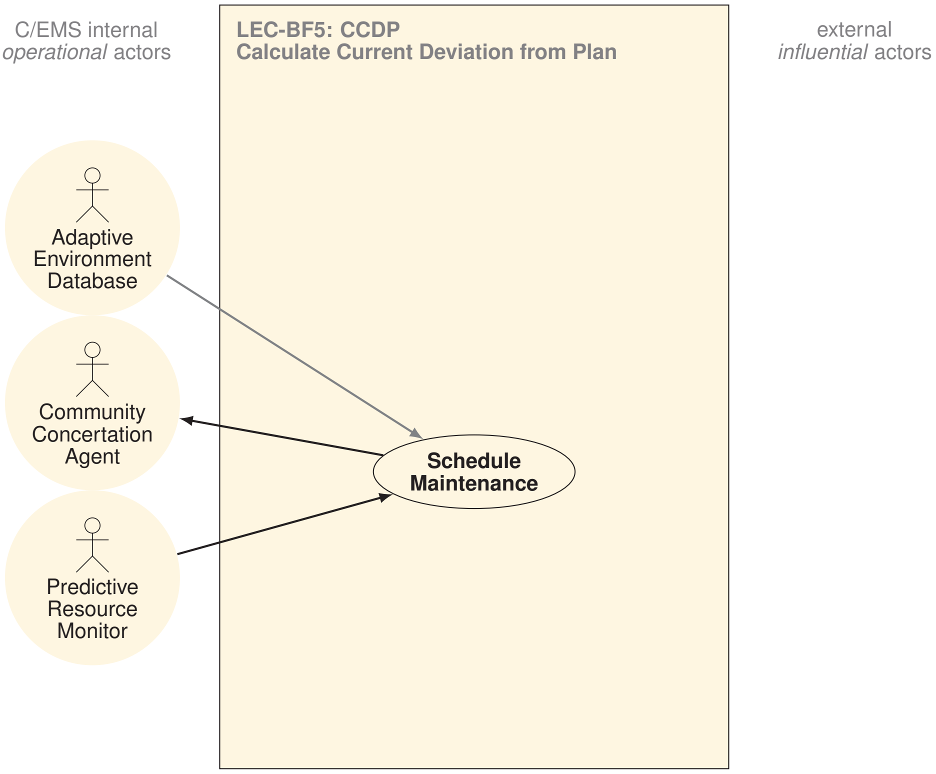

Figure 3.5.1: LEC-BF5-CCDP: Use Case diagram

LEC-BF4 reports the actual monitored production and consumption to the Predictive Resource Monitor, where deviation from the plan become apparent. If the deviation exceeds a negligibility threshold in the deviation amount and persistence, it is reported back via the Schedule Maintenance module to the Community Concertation Agent.[24] On receiving a changed schedule, the Concertation Agent re-calculates schedules for adjacent assets, similar to calculating the planned schedules in LEC-BF2, which now shall smoothly (i.e., with minimal adjustments) mitigate the grid load deviation caused by the diverging asset.[25]

Once new schedules are calculated, LEC-BF6 shall forward them to the affected assets, which in consequence adjust their currently executed schedule. Thereby, the grid shall be prevented from any harm and unnecessary curtailment of local renewable sources effectively prevented.[26]

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[23] Adjacent resources are those that are connected to the distribution grid next to the source of the deviation. Possibly, the group of 'next' neighbours shall be increased recursively until a good solution can be found.

[24] The Concertation Agent uses an updated schedule for the upcoming time period, e.g., shifted up or down according to the apparent deviation, to calculate schedule adjustments for adjacent assets.

[25] If an asset deviates from the plan we shall assume that there is a persistent reason that hinders performing as planned, such that sending a request to return to the planned schedule would be useless.

[26] Local correction shall occur long before any counter actions of the DSO (or TSO) are triggered. That should be possible as long as deviations are small and their duration remains short. If in addition local primary reserve can be provided by the community itself, the mitigation of community internal prediction uncertainties would be even better.

3.6 Business Function LEC-6: Trigger On-demand Schedule Corrections (TOSC)

Aside from immediately required schedule changes caused community internally, e.g., by LEC-BF5, ad hoc changes may also be triggered by the environment: The DSO may request to execute flexibility (ancillary service) sold by the community, or some critical situation (fault/alarm) may require immediate action.

In case the necessary changes requires switching to a pre-calculated schedule, these may be present at the Member Energy Management System and LEC-BF6 either reduces to signalling the resources to which schedule they shall switch, or where the Member Energy Management System perform the switch-over autonomously, to update the Predictive Resource Monitor to match the current state.[27] If pre-defined schedules are not available, the Community Concertation Agent needs to calculate new schedules prior changes can be subsequently triggered.

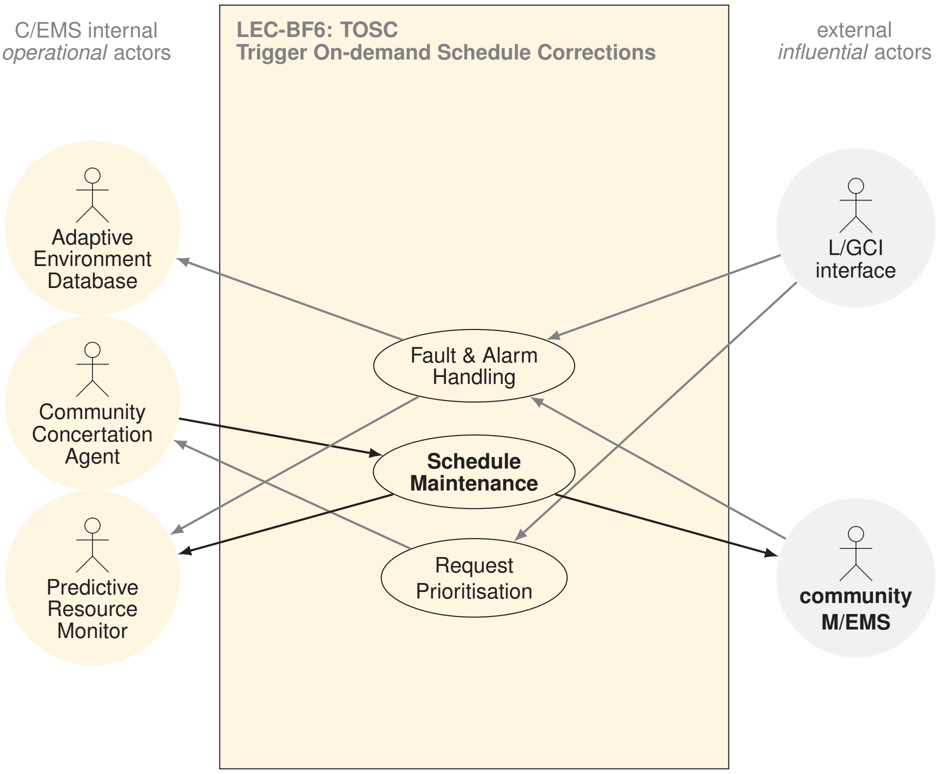

Figure 3.6.1: LEC06-TOSC: Use Case diagram

The execution of LEC-BF6 depends on the cause for an ad hoc correction and the options available:

- The Community Concertation Agent has new schedule(s) to be executed ad hoc:
  - Similar to LEC-BF3 forward corrected schedules to the according Member Energy Management Systems.
  - Every Member Energy Management System (or device in the field) that receives a new schedule with a start time prior the current time shall switch to the new schedule as soon as possible.
- The Local Grid Control Instance requests an operation mode for which pre-defined schedules exist:
  - Assess the legitimacy and priority of the request, and how to respond collectively.
  - Signal all affected Member Energy Management Systems to which schedule they shall switch.
- The Member Energy Management System has autonomously switched to a different schedule:
  - Inform the Community Energy Management System via an alarm which schedule is now active.
  - If necessary attach the new schedule to the message.

Finally, the Predictive Resource Monitor is updated to always represent the assumed future as good as possible.

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[27] Predefined schedules may be activated by changing schedule priorities or by replacing the existing schedule with the new schedule. A virtual 'emergency' schedule always present is the NULL schedule, i.e., disconnecting the energy asset/customer from the grid. This emergency action will in general be triggered locally, not via the Community Energy Management System, either locally when recognising a fatal condition (when a fuse blows), or when the DSO activates a breaker to physically disconnect the customer, more often a small group of customers, from the grid.

3.7 Business Function LEC-7: Accumulate Member Energy Budgets (AMEB)

All planned and actually monitored power flows shall be recorded and made transparently available to the respective Energy Community member. Accumulating the energy provided and consumed by the members is also the basis for a posterior remuneration (LEC-BF9) and adaptive shares assignment (LEC-BF8).[28] We assign this to the Benefits Accounting use case because this business function is entirely decoupled from any physical energy management.

The output of LEC-BF7 is twofold: On one hand it records and tells each member individually how much energy it has got/contributed from/to its peers, and on the other hand, it tells what is expected in the near future (as far as yet scheduled). Latter is optional, but a nice attempt to inform the member on what it might expect – a transparency bonus (a carrot).

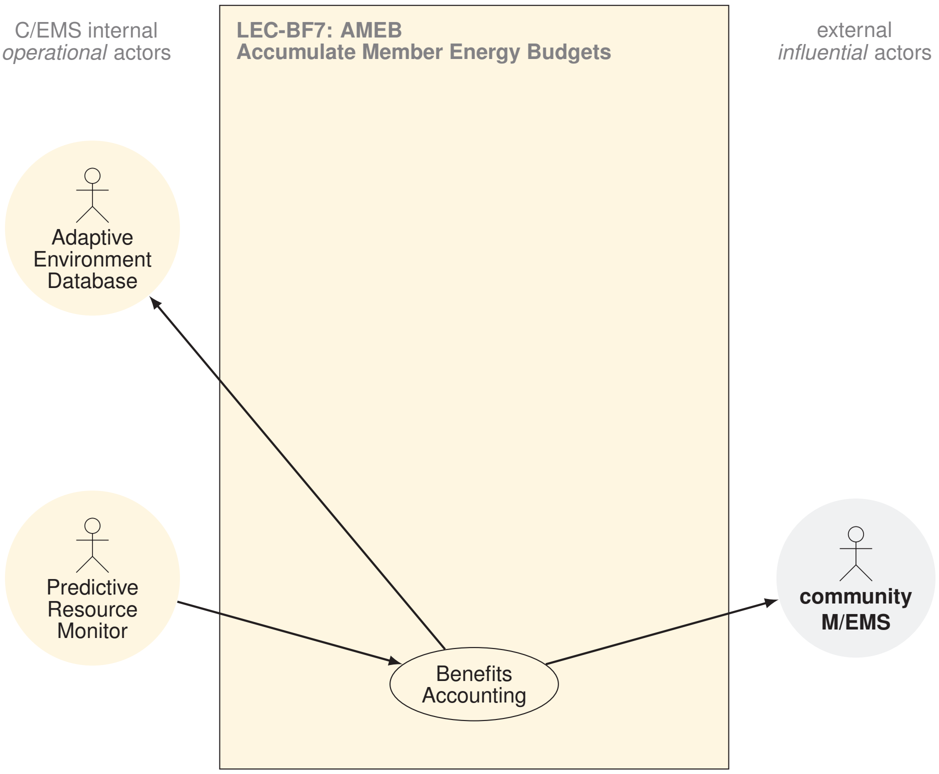

Figure 3.7.1: LEC07-AMEB: Use Case diagram

Every change on power and energy assignments within the Predictive Resource Monitor triggers the forwarding of the current data to the affected Member Energy Management System and to the Environment Database for internal logging. Thereby, the data is stored redundantly, twice locally[29] and once at member premises. If no data storage is possible at customer premises, an according on-line interface shall be provided to allow the member to look up all data relevant any time.

An option to reliably record and store at least the actually executed energy flows would be the private distributed ledger technology. The distributed Member Energy Management Systems can serve as storage entities for the maximally redundant maintenance of the encrypted transactions (data blocks).

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[28] Energy flow based remuneration may be optional. Being transparent is not, it is essential to achieve trust of members in the Energy Community and to enable them to perform proper community governance based on facts.

[29] It is important to note that logging is essentially required to track the history of actions because the Predictive Resource Monitor is assumed to remember the latest relevant data only for performance reasons.

3.8 Business Function LEC-8: Adjust Share Fulfilment Weighting (ASFW)

The intention of LEC-BF8 is to recurrently adjust the shares assignment among the Energy Community members based on the amount of shares a member is planned to get (and/or provide) and the amount that the member actually has achieved (and/or contributed).[30]

The planned shares and how the available energy shall be distributed within an Energy Community is a central governance issue. The problem is to actually realise the planned distribution because shares can only be assigned when demand and availability coincide. Timely coincidence of supply and demand is not always given, and therefore, over time the shares assignment may diverge from the planned and aggreed upon shares distribution.

Recurring share assignment adaptation is an option to counteract accumulating deviation from the planned energy distribution and benefits sharing. If correctly implemented, any deviations should be in the long term equalised, at least as far as possible.[31]

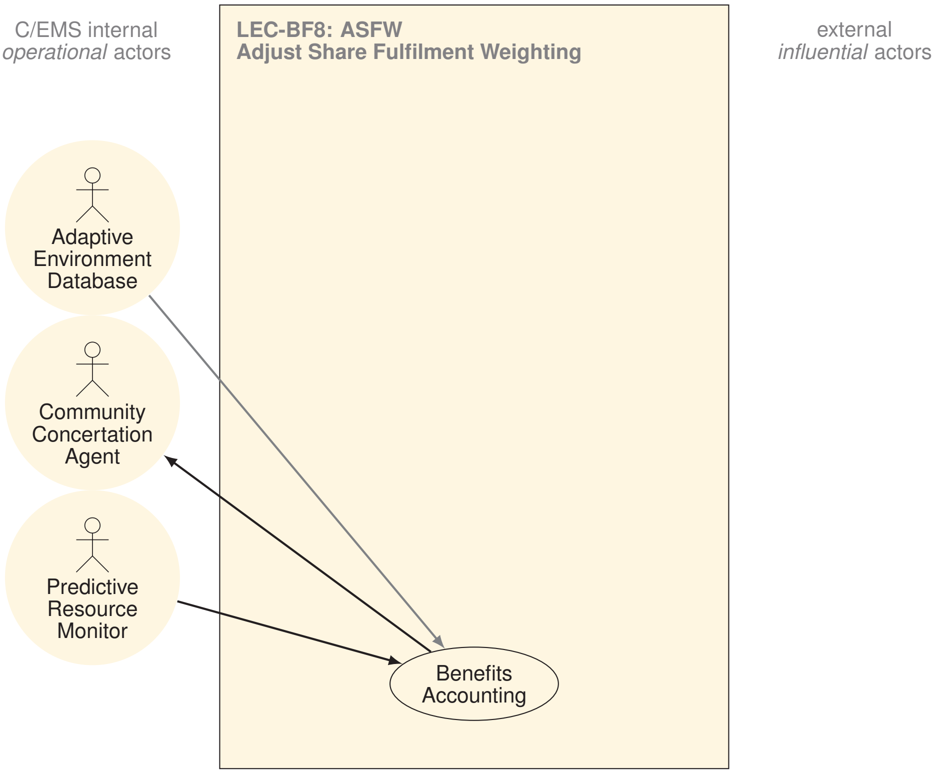

Figure 3.8.1: LEC08-ASFW: Use Case diagram

Based on the agreed sharing quotas, defined by the joint Energy Community governance and stored in the Environment Database, and the actually assigned flows, reported by the Resource Monitoring and accumulated by LEC-BF7, deviations become apparent.

Based on the identified sharing deviation the weighting factors (current quotas) used by the Community Concertation Agents shall be adjusted, such that from now on those having achieved more than intended will in average get less, and vice versa, those that yet have not got their shares aliquotely, can in future get more.[32]

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[30] The shares each Energy Community member shall get should be in line with the member's contribution to the Energy Community. Either in terms of contributed energy or in terms of financial contributions, or a mixture thereof.

[31] Evidently, if an Energy Community member never or very rarely needs energy when there is energy available from peers, it will not get many shares, independent of the weighting factor. A power provider, e.g., a small municipal hydro power station, either operates on good will for the better of the community, or will request some form of compensation.

[32] If the insertion tariff is low, the community needs to decide whether to still forward shares to over-fulfilled members even if that increases the sharing imbalance. Where financial remuneration is possible, those getting more than planned need to pay the extra shares they got to those that did not get them.

3.9 Business Function LEC-9: Distribute Member Benefits and Compensation (DMBC)

Participating in an Energy Community needs to be at least in some way attractive. Obvious are financial savings and economic benefits.[33] The aim of LEC-BF9 is a transparent process to equitably distribute community earnings.

For a community owned legal entity it is evident that gained net-income is distributed to the owners (shareholders). Individual investments and contributions to a joint property result in ownership shares and a dividend.[34] The technical system specifications required for a trustworthy implementation of both shall be covered by the use cases and integration profiles required to realise LEC-BF9.

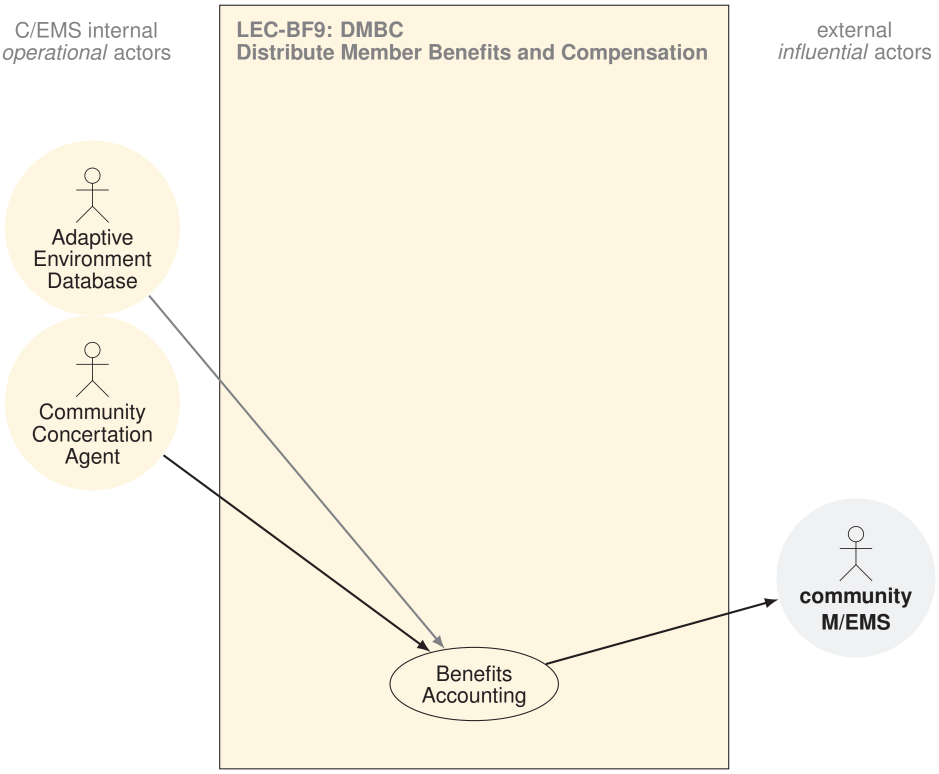

Figure 3.9.1: LEC09-DMBC: Use Case diagram

Based on the data kept in the Adaptive Environment Database on community composition and contributions received from individual members, the gained net-profits shall be divided among members according to a jointly agreed scheme. In case of sold flexibility, this shall consider who actually responded by ad hoc changing a schedule (demand response), which shall be reported by the Community Concertation Agent.[35]

To encourage members to optimally serve the community, their individual profit shall increase the more they adjust their behaviour to optimise the profit of the community as a whole. For a fast feedback, it is recommended that the attempts to better serve the community shall result in an according signal sent to their Member Energy Management System.[36] This feedback might be directly used for recursive adjustments within customer premises to improve the behaviour and thereby the benefit from participating in the Energy Community.

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[33] For many people, in particular those not bound to economic rationality, also altruistic reasons exist to invest and contribute to Energy Communities: (a) support the poor, (b) foster regional business, (c) increase community welfare, (d) maintain a liveable environment, (e) save the planet from collapsing. All these have severe economic implications, but on a vague time scale, assumed difficult to address. However, if the associated risks and benefits can be somehow represented monetarily, these can be introduced in this business function likewise.

[34] A viable way to increase individual benefits shall be participation in collective investments; either on demand, or regularly in small shares, where both might be via monetary as well as in kind contributions.

[35] Seamless logging and making the impact of actual demand response visible to members appears to be indispensable for lessons learning. Transparency of the reasons why some members serve the community better than others is also important to prevent envy among members as good as possible.

[36] In some cultures a ranking may be utile to show how good one member performs in comparison to others; in other cultures – where altruism prevails competition – an appealing reward might be collected points, either in total achieved by the community or individual comparison with the average points collected by similar members.

3.10 Business Function LEC-10: Coordinate Overlapping Community Actions (COCA)

The eponymous task of LEC-BF10 is to coordinate actions of communities and other instances that manage clients within the same grid segment. That also applies in case the community is embedded in a hierarchy or a part of a cellular mesh of neighbours or a randomly linked swarm of distributed control entities.

If community members participate also in a Demand Response or Demand Control scheme operated by some other instance than the Community Energy Management System, e.g. a DER aggregator or the local DSO, the actions in response to these instances need to be communicated to the Community Energy Management System. Either directly via a communication link connecting the different management systems or relayed through the clients Energy Management System.

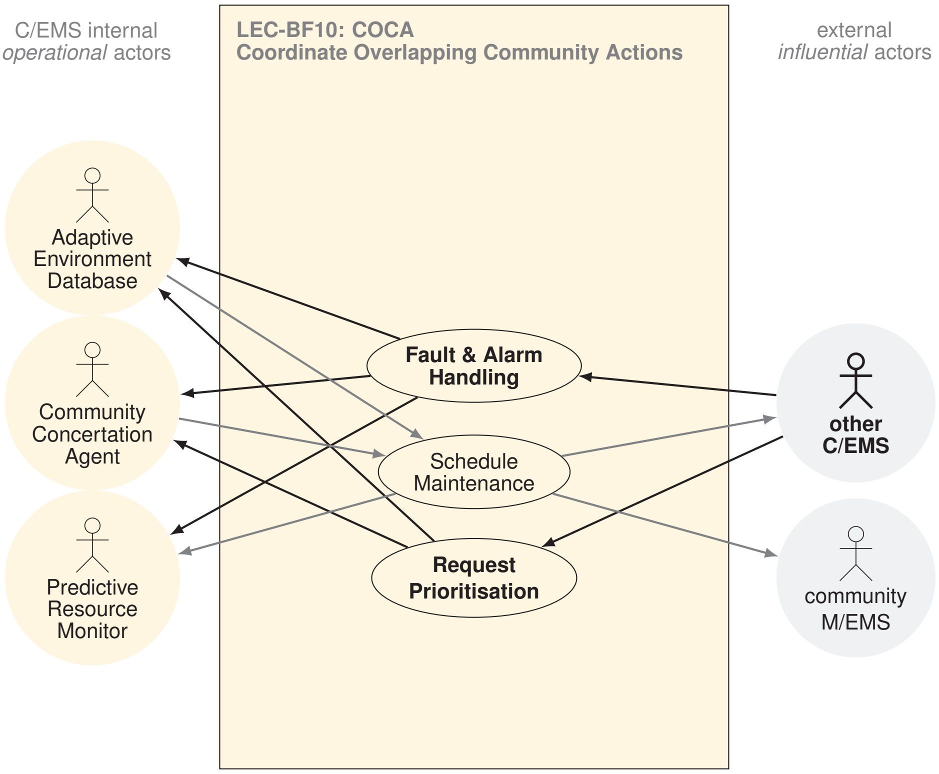

Figure 3.10.1: LEC-BF10-COCA: Use Case diagram

The technical use cases directly involved in handling messages from other Community Energy Management Systems and alike are *Request Prioritisation* and *Fault & Alarm Handling*.[37] Received messages are processed and forwarded to internal actors, which trigger other use cases in response, i.e., those of LEC-BF6.[38] Vice versa shall the community send messages to other Community Energy Management Systems to inform them on faults, alarms, environmental changes, and own requests that interfere with their activities.

Table 3.10.1 shows that the response to receiving a message from some other Community Energy Management System can be handled by a single process covering most expectable messages. However, this process triggers other possibly very complex processes, e.g., adjusting and redoing of active and planned schedules respectively.

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[37] Evidently, for LEC-BF10 Community Energy Management Systems interoperability is of eminent importance. However, in case the clients' Member Energy Management System operates as message relay it can parse messages and translate them such that they are understood by the individual Community Energy Management Systems, which might not be interoperable when directly linked. The processing of relayed messages shall be identical to directly received messages.

[38] In contrast to LEC-BF6 we shall in general not assume here that pre-calculated schedules are available for fast switching. The possibly required responses may be too state specific to reduce them to a few.

Table 3.10.1: Potential messages and message handling

message received	*response to message*
• resource failure • resource occupation • request for resource	1. validate & prioritise message 2. identify affected schedules 3. reject request if own priority allows (exit) 4. block resource in usable environment 5. maintain (adjust) active schedules 6. maintain (redo) planned schedules 7. forward info on new usage of shared resources

4 Meta-Actors

The discussion of business options and thereto required Business Functions reveals the system's Meta-Actors, i.e., the individual system parts that in general become implemented at different locations as some address-able entity. These independent parts take over system wide responsibilities and communicate with each other as required to contribute their share to realise the different Business Functions required for a certain scenario.

The entities responsible for the core functionalities of an Energy Community are:

- COMMUNITY ENERGY MANAGEMENT SYSTEMS
- MEMBER ENERGY MANAGEMENT SYSTEMS
- LOCAL GRID CONTROL INSTANCES

4.1 Energy Community operation entities

The core entities that are essentially required to operate an Energy Community that aims on actively managing and controlling timed energy flows among its members are here listed and briefly defined.

4.1.1 Community Energy Management System – C/EMS

On community level, the core task is *concertation*, i.e., temporal arrangement of a variety of resources to achieve a greater good. Theoretically, there might exist quite a plurality of ways to achieve local balancing. However, the smaller the community is and the less offers and requests can be scaled and shifted in time, the less options remain practical. Finding a viable balancing solution cannot be granted.

Powering customer appliances from the grid is more than a reinsurance, the grid also covers timing variances and unexpected deviations from planned power schedules. For example, cooking a meal will probably not be perfectly aligned with the scheduled power insertion adjustments at a neighbouring PV-rectifier. Also well manageable appliances may not execute the planned schedule due to some unexpected local event. For example, a non-managed appliance can cause a blown fuse that also affects the managed appliance.

The uncertainty on actually fulfilling planned schedules makes near real-time monitoring and on-demand adjustment of schedules necessary. Preparing counter-actions for expectable deviations shall therefore be included in the ahead of time schedule planning. Reliable *risk management* is essential to gain trust from the Distribution System Operator responsible for the safety of all connected clients.

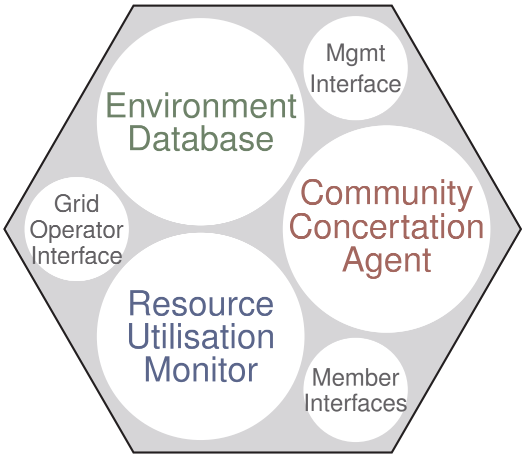

Figure 4.1: Community Energy Management System – a composition of modules and interfaces

In case the regions covered by different Energy Communities overlap, or in case clients may contribute to several Energy Communities in parallel, the actions of their Community Energy Management Systems shall be coordinated. A direct link to inform neighbouring Community Energy Management Systems and an according consideration of their actions via dedicated behaviour models shall be foreseen to cover this situation.

A direct link with the local Distribution System Operator (DSO) seems appropriate as well: (a) to keep the DSO informed about all planned energy flows among community members, and (b) to provide an interface to inform the Community Energy Management System in case the DOS took emergency measures to assure grid safety that might interfere with community operation. A possible approach to integrate DSO needs may be the *traffic-light system* outlined in Section 5.6.4.

4.1.2 Member Energy Management System – M/EMS

An Energy Management System (EMS) at customer premises translates customer, grid, and community requirements into dedicated control signals distributed to the locally managed energy appliances within customer premises. How internal and external requests are coordinated, split and translated into commands controlling the different available appliance is the core task these Meta-Actors shall perform aside from communicating with the Community Energy Management System, and possibly relaying parsed messages among Community Energy Management Systems in case the member contributes to several Energy Communities.

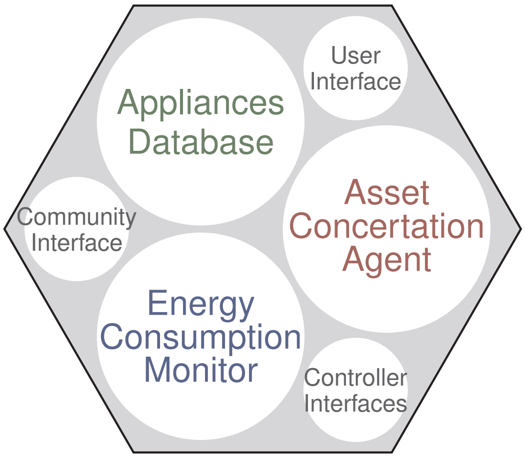

Figure 4.2: Member Energy Management System – a composition of modules and interfaces

The common prioritisation (above any intelligence) is grid safety over customer demands over community requests. For example shall no customer be allowed to insert energy if the grid voltage at the access point is above the maximum allowed. On the other side shall an EMS override community requests whenever a customer manually expresses the need for power to an appliance. The Member Energy Management System must not decide what is a life endangering emergency need and what is not.

To be customer friendly, operation shall be mostly autonomous and default settings shall satisfy 80% of all potential customers (Pareto). Activation of an appliance shall be available via the regular interface. For example, pressing some 'Start' button on the washing machine shall start the washing program. In general, an appliance shall not be interrupted by the EMS as long as an energy consuming process is executed. For example, the EMS shall allow the customer to cook an entire meal – as stated in any recipe.

To supervise its actions the EMS needs to monitor the energy consumption. It shall not be assumed that responses from simple energy appliances are always available and sufficient. The customer interface of capable Smart Meters may provide the necessary metering. However, the total energy consumption will include considerable shares caused by non-managed appliances, for example a hair-drier. Somehow sorting out such background load seems required to correctly monitor the EMS performance, in particular to measure the actual response to grid and community requests.

4.1.3 Local Grid Control Instance – L/GCI

The Local Grid Control Instance is a local or virtual (realised within a control centre) control instance that covers and handles a specific grid section. These instances are assumed per grid level, and *if no such entity is available the Community Energy Management System shall create it internally*. These control instance shall at least monitor the power quality across their section and trigger informative allerts if limits are exceeded. More sophisticated instances may also be sufficiently smart to engage local adjustments, for example triggering reduced power insertion or load via signals to locally connected customers that voluntarily participate in grid stabilisation (a local *flexibility market*). As of 2020, such localised instances may be rarely available in the mid and low voltage grids, but with the transition into *Smart Grids* these *Local Grid Control Instances* will be almost everywhere available, often virtual as *Digital Twin* of the local LV distribution grid being a small part of a *Regional Distribution Control Center*.

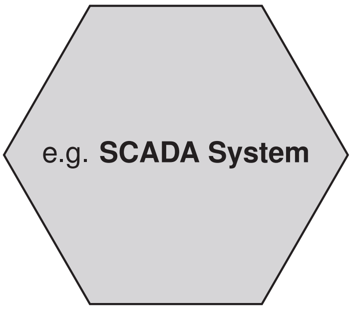

Figure 4.3: Local Grid Control Instance – a composition of modules and interfaces

In conjunction with Energy Communities the Local Grid Control Instances can support the optimal utilisation of grid resources. Their data should be more precise and timely than the sectional loads predicted by Community Energy Management Systems based on the incomplete measurements at the access points (smart meters) of the local community members.

In case a Local Grid Control Instance can influence the energy flows of some customers locally connected, this represents a kind of Energy Community. However, the control of the actions remains with a single dominating party, the local DSO, such that this scenario does not legitimate calling it an Energy Community according to European Commission directives. Still, a Community Energy Management System developed for Energy Communities can be used likewise to manage this type of clients.

In case members of different Community Energy Management Systems reside in the same grid section the Local Grid Control Instance might be used to relay information among the different Community Energy Management Systems if interoperability via a direct coordination link is not feasible. The Local Grid Control Instance may even become a central hub for the coordination of different Community Energy Management Systems, in particular if many shall cooperate without causing ambiguity.

4.1.4 Energy Assets

The control-able appliances an Energy Community is composed of are the effective assets. In general, these are assumed to be controlled by the individual customer that owns the physical hardware or uses the appliance. Where more than one control-able appliance is present, it can be asumed that some coordination of these is performed within customer premises, i.e., behind the meter. Control can be automatised or manual by the customer deciding when to use them. Latter is the only option for assets lacking a remote control interface and those not being integrated in a home energy management system (HEMS).

For many remote control-able asset types (appliance families) there exist different industry standards. Many require wired connections others use short range radio. Some might use PLC (power line communication), which saves extra equipment. Consequently, there is no harmonised base standard to address the basic needs for controlling assets. The customer needs to integrate them individually, e.g., via a third party platform that offers all the interfaces required. The platform can be local hardware or a cloud service, latter for Internet connected appliances only.

4.1.5 Community members

Last but not least shall the user be considered. These include households, business, municipalities, and public utilities. They cannot be controlled in a technical sense, but to achieve environmental benefits they should adapt their behaviour and use energy with more awareness. To enable direct user response to the availability of cheap/green local generated electricity, the users need to get feedback that is easily and instinctively recognised; alike a green, yellow, or red light. Based thereon, a user can consciously decide whether to activate or deactivate an appliance.

Users commonly assume there is ample electricity available all the time. And effectively, there is enough electricity to run any of the usual appliances because the electricity system is based on the pull paradigm: Whenever an appliance is activated or deactivated some power generator somewhere in the electricity system adjusts instantly to compensate the power drop or rise caused by activating or deactivating the appliance.[39] Behaviour changes occur slowly. In an initial phase the response may be good, but after a while curiousness fades and accordingly the response to signals. In particular when the achieved benefits are marginal [12].

The most predictable user in that respect is business: *If there is a return on investment they commonly adjust to maximise their profit*, but only as long as adjustments do not harm their business processes. A positive return on investment needs to be achieved in short time to validate investments financed via loans (economic sustainability). The response of municipalities and public utilities depends on the benefits achieved: Latter *gain nothing from achieving financial savings* aside from a budget cut, whereas former are *advised to spend no more than absolutely necessary.* In general, municipalities have control over public utilities. To efficiently execute that control on budgets they need the technical backing to correctly estimate a utility's financial needs.

The response of households to different benefits *depends on capabilities and the social situation of the people* living in the household. An indication on the benefits that different households appreciate can be derived from the five need levels shown in Figure 4.4. The lower two are considered deficit levels, if these are not fulfilled there is hardly any desire for higher level needs. Desires beyond personal needs and wishes are of importance only if all other needs are sufficiently fulfilled. There may be less people at this level, but they often are influencers, i.e., admired by others that wish to have the same things. Although most do not really need these things, they feel better having them.

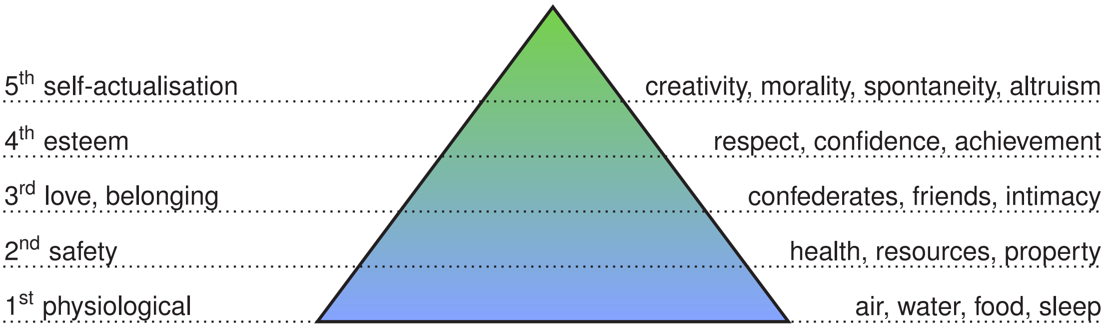

Figure 4.4: Maslow's hierarchy of people's needs

From a product management view, user can be categorised into the classes shown in Figure 4.5. In the early phases the decision to invest in a novel product depends on the willingness to take a risk. The majority follows when products are established. Laggards oppose change and prefer products they know to serve their needs.

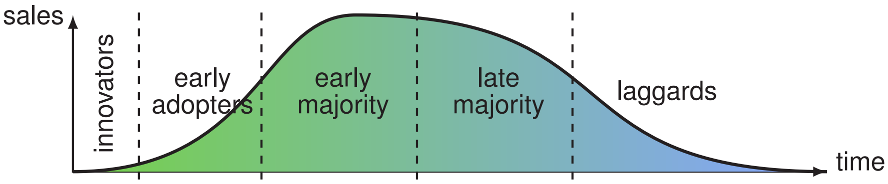

Figure 4.5: Customer classes along the product life cycle

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[39] Power drop propagates at the speed of light, faster than a digital message could ever be generated, transported, and processed.

4.2 Environmental Meta-Actors

Operation of an Energy Community involves external entities that either influence the operation or are influenced by the operation of an Energy Community. These are the humans participating, stakeholders they or the Energy Community have contracts or other agreements to obey, and so on. Here and there these may be more or less involved in the Energy Community operation process, not always, and not in every situation or scenario.[40]

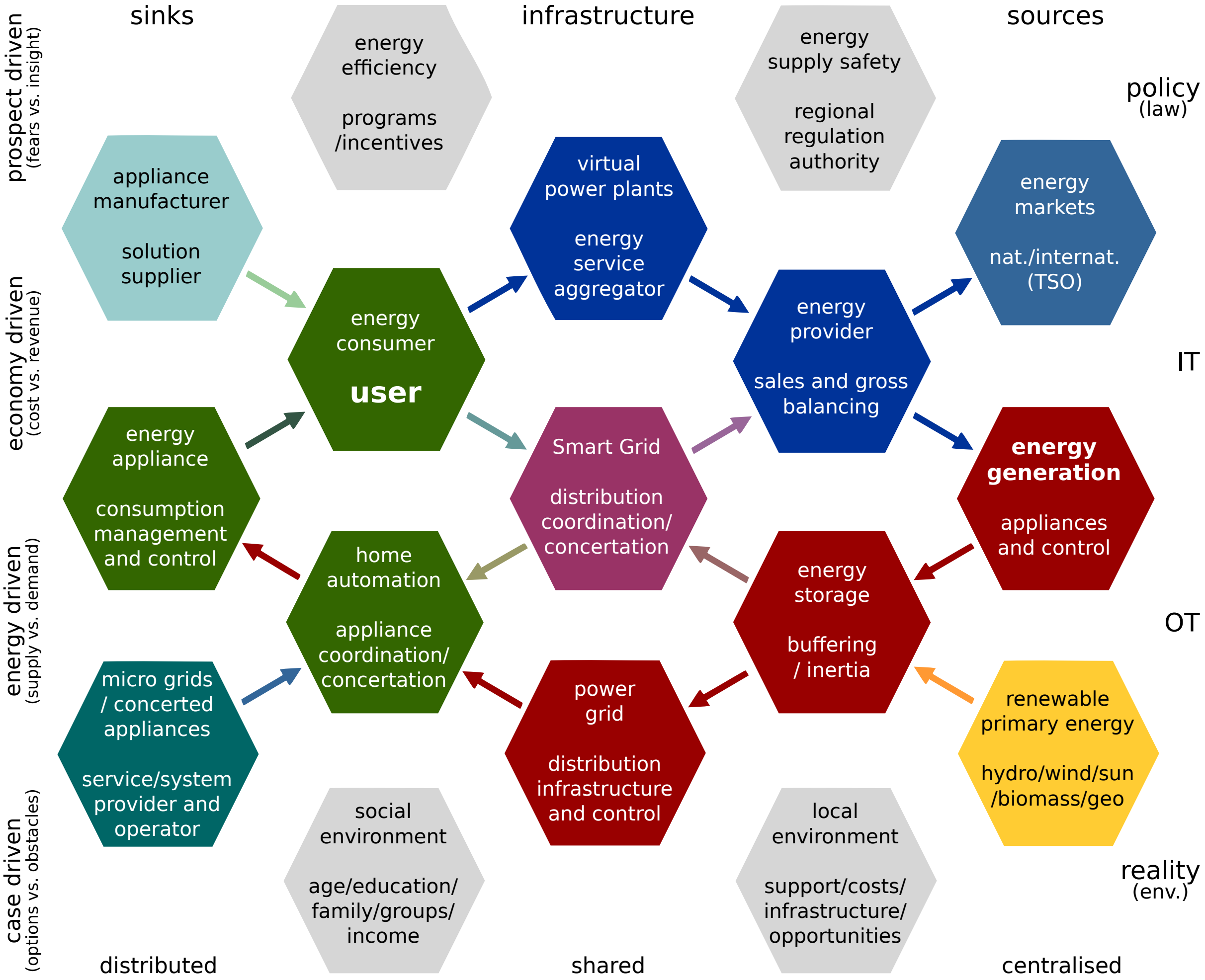

Figure 4.1: Energy system entities [13]: Energy Communities are a service and therefore in a similar position as virtual power plants and their operators, the aggregators, though probably with smaller scale, different primary aim, and Local Energy Communities bound to a specific region. [🅭🅯🄏🄎 Gerald Franzl – reproduced with permission]

4.2.1 Local Grid Operator

The local grid operator is the most important external entity, in particular because we assume that an Energy Community uses the local (public) grid to physically interconnect its members. Energy Communities may rent or own grid resources, but considering that members my leave any time, it cannot be assumed that only members are connected and supplied with energy. I.e., if an Energy Community owns grid resources it will be bound to the local grid operations regulations.

The members of an Energy Community will always need energy meters, commonly smart meters, which have to be operated by an authorised entity. Latter may be a dedicated authority, or is performed by the grid operator. Still, the meters physically connect private wires to the power grid operated by a local distribution system operator (DSO).

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[40] External Meta-Actors introduced with IES Business Functions in Section 3 always shall be briefly defined here. Other entities shall be listed and defined for better understanding of a typical Energy Community environment only (*holistic view*).

This grid operator is finally responsible for grid safety and reliable power supply. Power delivery is not performed by the individual energy supplier, latter only trade energy on the market. Thus, if an Energy Community wants to physically distribute energy among its members, it needs to cooperate with the local grid operator.

Therefore, an interface to this external stakeholder's grid operation centre (e.g., a SCADA system) is prominently foreseen (L/GCI), even though today the low voltage grid is rarely monitored in detail. With the transition to smart grids this observation gap will rapidly vanish. Good smart meters already measure the power quality at the connection points, which provides dense power monitoring along supply lines.

4.2.2 Energy Supplier

As already stated in section 2.4.2 will Energy Communities in general be too small to guarantee 24/7/365 power supply to its members. In addition shall the membership in Energy Communities be voluntary, and thus must an exit without hassles be possible, meaning that no end-customer can be bound to an Energy Community or forced to become a member. The Energy Community could become the energy supplier for all its members buying the deficits from a single supplier. If the majority of the energy a member gets is bought from that supplier and not generated within the Energy Community, such that the delivered electricity is similarly priced as on the regional electricity market, this may render the Energy Community unattractive and might contradict the right of the end-customer to freely choose the energy supplier.

More convenient for the Energy Community and conforming with the law on free supplier choice is a multi-supplier regime where the same customer gets energy from the Energy Community and an individually chosen electricity supplier. In section 2.4.2 it is shown how splitting the consumption and distribution of community shares could be effectively achieved with readily available means.

4.2.3 Smart Meter – Advanced Metering Infrastructure (AMI)

The core means to assess the electricity distribution within an Energy Community are the smart meters of the members. If such is not available or the smart meter provided by the grid operator too poor to be used, an alternative metering system needs to be installed. Participation in an Energy Community is assumed not possible without continuous electricity consumption and insertion monitoring to record where the internally produced electricity actually has gone.

If fast, i.e., close-to-realtime, flow-control is envisaged or needed, then the customer interface of smart meters needs to be used. If meter values in 15 minute intervals made available not prior the next day are sufficient, than the values recorded by the advanced metering infrastructure are sufficient. To access either, the member needs to grant access, best in writing to obey the private data protection act.

The customer interface is not provided by all smart meters, may be different for different brands, and can be very basic, e.g., an infrared light that blinks once whenever a certain amount of electric energy has been used, a time continuous single value (1-bit) communication interface.

4.2.4 DER Aggregator

The aggregation of DER in order to trade the aggregted production on the different electricity markets is a business. It is based on predicting the production and selling that.

DER aggregation is required because trading on electricity markets requires a certain size (capacity) for reliability reasons. In particular challenging is the reserve electricity market because traders need to guarantee the capability to actually deliver the electricity sold. At the same time can on this market the highest energy prices be achieved.

The other market of particular interest is the spot market, i.e., the intra day market where energy shares are traded to compensate prediction deviation. Capacity above what had already been sold is offered. If for example the weather is better than expected, a lot of electricity may be available at low prices, whereas in the opposite case prices can be very high, offering those traders that have held back some capacity good deals.

The basic business is that of a broker: Guess the production, sell most on the day-ahead market, but keep a share for the intra-day market. The more risk a trader is willing to take, the more electricity is traded on the spot market. Also big electricity customers may shop electricity on the spot market and in average reduce their electricity bill.

The focus on predicting demand and supply ahead-of-time makes aggregators an interesting business partner for Energy Communities that wish to outsource the load and generation prediction. Even the asset management itself might be outsourced. However, for Clean Energy Package compliant Energy Communities the members of the community need to decide the sharing strategy, i.e., the business partner needs to offer a transparent strategy the Energy Community governance can choose to use.

4.2.5 Reserve Energy Broker

For really big Energy Communities controlling a sufficient amount of electricity it might be possible to participate in the reserve market. To do so, community control needs to assure that the promised capacity is always available. Either by increasing the electricity generation or by reducing the consumption, or most likely, a combination of both.

For the common scope of Local Energy Communities that might be unachievable. More likely is the aggregation of many Energy Communities by an aggregator, in particular for negative reserve, i.e., increased load to cope with temporary regional overproduction of the aggregators assets if these cannot be curtailed.

In future such small control-able assets might be traded on a dedicated high frequency *flexibility market* managed by regional DSOs in addition to the higher volume inter-regional and inter-national second and third level reserve markets managed by TSOs.

4.2.6 Regional regulations and their enforcement bodies

Regulations are required to prevent customers from being ripped off by selfish monopolists. Grid operation is de facto a monopoly business because establishing parallel resources is too costly and harsh competition considered a safety risk. Though regulations shall protect the customers, they nowadays often appear to protect the monopolist and the surrounding establishment.

Some regulations seem outdated and are still kept in force. Typically, there is no harm done, but sometimes these hinder modernisation and new business models. The officials in charge may not always be aware of the potentials and fear loosening Pandora's knot. True, changing regulations shall be done with much care, but more importantly with a lot of good ambitions.

Recently, regulatory sandboxes became modern. These serve as confined playground to gather experience on the impact of alternative regulations, if the performed experiments actually reveal them. Thus, sandboxes need a neutral peer review as any scientific results do, to validate findings and assess the quality.

4.2.7 Environment information services, platforms and data-bases

Geographic information and weather forecasts are today widely available from the Internet. Some are open source, other more detailed, more accurate or more pre-processed sources are available for a usage fee. Latter may even provide customised interfaces.

The information these provide is essential for ahead-of-time distribution planning, i.e., pro-active load shifting. If an Energy Community cannot afford load and production prediction, this service and even the actual management and monitoring of energy flows can be outsources to a business partner that performs that on behalves of the Energy Community. In particular, aggregators should have access to these services for their own business and might offer these services for a reasonable fee.

4.3 Energy Community Services

The services that enable and define an Energy Community result from the location in the energy system (Figure 4.1), the capabilities of the energy assets and control systems at hand, the community founding intention (e.g., agreed upon in a consortium agreement), and the composition of contributing members. Alike the aims of different Energy Communities that cover a variety of good targets, so vary the services required and provided.

4.3.1 Community internal services

The community internal services are the basis of any Energy Community. They enable and realise the community aims. Depending on the foundations of establishing a community these are:

◊ **Energy sharing:** To establish an Energy Community it is necessary that the community members agree to some collaborative form of energy sharing. Either by sharing jointly owned resources or by sharing the excess capacity of individually owned resources contributed by individual members.

◊ **Joint self-consumption:** The members on an Energy Community shall profit from utilising the increased balancing flexibility of aggregated energy sources. The energy demand of participating members shall be fulfilled as far as feasible utilising community internal energy production (and storage) assets.[41]

◊ **Joint provisioning of ancillary services:** An Energy Community may, alike any active customer (prosumer), do business by selling excess energy and ancillary services. At least for the latter, the service quality and thus the achievable price depends on system size and reliance in the offer.

◊ **Joint financing of community assets:** The legal form of the Energy Community shall enable the members to jointly invest in, and profit from, jointly owned and shared community assets.

◊ **Joint community governance:** According to the EU directives shall Energy Communities be governed by the members themselves in a non-discriminatory fashion where no member shall be able to dominate decisions.

◊ **Fair benefit distribution:** Last but not least shall all the benefits achieved by cooperating in an Energy Community be fairly shared. Paramount is transparency to suppress envy and doubt.

4.3.2 Surrounding supportive services

To operate an Energy Community it needs to be embedded in its physical and organisational environment. To establish and integrate Energy Communities, the environment needs to offer supportive services.

◊ **Appropriate regulations:** Energy Communities may endanger legacy business, but regulations shall not protect business. Regulatory measures are only validated where they protect the people from voracious and potentially harmful behaviour and practices of both, companies and customers likewise.

◊ **Grid resources:** To share energy produced at different member sites with other members physically connected by the public grid it is necessary that the required power can be transferred over the local grid resources.

◊ **Local grid tariffs:** The grid tariffs on local power flows among community members shall not include compensation for not affected higher grid level infrastructures. Local tariffs shall effectively support grid friendly local production and demand balancing within communities.

◊ **Optimised grid utilisation:** The grid access capacity shall be dynamically determined depending on the actual utilisation given the community cooperates with the local grid operator (e.g. SCADA integration) and provides reliant power control that assures grid safety.

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[41] In case a member owned asset is shared, it is evident that only the flexibility not utilised within member premises is actually share.

◊ **Multi-supplier regime:** Community members shall remain customers of their individually chosen energy suppliers, in addition to consuming energy originating from within the Energy Community. The metering system operator shall provide meter data assignment to different suppliers, which shall include Energy Communities as source for locally generated and consumed energy.

◊ **Energy market integration:** As legal entity, an Energy Community shall have equal opportunities in respect to energy market offers and services alike comparable sized active customers. Energy Communities shall have equal access to energy market information, i.e., intra day prices, to align community internal energy management with market signals. Established energy companies shall be enabled to provide means and services to host and support the Energy Community management and the integration in the different energy markets (Service-as-a-service).

4.3.3 Society services

The responsible EU directorates pronounce that Energy Communities shall be a novel *social concept* intended to empower all energy customers to participate in the energy transition with individually feasible means. Therefore, Energy Communities shall prioritise social benefits over any commercial profit. Thus, running an Energy Community shall not be a business; instead shall the prime aims be regional (environmental) benefits and social well-being.

◊ **Increase regional RES integration:** Connecting more renewable energy sources (RES) to the local grid shall be enabled by better control and utilisation of local grid resources together with maximally balanced local production and demand. If higher level resources become partly isolated from the volatility introduced by locally connected renewable sources, an else necessary grid capacity extension by major international enterprises may be postponed.

◊ **Sustainable regional revenues:** The installation, maintenance and operation of local RES shall directly benefit local business. Also selling flexibility, i.e., frequency reserve to DSOs and over-production capacities on the reserve energy market, will also raise local income and taxes, which may support the attractiveness of some remote areas (smart regions) and also that of alternative business endeavours in municipal environments (smart cities).

◊ **Foster green energy:** Offering affordable renewable energy shall drive the transition toward a 100% renewable electricity supply. Excess energy may be converted and/or buffered into local community storage facilities and thereby the need for fossil reserve energy reduced. Better than storage is connecting the local demand to the local production. However, that needs demand flexibility, which is a very innovative approach yet to be diffused.

◊ **Prevent energy crises:** Fossil energy often depends on imports from regions with instable political conditions. Regional sources do not depend on the courtesy of other nations. Energy supply from local sources enables stable prices and global independence.

◊ **Inclusion of everyone:** Energy Communities shall also enable those that due to any reason cannot invest directly in the energy transition to participate their share and also to profit from their investment by getting access to affordable green energy in a magnitude similar to those that could afford investments straight away, without participating in an Energy Community.

◊ **Support community thinking:** Building a community of people that act together when governing an Energy Community can support the well-being of each by establishing a team mindset and by allowing more everyday altruism. Listening to and solving the needs of others may also reduce own worries and thereby increases individual happiness in multiple directions.

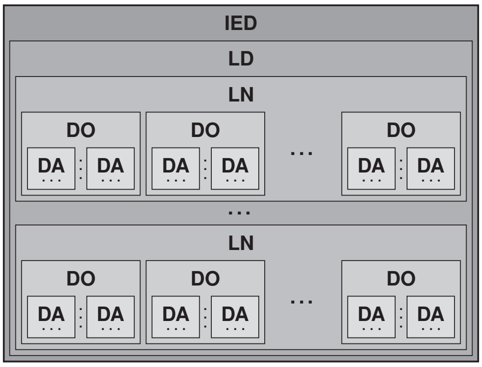
5 State-of-the-art — common standards, tools and good practice examples

*This section provides space to identify and briefly discuss existing standards and tools that may be used and required to operate an Energy Community. Also practical examples are welcome (*state-of-the-art*), in particular references and links to results and experiences from R&D projects, sandboxes, trials and first deployments, etc.*

5.1 Standards commonly used with Smart Energy Systems

◊ **IEC 61850 [14]** is a family of standards that covers largely all aspects relevant for connectivity and cooperation of Intelligent Energy Device (IED) in a very Information Technology (IT) centric fashion. A central piece of 61850 is the data model, a hierarchic data structure to address, store, process and exchange information.

IEC 61850 describes how intelligent electronic devices (IEDs) can be represented as logical devices (LDs) composed of logical nodes (LNs) with data objects (DOs) composed of several data attributes (DAs), as shown in Figure 5.1. IEDs can communicate, i.e., date objects and attributes can be accessed remotely, once a connection between two IEDs is established and the logical configuration of the communicating LDs is mutually known.



IED . . . Intelligent Electronic Device
LD . . . Logical Device (tech. unit)
LN . . . Logical Node (funct. unit)
DO . . . Data Object (stack of info)
DA . . . Data Attribute (piece of info)
. . . Common Data Class (info type)
. . . Functional Constraints (limits)
. . . Data Type (info encoding)
. . . Data (sequence of bits)

Figure 5.1: IEC 61850 data structure

The composition of different LNs, their mandatory and optional data objects and attributes, are specified for a default normalised use. However, the access to individual data objects and attributes shall be individually specified, such that only IEDs authorised to read or write a specific data object/attribute are allowed to do so. This authorisation may even be restricted to specific conditions, i.e., state dependent.

Every data attribute (information bit) is further defined by assigning a common data class and functional constraints. Former specify the data type and the data encoding formats, latter the data range and access/modification constraints. Commonly, data objects can only be read as a whole, but not written as a whole due to conflicting access constraints (read&write, read-only, write-only, no-access). During operation, it is common to always address data attributes individually to prevent issues with conflicting read/write constraints.

IEC 61850 follows the open definition paradigm, meaning that it provides features to configure any data structure and to add new functionalities via combining the set of initially provided and already added features. However, the default data structures and functionalities are in general sufficient for todays SCADA[42] systems.

The modular IEC 61850 data structures can be openly designed to needs. Any imaginable energy entity, intelligent or dumb like a meter, can be modelled as an IED via designing an according data model. Data models of IEDs can be transferred via a configuration file holding (actually specifying) the data model in XML[43]. This digital description of an IED can be easily distributed, even automatically at the time a new or changed IED (re-)registers to a system-of-systems. However, latter is rarely used due to security concerns (*security by hiding*).

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[42] Supervisory Control And Data Acquisition

[43] eXtensible Markup Language

♢ **IEC 60870 [15]** is a family of standards that precedes IEC 61850 and provides similar features implemented far more *Operations Technology* (OT) oriented, focusing on minimal effort and bandwidth demand to achieve close to deterministic, tightly upper bound response times and low FPGA[44] footprint[45].

IEC 60870 and its part on communication over public data-networks, the IEC 60870-5-104 (short '104'), has been deployed widely in the DACH area (Germany, Austria, Switzerland). Due to being very resource efficient there are hardly any operation comfort oriented features included. Configuration of components is based on manual device programming, which in case of communication can require the programming of identical data structures at every involved device.

5.2 General Purpose Communication Standards – IT defaults

All Energy Community entities (Meta-Actors) that cooperate to realise a *Business Function* need to exchange some information. They may use different standards for different connections, but where directly connected, they need to use the same communication means. *Transactions* shall specify the required communication procedures, including the standards and the actually used features thereof.

The plurality of standards that for example enable IP or Ethernet based communication is too extensive to be listed in detail. The underlying IETF RFCs and ITU standards are all public, their details need not be specified in the Technical Framework. Communication technologies widely in use are for example:

application: HTTPS, SMTP, XMPP, FTP, . . .
presentation: HTML, XML, SCL, MMS, ASN, GOOSE, SMV, . . .
session: TLS, AES, ICE, TPKT, QUIC, . . .
transport: TCP, UDP, SCTP, SRTP, RTSP, . . .
network: IP, IPv4, IPv6, ARP, ATM, ISDN, SDH, OTN, MPLS, VLAN, . . .
link: RS-232, RS-485, M-Bus, HDLC, Eth(MAC), PLC, GPRS, LoRaWPAN, . . .
media: twisted pair, PSTN, Cat6, SMF, MMF, S-FSK, GSM, 5G-NRL, . . .

This plurality of standards and features serves a wide range of applications and supports adaptation to the local situation, i.e., the actual environment, which evidently includes Smart Energy Systems. The layering applied is specified in ITU-T X.200 for any digital communication system. It decomposes the complexity and enables flexible communication stacks because thereby the technologies serving a layer become compose-able and interchangeable.

Profiling, i.e. specifying what exactly to use in which situation, is the key to choose the best solution. Aside from technical aspects the selection shall also consider economic aspects as for example implementation effort and licensing costs. If performed jointly, profiling assures interoperability and reduced development costs because only one solution (communication stack) needs to be supported.

5.3 Market Communications Procedures and Standards

Market actors are bound to the electrical system via regulation only, i.e., via the balancing rules and their commitment to pay high prices in case their predictive energy trading does not match with actual energy flows monitored. The bondage is economical, not physical.

Given the laps of time between buying electricity and getting the bill for balancing power, the communication among market actors is less delay critical and can be performed manually if needed (e.g., via e-mail). According procedures were regionally developed and are enforced by regulations for many use cases.

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[44] Field-Programmable Gate Array

[45] Here *footprint* refers to the amount of programmable logic blocks required to implement the functionality, which is commonly specified in a hardware description language (HDL) that may be compiled from C-like program syntax using electronic design automation tools.

◊ **EDA:** To harmonise the electronic communication means, the Austrian „Energiewirtschaftlicher Datenaustausch (EDA)“ platform [www.ebutilities.at] was created. Using ebXML [ISO 15000, www.ebxml.org] it can be implemented via the Ponton x/p Messenger product [PONTON GmbH, www.ponton.de].

◊ **ebXML:** The *"Electronic Business eXtensible Markup Language"*, commonly known as e-business XML or ebXML, is a family of XML based standards by OASIS [Organization for the Advancement of Structured Information Standards] and UN/CEFACT [United Nations Centre for Trade Facilitation and Electronic Business] whose mission is to provide an open, XML-based infrastructure that enables the global use of electronic business information in an interoperable, secure, and consistent manner by all trading partners.

The ebXML architecture is a unique set of concepts; part theoretical and part implemented by the ebXML standards, i.e., the ISO 15000 standards family. Latter provide formal XML-enabled mechanisms, whereas the ebXML architecture defines concepts and methodologies to implement e-business solutions.

Electronic business eXtensible markup language (ebXML):
ISO 15000-1: ebXML Collaborative Partner Profile Agreement (ebCPP)
ISO 15000-2: ebXML Messaging Service Specification (ebMS)
ISO 15000-3: ebXML Registry Information Model (ebRIM)
ISO 15000-4: ebXML Registry Services Specification (ebRS)
ISO 15000-5: ebXML Core Components Specification (CCS)

OASIS technical committees and UN/CEFACT retain responsibility for maintaining and advancing the specifications: The Core Components Technical Specification (CCTS) is continued within UN/CEFACT, whereas the Universal Business Language (UBL) specification is used within OASIS to implement specific XML transactions by applying the principles of CCTS for typical supply chain transactions such as invoice, purchase order, shipping notice and so on.

↪ *Collaborative Partner Profile Agreements* (ebCPP) are XML based documents specifying a trading agreement between trading partners. Each trading partner needs a Collaboration Protocol Profile (CPP) document that describes abilities in an XML format. This includes for instance messaging protocols and security capabilities the partner supports. A CPA (Collaboration Protocol Agreement) is the intersection of two CPP documents and describes the formal relationship between two parties. The following information is typically contained in a CPA document:

- **Identification information:** unique identifiers for each party and their roles within the trading relationship
- **Security information:** for instance, whether digital signatures are required and which algorithms are used
- **Communication information:** the protocols used to exchange documents
- **Endpoint locations:** the URL service and action messages shall be sent to
- **Acknowledgement rules:**
  - whether acknowledgements are required for all messages
  - whether duplicate messages shall be ignored
  - how long to wait before resending messages still awaiting acknowledgement
  - how many times to resend messages before giving up

↪ *Messaging Service Specification* (ebMS) describes a communication-neutral mechanism that the *Message Service Handlers* (MSH) must implement in order to exchange business documents. ebMS 3.0 is the current version of the specification designed as extension on top of SOAP [Simple Object Access Protocol] with attachments specification. The SOAP message contains the meta-data required to exchange business documents in a secure and reliable manner, while the business payload is transferred attached to the SOAP message. Multiple business payloads may be attached to a single message, and the format of the payloads is beyond the scope of the ebXML specifications. The information that trading partners place in ebMS messages is defined by the CPA agreement that specifies their relationship. The following information is typically contained within ebMS messages:

- **Message ID:** a unique identifier
- **Addressee:** who the message is for
- **Originator:** who sent the message
- **Conversation ID:** identifier that links related messages
- **Signature:** digital signature based on XML Signature specification
- Indication whether duplicate messages shall be ignored
- Indication whether acknowledgements are required

The ebMS is communication protocol neutral. The most commonly used underlying data network services (OSI application layer[46]protocols) are HTTP and SMTP.

◊ **CIM:** The Common Information Model (CIM), is a standard developed by the electric power industry, officially adopted by the International Electrotechnical Commission (IEC), that aims to allow application software to exchange information about an electrical grid. CIM is maintained as a UML model and defines common vocabulary and basic ontology for the electric power industry. The CIM is also used to derive electronic messages for the wholesale energy market within the framework for energy market communications specified by IEC 62325. ENTSO-E [www.entsoe.eu] is a major contributor to the *European style market profile*, which is a profile derivation from the CIM to harmonize the energy market data exchanges in Europe.

The standard that defines the core packages of the CIM is IEC 61970-301, focusing on the needs of electricity transmission. Related applications are energy management systems, SCADA, planning and optimization. The IEC 61970-501 and 61970-452 standards define an XML format for network model exchanges using RDF, the Resource Description Framework specified by the World Wide Web Consortium (W3C). The IEC 61968 series of standards extend the CIM to meet the needs of electrical distribution, where related applications include distribution management system, outage management system, planning, metering, maintenance work management, geographic information system, asset management, customer information systems and enterprise resource planning.

To ensure that the CIM standards are developed in line with TSO requirements, ENTSO-E maintains liaisons with IEC TC 57/WG13, the working group on *software interfaces for operation and planning of the electric grid*, and IEC TC57/WG16, the working group on *deregulated energy market communications*. The CIM standards are continuously evolving to meet changing requirements. Data exchange increases in frequency and distribution with the integration of RES and the introduction of smart grids (i.e., the *digitalisation*).

Specific ENTSO-E CIM standards ensure to reflect the complexity of TSO based data exchange. ENTSO-E runs interoperability tests on a yearly basis to demonstrate the interoperability of its CIM standard and the IEC standards, and to support CIM development for grid models and market exchanges. Experience gained from developing and implementing CIM standards directly contributes to future network codes[47]. development, i.e., specification of data exchange processes.

↪ *CIM for Grid Models Exchange* enables the exchange of data necessary for regional or pan-European grid development studies, and for future processes related to network codes. Grid model exchange covers a variety of use cases, which include exchanging

- Equipment information: power system equipment data,
- Topology information: topology related information on grid elements,
- Power system state variables: results from initial load flow simulation,
  and with newer standards only,
- Steady state hypothesis information: load, generation, and related data necessary for load flow simulation.

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[46] see ITU-T X.200 for info on layering and the OSI model for digital communication

[47] Network codes are a set of rules drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), to facilitate the harmonisation, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market, and achieving the European Union's energy objectives [16]

In addition, grid model exchange can benefit from information related to dynamics, diagram layout and geographical location for elements in the power system. These features were developed in the latest drafts of the ENTSO-E CIM standards to cover the specific business requirements of TSO grid model exchanges.

ENTSO-E CIM standards for grid models exchange are based on:
IEC 61970-552: CIM XML Model Exchange Format
IEC 61970-301: Common Information Model (CIM) Base
IEC 61970-302: Common Information Model (CIM) for Dynamics Specification
IEC 61970-452: CIM Static Transmission Network Model Profiles
IEC 61970-453: Diagram Layout Profile
IEC 61970-456: Solved Power System State Profiles
IEC 61970-457: Common Information Model (CIM) for Dynamics Profile

IEC 61968-4: Application integration at electric utilities – System interfaces for distribution management – Part 4: Interfaces for records and asset management.

↪ *CIM for Energy Markets* , i.e., the IEC 62325 standards, comprise a framework for energy market communications, i.e., for the exchange of data required by deregulated energy markets. The standards encompass two market styles: European and North American style.

The foundation of the IEC 62325 series are:
IEC 62325-301: CIM extensions for markets – abstract model introducing the objects required for operating electricity markets, and
IEC 62325-450: Profile and context modelling rules – the international standard on generating profiles.

Based on these two standards, the IEC 62325-351 *"CIM European market model exchange profile"*, and the IEC 62325-451-'X' series based thereon, are being maintained and further developed, notably for Europe's internal electricity market (IEM).

The European style market profile (ESMP), as defined in IEC 62325-351, provides the core components for use in the IEC 62325-451-'X' standards, which target specific core business processes within Europe's internal electricity market, such as scheduling, settlement, capacity allocation and nomination, acknowledgement, etc.

The IEC CIM 62325 series of standards consists of:
International Standards
IEC 62325-301: CIM Extensions for markets
IEC 62325-450: Profile and context modelling rules
IEC 62325-351: CIM European market model exchange profile
IEC 62325-451-1: Acknowledgement business process and contextual model
IEC 62325-451-2: Scheduling business process and contextual model
IEC 62325-451-3: Transmission capacity allocation business process (ex-/implicit auction) and contextual models
IEC 62325-451-4: Settlement and reconciliation business process, contextual and assembly models
IEC 62325-451-5: Problem statement and status request business processes, contextual and assembly models
IEC 62325-451-6: Publication of information on market, contextual and assembly models
Technical Specifications
IEC 62325-503: Market data exchanges guidelines for the IEC 62325-351 profile
IEC 62325-504: Utilization of web services for data interchanges on the European electricity market

To facilitate the migration to IEC CIM 62325 series, and for the transformation of ENTSO-E's xml files into IES COM 62325 compliant ones, see the *ENTSO-E schema and style-sheet to convert to CIM instances*.

↪ The *Electronic Data Interchange (EDI) Library* contains documents and definitions approved by ENTSO-E for the harmonisation and implementation of standardised electronic data interchanges.

`https://www.entsoe.eu/publications/electronic-data-interchange-edi-library/`

The implementation guides contained are one of the building blocks for using UML-based (Unified Modelling Language) techniques in defining processes and electronic documents for interchange between actors in the electrical industry in Europe. The guides are generally targeted towards business-to-business application interfaces using the full power of the acknowledgement process. However, it may be equally put into place in a more user-orientated fashion through a web-based service where the key elements of the acknowledgement process are implicit in the service itself.

For info on using XML instances see: www.entsoe.eu/Documents/EDI/Library/EDI best practices v2.1.pdf

↪ *ENTSO-E CIM Tool Governance* comprises CIMContextor and CIMSyntaxgen Governance. These products are used to develop and maintain UML profiles within the common information model (IEC 61968-11, IEC 61970-301, IEC 61970-302 and IEC 62325-301) by utilities and software vendors. They also enable automated generation of documentation and XML schemata.

- 20170228_CIMContextor_and_CIMSyntaxgen_governance.pdf
- CimContextor 2.9.4 & CimSyntaxgen 2.3.7
- User manual
- CimconteXtor & CimsyntaxGen update

Disclaimer: CIMContextor and CIMSyntaxgen have been developed by ZAMIREN (France). They are open software published under the free software license agreement CeCILL-B. The software is supplied “as is” without any other warranty than provided for in Article 9 of the license agreement. Any losses suffered from the Software shall only be compensated in accordance with Article 8 of the license agreement. For questions and access to source codes contact: CIMContextor@entsoe.eu

5.4 Procedures and Standards to monitor and control individual devices

The interfaces to control different energy appliances are very diverse. They evolved with the progress of the available control options and means. Today, basically every type of appliance provides its specific interface. There exist many attempts for harmonisation, commonly confined to classes of appliances. A generic Energy Management System shall provide a standardised interface and will parse generic messages received into messages understood by the appliances, and vice versa. For example, controlling a legacy water boiler may be realised via an analogous 0 to 10 V signal. To integrate that in an Energy Management System the analogous signal needs to be provided via a digital-to-analogue converter. Similar for the conversion of digital signals in case different data-encoding occurs. Here, digital interfacing means are considered only.

◊ **MODBUS:** is an application-layer messaging protocol, positioned at level 7 of the OSI model. It provides client/server communication between devices connected on different types of buses or networks. The de facto industrial serial standard since 1979, MODBUS continues to enable millions of automation devices to communicate. Today, support for the simple and elegant structure of MODBUS continues to grow. The Internet community can access MODBUS at a reserved system port 502 on the TCP/IP stack.

MODBUS is a request/reply protocol and offers services specified by function codes. MODBUS function codes are elements of MODBUS request/reply PDUs. This protocol specification document describes the function codes used within the framework of MODBUS transactions.

Originally published by Modicon (now Schneider Electric) in 1979 for use with its programmable logic controllers (PLCs) it is now a commonly available means of connecting industrial electronic devices. Modbus uses the RS485 or Ethernet as its wiring type. Modbus supports communication to and from multiple devices connected to the same cable or Ethernet network.

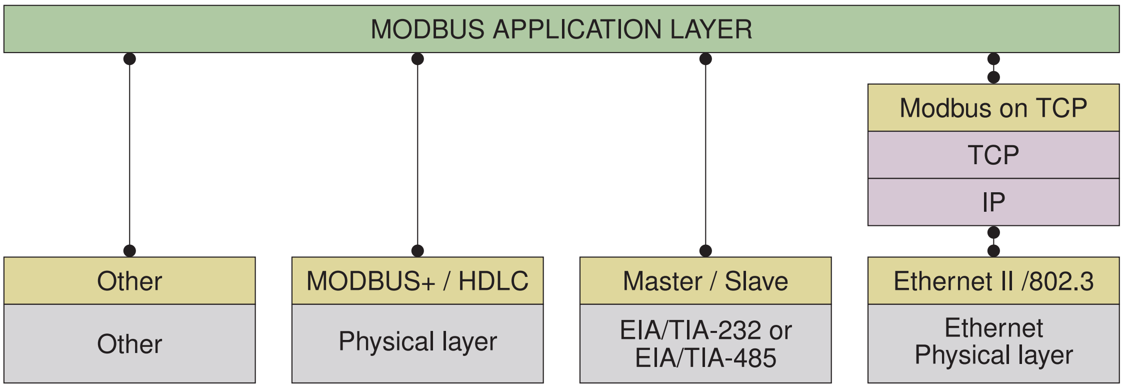


Figure 5.1: Modbus Communication Stack [17]

Modbus is often used to connect a remote terminal unit (RTU) to a supervisory computer of Supervisory Control and Data Acquisition (SCADA) systems in the electric power industry. Many of the data types are named according to industrial control of factory devices, such as Ladder logic because of its use in driving relays: A single physical output is called a coil, and a single physical input is called a discrete input or a contact.

Since Modbus was designed in the late 1970s to communicate to PLCs, the number of data types is limited to those understood by PLCs at the time. Large binary objects are not supported.

Table 5.1: Object types provided by a Modbus slave device:

Object type	Access	Size	Address Space
Coil	read-write	1 bit	00001 – 09999
Discrete input	read-only	1 bit	10001 – 19999
Input register	read-only	16 bit	30001 – 39999
Holding register	read-write	16 bit	40001 – 49999

Accordingly, Modbus commands can instruct a device to:

- change the value in a register: write to a Coil or Holding register
- read 1-bit I/O ports: read data from Discrete and Coil ports
- command the device to return one or more values contained in Coil and Holding registers.

Every Modbus command contains the 8-bit Modbus address of the device it is intended for (1 to 247). Only the addressed device will respond and act on the command, even though other devices might receive it. Address 0 is used with specific broadcast-able commands only, these are acted on by all devices but not acknowledged by any.

No standard way exists for a node to find the description of a data object, for example, to determine whether a register value represents a voltage or a temperature.

Since Modbus is a master/slave protocol, there is no way for a field device to "report an exception" (except over Ethernet TCP/IP, called open-mbus). The master node must routinely poll each field device and look for changes in the data. This consumes bandwidth and network time in applications where bandwidth may be expensive, such as low-bit-rate radio links.

Modbus transmissions must be contiguous, which limits the types of remote communications devices to those that can buffer data to avoid gaps in the transmission. Modbus protocol itself provides no security against unauthorized commands or interception of data. However, Modbus commands contain checksum information (16-bit CRC) to allow the recipient to detect transmission errors.

A Modbus "frame" consists of an Application Data Unit (ADU), which encapsulates a Protocol Data Unit (PDU), where ADU = Address + PDU + Error checksum, PDU = Function code + Data:

- RS232/RS485: ADU = 253 bytes + Server address (1 byte) + CRC (2 byte) = 256 byte.
- TCP MODBUS: ADU = 253 bytes + MBAP (7 byte) = 260 byte.

MODBUS uses a ‘big-Endian’ representation for addresses and data items. The byte order in Modbus data frames is most significant byte first, i.e., the more significant byte of a multi-byte value is sent before the next lesser significant. E.g.: the two byte value 0x1234 (a word) is transmitted as two consecutive bytes, sent in the order 0x12 than 0x34.

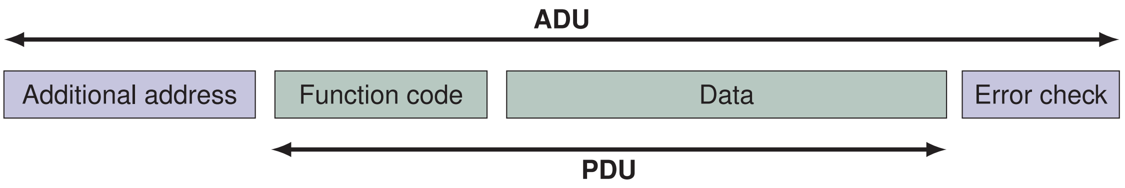


Figure 5.2: Modbus ADU and PDU composition [17]

The MODBUS protocol defines three PDUs. They are:

- **MODBUS Request PDU:**
  mb_req_pdu = {function_code, request_data}, where
  function_code = [1 byte] MODBUS function code,
  request_data = [n byte] function code dependent, usually information such as variable references, variable counts, data offsets, sub-function codes etc.
- **MODBUS Response PDU:**
  mb_rsp_pdu = {function_code, response_data}, where
  function_code = [1 byte] responded to MODBUS function code,
  response_data = [n byte] function code dependent, usually information such as variable references, variable counts, data offsets, sub-function codes, etc.
- **MODBUS Exception Response PDU:**
  mb_excep_rsp_pdu = {exception-function_code, request_data}, where
  exception-function_code = [1 byte] MODBUS function code + 0x80
  exception_code = [1 byte] MODBUS Exception Code.

For a normal response, slaves repeat the function code. Should a slave need to report an error, it will reply with the requested function code plus 128 (hex 0x80), e.g., 3 becomes 131 = hex 0x83, and will only include one byte of data, known as the exception code.

				Function Codes			
Objective			*executed action*	Code	Subcode	(hex)	Section
Data Access	1 bit Access	Physical Discrete Inputs	Read Discrete Inputs	**02**		**02**	6.2
		Internal bit or Physical coils	Read Coils	**01**		**01**	6.1
			Write Single Coil	**05**		**05**	6.5
			Write Multiple Coils	**15**		**0F**	6.11
	16 bit Access	Physical Input Registers	Read Input Register	**04**		**04**	6.4
		Internal Registers or Physical Output Registers	Read Holding Registers	**03**		**03**	6.3
			Write Single Register	**06**		**06**	6.6
			Write Multiple Registers	**16**		**10**	6.12
			Read/Write Multiple Registers	**23**		**17**	6.17
			Mask Write Register	**22**		**16**	6.16
			Read FIFO queue	**24**		**18**	6.18
	File Record Access		Read File record	**20**		**14**	6.14
			Write File record	**21**		**15**	6.15
Diagnostics			Read Exception status	**07**		**07**	6.7
			Diagnostic	**08**	00-18,20	**08**	6.8
			Get Com event counter	**11**		**0B**	6.9
			Get Com Event Log	**12**		**0C**	6.10
			Report Server ID	**17**		**11**	6.13
			Read device Identification	**43**	14	**2B**	6.21
Other			Encapsulated Interface Transport	**43**	13,14	**2B**	6.19
			CANopen General Reference	**43**	13	**2B**	6.20

Figure 5.3: Modbus public Function Codes [17]

There are three categories of MODBUS Functions codes. They are :

↪ *Public Function Codes* are well defined function codes, guaranteed to be unique, validated by the MODBUS.org community, publicly documented, have available conformance test, includes both defined public assigned function codes as well as unassigned function codes reserved for future use.

↪ *User-Defined Function Codes* can be defined in two ranges, i.e., from 65 to 72 and from 100 to 110 (decimal), can be selected and implemented in addition to those supported by the specification, but there is no guarantee that the use of the selected function code will be unique, and if the user wants to re-position the functionality as a public function code, he must initiate an RFC to introduce the change into the public category and to have a new public function code assigned, given that the MODBUS Organization, Inc. expressly reserves the right to develop the proposed RFC.

↪ *Reserved Function Codes* are Function Codes currently used by some companies for legacy products that are not available for public use. See Annex A of the specification on MODBUS RESERVED FUNCTION CODES, SUBCODES AND MEI TYPES.

The original version of the Modbus protocol was defined for serial ports. However, there exist many derivatives of the Modbus protocol for other ports and transport protocols. Some variants even introduce their own data formats.

↪ *Modbus RTU* is the most common implementation of Modbus based serial communication and makes use of the compact, binary representation of data. RTU implements the {commands | data | checksum} format and Cyclic Redundancy Check (CRC) that enables transmission error detection to assess the reliability of data received. RTU message must be transmitted with no gaps because each message is framed (separated) by idle (silent) periods.

↪ *Modbus ASCII* makes use of ASCII characters. The ASCII format uses a longitudinal redundancy check checksum. Modbus ASCII messages are framed by leading colon (":") and trailing newline (CR/LF) characters.

↪ *Modbus TCP/IP or Modbus TCP* is used for communications over TCP/IP networks using port 502. Checksum calculation is not required because error detection is performed on lower layers. Modbus *over* TCP/IP or Modbus *over* TCP or Modbus *RTU/IP* is a sub-variant that keeps the checksum as with Modbus RTU.

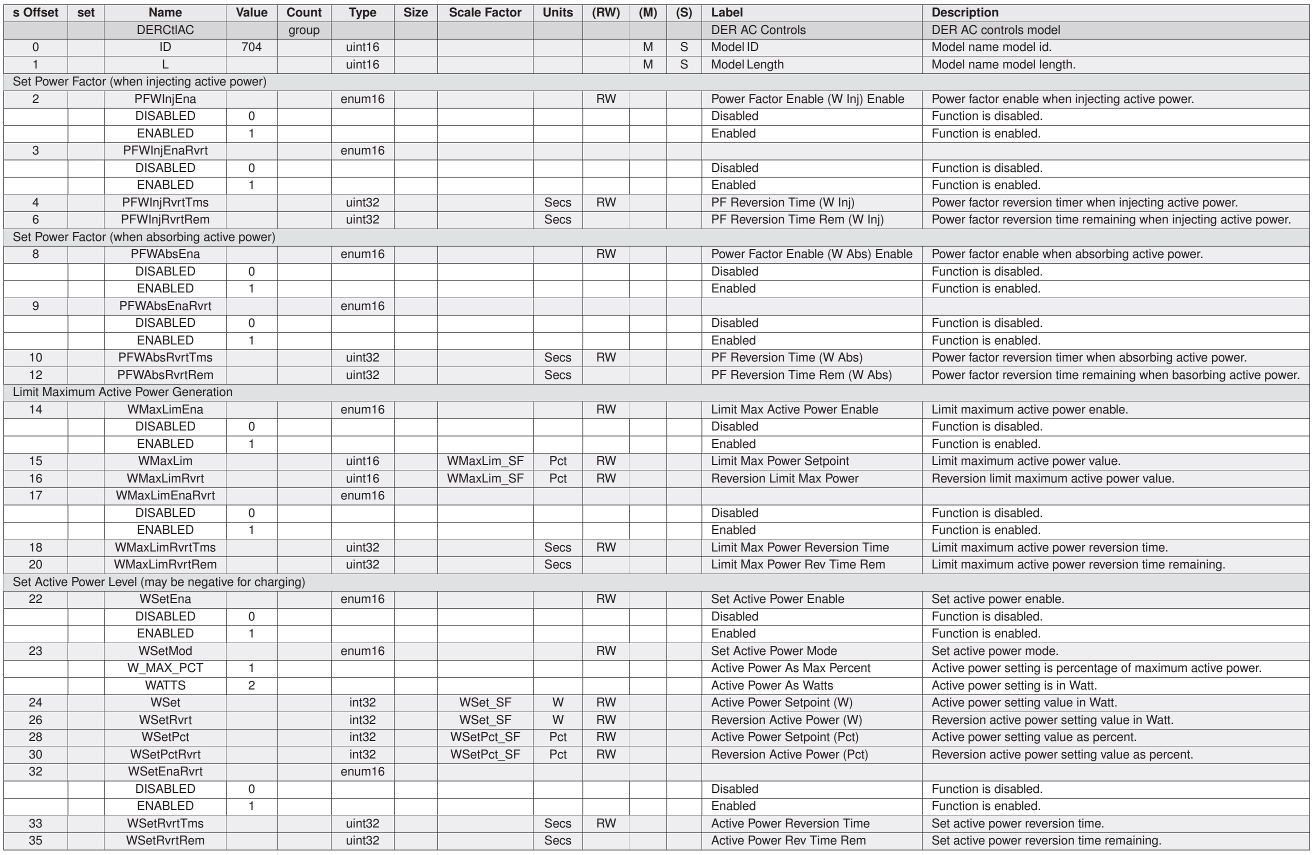
↪ *Modbus over UDP* is an experiment that saves the overheads of TCP. The unpredictable and non-detectable loss of messages is accepted.

↪ *Modbus Plus (Modbus+, MB+ or MBP)* is proprietary to Schneider Electric and unlike the other variants, it supports peer-to-peer communication between multiple masters. It requires to handle fast HDLC-like token rotation. It uses twisted pair at 1 Mbit/s and includes transformer isolation, which makes it transition/edge-triggered instead of voltage/level-triggered. Special hardware is required to connect Modbus Plus to a regular computer.

↪ *Enron Modbus* is an extension developed by Enron Corporation to support 32-bit integer and floating-point variables as well as historical and flow data. Data types are mapped using standard addresses.

↪ ***SunSpec Modbus*** is an open communication standard that specifies common parameters and settings for monitoring and controlling Distributed Energy Resources (DER). SunSpec Modbus utilizes *SunSpec Information Models* and is specified in IEEE$^{\text{TM}}$ 1547-2018, the U.S. national standard for DER. The SunSpec Alliance is an industry alliance pursuing information standards to enable *plug&play* system interoperability. SunSpec standards address operational aspects of solar PV power and energy storage plants on the smart grid, including residential, commercial, and utility-scale systems.

Data format and function calls are identical for most common Modbus variants, only the encapsulation differs. Still, the variants are not interoperable, master and slaves need to use the same variant to actually connect. Modbus RTU, Modbus ASCII and Modbus Plus use an RS-485 single cable multi-drop network where only the node assigned as the Master may initiate a command. All other devices are slaves and respond to requests and commands only. For the protocols using Ethernet, such as Modbus TCP, any device can initiate a Modbus command, thus all can act as a Master. Still, one device shall act as Master only (at a time) to prevent response confusion.



s Offset	set	Name	Value	Count	Type	Size	Scale Factor	Units	(RW)	(M)	(S)	Label	Description
		DERCtlAC		group								DER AC Controls	DER AC controls model
0		ID	704		uint16					M	S	Model ID	Model name model id.
1		L			uint16					M	S	Model Length	Model name model length.
Set Power Factor (when injecting active power)													
2		PFWInjEna			enum16				RW			Power Factor Enable (W Inj) Enable	Power factor enable when injecting active power.
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
3		PFWInjEnaRvrt			enum16								
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
4		PFWInjRvrtTms			uint32			Secs	RW			PF Reversion Time (W Inj)	Power factor reversion timer when injecting active power.
6		PFWInjRvrtRem			uint32			Secs				PF Reversion Time Rem (W Inj)	Power factor reversion time remaining when injecting active power.
Set Power Factor (when absorbing active power)													
8		PFWAbsEna			enum16				RW			Power Factor Enable (W Abs) Enable	Power factor enable when absorbing active power.
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
9		PFWAbsEnaRvrt			enum16								
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
10		PFWAbsRvrtTms			uint32			Secs	RW			PF Reversion Time (W Abs)	Power factor reversion timer when absorbing active power.
12		PFWAbsRvrtRem			uint32			Secs				PF Reversion Time Rem (W Abs)	Power factor reversion time remaining when basorbing active power.
Limit Maximum Active Power Generation													
14		WMaxLimEna			enum16				RW			Limit Max Active Power Enable	Limit maximum active power enable.
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
15		WMaxLim			uint16		WMaxLim_SF	Pct	RW			Limit Max Power Setpoint	Limit maximum active power value.
16		WMaxLimRvrt			uint16		WMaxLim_SF	Pct	RW			Reversion Limit Max Power	Reversion limit maximum active power value.
17		WMaxLimEnaRvrt			enum16								
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
18		WMaxLimRvrtTms			uint32			Secs	RW			Limit Max Power Reversion Time	Limit maximum active power reversion time.
20		WMaxLimRvrtRem			uint32			Secs				Limit Max Power Rev Time Rem	Limit maximum active power reversion time remaining.
Set Active Power Level (may be negative for charging)													
22		WSetEna			enum16				RW			Set Active Power Enable	Set active power enable.
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
23		WSetMod			enum16				RW			Set Active Power Mode	Set active power mode.
		W_MAX_PCT	1									Active Power As Max Percent	Active power setting is percentage of maximum active power.
		WATTS	2									Active Power As Watts	Active power setting is in Watt.
24		WSet			int32		WSet_SF	W	RW			Active Power Setpoint (W)	Active power setting value in Watt.
26		WSetRvrt			int32		WSet_SF	W	RW			Reversion Active Power (W)	Reversion active power setting value in Watt.
28		WSetPct			int32		WSetPct_SF	Pct	RW			Active Power Setpoint (Pct)	Active power setting value as percent.
30		WSetPctRvrt			int32		WSetPct_SF	Pct	RW			Reversion Active Power (Pct)	Reversion active power setting value as percent.
32		WSetEnaRvrt			enum16								
		DISABLED	0									Disabled	Function is disabled.
		ENABLED	1									Enabled	Function is enabled.
33		WSetRvrtTms			uint32			Secs	RW			Active Power Reversion Time	Set active power reversion time.
35		WSetRvrtRem			uint32			Secs				Active Power Rev Time Rem	Set active power reversion time remaining.

Figure 5.4: SunSpec DER AC controls model (excerpt) [18]

Modbus is popular in industrial environments because it is openly published and royalty-free. It was developed for industrial applications, is relatively easy to deploy and maintain, compared to other standards, and places few restrictions on the format of the data transmitted.

The development and update of Modbus protocols are managed by the Modbus Organization since April 2004, when Schneider Electric transferred all rights. The Modbus Organization is an association of users and suppliers of Modbus compliant devices that advocates for the continued use of the technology. However, being open source, many implementations are variations from the official standard. Thus, different varieties might not communicate correctly between equipment from different suppliers.

◊ **Zigbee:** is an IEEE 802.15.4 (Low-Rate Wireless Networks) based specification for a suite of high-level communication protocols for small scale low-power low-bandwidth wireless personal area ad hoc networks with low-power close proximity digital radios.

- Zigbee has a defined line-rate of 250 kbit/s
- Zigbee uses the 2.4GHz band and a self-healing mesh network
- Zigbee networks are secured by 128-bit symmetric encryption keys
- Zigbee is best suited for intermittent data transmission, e.g., from a sensor or input device
- Zigbee uses ad-hoc networking to relay data via intermediate nodes to devices not in radio reach
- Zigbee is typically used with applications that require long battery life and secure networking

The low power consumption limits radio transmission distances to 10–100 meter line-of-sight, depending on transmit power and environment characteristics. Applications include wireless light switches, home energy monitors, traffic management systems, and other applications that require short-range low-rate wireless data transfer.

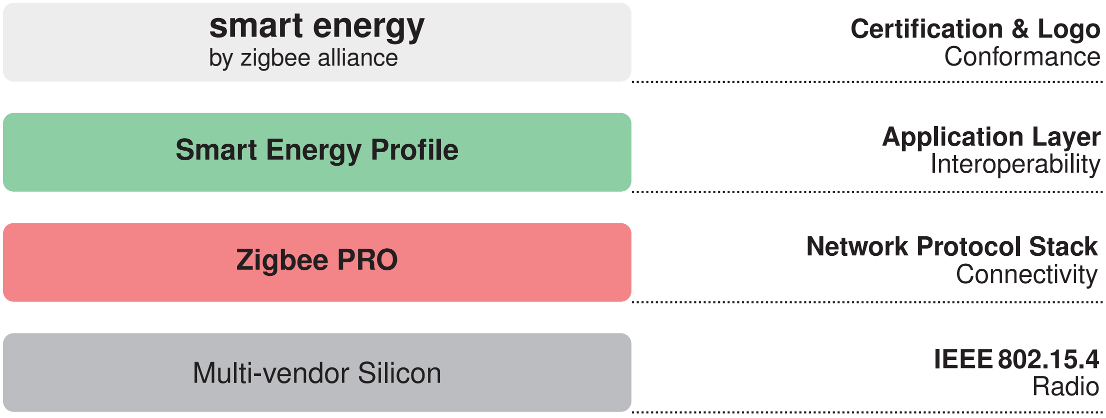


Figure 5.5: Zigbee PRO in the Smart Energy communication stack [19]

Zigbee was introduced in 1998, standardised in 2003, and revised in 2006. The technology defined by the Zigbee specification is intended to be simpler and less expensive than other wireless personal area networks (WPANs), such as Bluetooth or more general wireless networking (Wi-Fi).

◊ **DLMS/COSEM:** is part of IEC 62056, a set of standards for electricity metering data exchange. DLMS/COSEM specifies the data model, the messaging protocol and media-specific communication profiles. It can be applied for sensing, metering and control across electricity, gas, heat energy, water and more. It is standardised since 2002 as part of the IEC 62056 and EN 13757 standard suites.

IEC 62056-1-0: Smart metering standardisation framework
IEC 62056-3-1: Use of local area networks on twisted pair with carrier signalling
IEC 62056-4-7: DLMS/COSEM transport layer for IP networks
IEC 62056-5-3: DLMS/COSEM application layer
IEC 62056-6-1: Object Identification System (OBIS)
IEC 62056-6-2: COSEM interface classes
IEC 62056-6-9: Mapping CIM message profiles (IEC 61968-9) and DLMS/COSEM data models and protocols
IEC 62056-7-3: Wired and wireless M-Bus communication profiles for local and neighbourhood networks
IEC 62056-7-5: Local data transmission profiles for Local Networks (LN)
IEC 62056-7-6: The three-layer, connection-oriented HDLC based communication profile
IEC 62056-8-3: Communication profile for PLC S-FSK neighbourhood networks
IEC 62056-8-5: Narrow-band OFDM G3-PLC communication profile for neighbourhood networks
IEC 62056-8-6: High speed PLC ISO/IEC 12139-1 profile for neighbourhood networks
IEC TS 62056-8-20: Mesh communication profile for neighbourhood networks
IEC TS 62056-9-1: Communication profile using web-services – COSEM Access Service (CAS)
IEC 62056-9-7: Communication profile for TCP-UDP/IP networks

Other IEC 62056 parts for electricity metering (data exchange for meter reading, tariff and load control)
IEC 62056-21: Direct local data exchange
IEC TS 62056-41: Data exchange using wide area networks (PSTN[48] with LINK+ protocol)
IEC 62056-42: Physical layer services and procedures for connection-oriented asynchronous data exchange
IEC 62056-46+AMD1: Data link layer using HDLC protocol
IEC 62056-47: COSEM transport layers for IPv4 networks
IEC TS 62056-51: Application layer protocols
IEC TS 62056-52: Communication protocols management (DLMS server)
IEC 62056-61: Object identification system (OBIS)
IEC 62056-62: Interface classes for the COSEM object model

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[48] Public Switched Telephone Network

In DLMS/COSEM, all the data of electronic meters and devices become represented by mapping them to appropriate information classes and related attribute values. Any real-world thing mapped to an appropriate class type can be described by the attributes defined in the standard. The methods defined therewith allow operations to be performed on the attributes. Attributes and methods jointly constitute an object.

Conventionally, the first attribute of an object is the logical name, also defined as the OBIS code in case of LN referencing, being part of the object identification. Objects that share common characteristics are generalized as instantiations of an interface class with defined class_id. Instantiations of an interface class are called COSEM objects.

↪ DLMS or *Device Language Message Specification* (originally *Distribution Line Message Specification*) is the suite of standards developed and maintained by the DLMS User Association (DLMS UA) that has been adopted by the IEC TC13 WG14 into the IEC 62056 series of standards. The DLMS UA provides maintenance, registration and compliance certification services for IEC 62056 DLMS/COSEM.

↪ COSEM or *Companion Specification for Energy Metering* includes specifications that define the transport and application layers of the DLMS protocol. The specifications are grouped into four documents:

Blue Book: COSEM meter object model & OBIS (object identification system),
Green Book: architecture and protocols,
Yellow Book: conformance testing,
White Book: glossary of terms.

Products that pass the conformance test specified in the Yellow Book, become certified as DLMS/COSEM compliant by the DLMS User Association. The DLMS User Association is a non-profit organization based in Zug, Switzerland, founded in 1997 by leading utilities and meter manufacturers to develop and support a standard for smart meter data exchange.

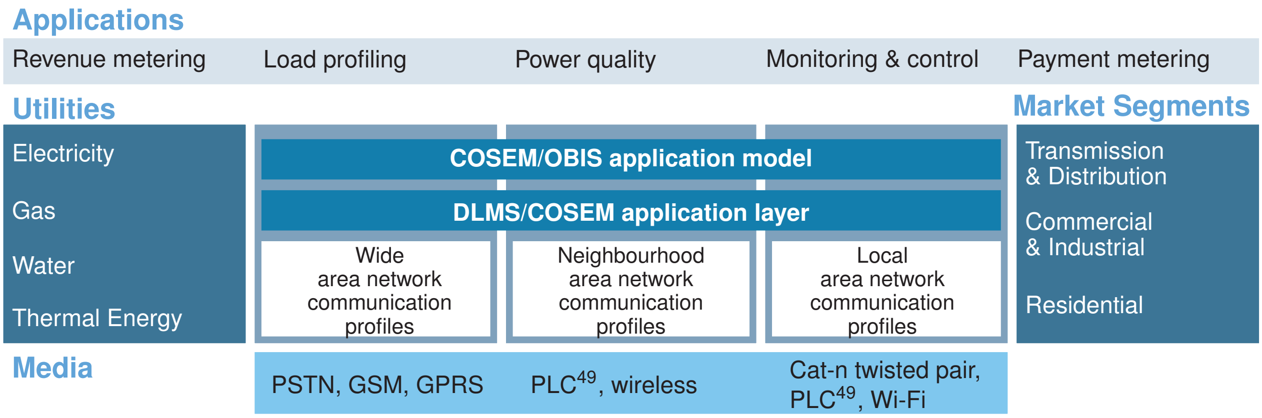

Figure 5.6: DLMS/COSEM overview [20]

DLMS/COSEM uses a client-server paradigm where the end devices, typically meters are the servers and the Head End Systems or concentrators are the clients. The DLMS/COSEM application layer provides:

- the ACSE services to connect the clients and the servers; and
- the xDLMS services to access the data held by the COSEM objects.

The xDLMS services are the same for each object. This allows adding new objects without affecting the existing application layer. The application layer also composes the messages, i.e., the Application Protocol Data Units (APDUs), it applies checks and removes cryptographic protection as needed, and it manages transferring long messages in blocks. Various built-in mechanisms optimize the traffic to the characteristics of the medium used.

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[49] Power Line Communication, e.g., IEC 61334, formerly known as IEC 1334

The DLMS/COSEM communication profiles specify the protocol stack and the binding of the lower protocol layers to the DLMS/COSEM application layer. Profiles are available for:

- Local ports, PSTN/GSM with HDLC data link layer RS232 / RS485;
- GPRS;
- IPv6, IPv4, TCP and UDP;
- S-FSK PLC;
- G3-PLC with UDP/ IPv6;
- Prime PLC without IP, with IPv6, IPv4, TCP and UDP;
- Wired and wireless M-Bus;
- Mesh networks with IPv6 and 6LowPAN;
- *and upcoming:* Wi-SUN and NB IoT.

The DLMS/COSEM specification is developed and maintained by the DLMS User Association:

- COSEM and OBIS are specified in the Blue Book;
- DLMS/COSEM application layer, lower layers and communication profiles are specified in the Green Book.

The contents of these Books are internationally standardized by IEC TC13 WG14 and CEN TC294.

5.5 Tools available for prototypes, sandboxes, and general deployments

*Because once released this document is published open source (*CC-BY-SA*) be aware not to include any proprietary information that cannot be disclosed. Open source tools are highly appreciated and shall be preferred over similar proprietary tools where no technical issues demand latter.*

5.5.1 OpenEMS

The *Open Energy Management System* (OpenEMS[50]) is a modular software platform for energy management applications. It focuses on controlling, monitoring and integrating energy storage systems together with renewable energy sources and complementary devices and services. Thus, it appears to be a platform option for Energy Community components, i.e., Community Energy Management System and Member Energy Management System.

The OpenEMS *"Internet of Things"* stack contains three software components:

- OpenEMS Edge that runs on-site and actually controls devices,
- OpenEMS UI that provides the generic user interface, and
- OpenEMS Backend, which runs on a (cloud) server and connects the decentralized Edge systems and provides aggregation, monitoring and control via the public Internet.

The components keep an open Websocket connection for bi-directional communication. The protocol is based on JSON-RPC, basically providing *Request, Success Response, Error Response,* and *Notification* messages. The features OpenEMS provides for a modern flexible Energy Management System include:

- Fast PLC-like control of (battery) inverters and other devices,
- Easy extension due to modern programming languages and modular architecture,
- Wide range of devices and protocols supported, and a
- Modern web-based on-line user interface.

The OpenEMS Backend can be deployed on a Debian Linux server and uses the JSON-RPC communication protocol to connect one or more OpenEMS Edge devices, either via REST/JSON (io.openems.backend.b2brest) or via Websocket (io.openems.backend.b2bwebsocket).

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[50] Not to be mistaken with the *Open Electromagnetic Field Solver*, which is also named OpenEMS.

The OpenEMS Edge Controller holds the logic (e.g., a state machine) or an algorithm (e.g., a prediction engine) that "controls" a hardware device. The logic of each active Controller is executed regularly on every Cycle, i.e., once per second.

To connect to hardware several communication protocols are implemented as bridges:

M-Bus: standard for fieldbus communication (see www.openmuc.org/m-bus/user-guide/)
Modbus/TCP: standard for fieldbus connection over TCP/IP network
Modbus/RTU: standard for fieldbus connection over RS485 serial bus
OneWire: protocol for home automation that directly talks to the OneWire busmaster

◊ **Modbus/TCP:** This API provides a Modbus-Slave implementation that connects a Channel to an external device via Modbus/TCP. How to *connect an electricity meter* to OpenEMS Edge via Modbus/TCP is explained as an example on how to connect hardware.

◊ **REST:** Via this API can external hardware access Channels using JSON/REST calls on port 8084.

◊ **Websocket:** The API enables external access via JSON/REST to OpenEMS Edge using HTTP and includes access to Channels and JSON-RPC Requests. It is also used to connect locally an OpenEMS UI, that creates charts dynamically according to the components enabled. The OpenEMS UI can be compiled to execute it outside of an IDE.

↪ *Open Source:* OpenEMS development was started by FENECON GmbH. It is the software stack in behind the *FEMS - FENECON Energy Management System*. The source code is available online at http://openems.io and on GitHub. New versions are released after every Scrum Sprint and are tagged accordingly. The master branch always holds the stable release. Governance of the OpenEMS project was taken over by the newly founded *OpenEMS Association e.V.* in 2019, which invites third parties like universities, hardware manufacturers, software companies, commercial and private owners to use OpenEMS for their own projects and are glad to provide support with first steps. If interested in the OpenEMS development team contact info@openems.io.

↪ *License info: OpenEMS Edge* and *OpenEMS Backend* are © 2016–2020 by FENECON GmbH and can be redistribute and/or modified under the terms of the Eclipse Public License version 2.0. *OpenEMS UI* is also © 2016–2020 by FENECON GmbH but can be redistribute and/or modified under the terms of the GNU Affero General Public License version 3.

◊ **Simulation option:** OpenEMS provides virtual devices for testing and development. For such a simulation environment the component that realise communication with external hardware need to be replaced by the more generic components tagged with the *"Simulator"* prefix.

↪ *DataSources* generate lists of data and provide their content as channel. The data can be generated by an augmented random generator or read from a data file, e.g., using the *"Simulator Datasource: CSV Reader"*.

↪ *Devices* replace hardware bound components like meters or inverters. The consequential two device types are:
acting devices — who's actions depend on data-sources not other devices, and
reacting devices — that deduce their behaviour from other device's channels/properties.

5.5.2 OpenMUC

The OpenMUC framework offers software solutions for monitoring and control systems. It consists of a Java framework to implement *monitoring and control applications*, and Java libraries that integrate some popular communication standards (e.g., IEC 61850, IEC60870-5-104, DLMS/COSEM, M-Bus, IEC 62056-21, SML). The software is 100% pure Java and runs on most operating systems (Linux, Windows, Mac) and CPU architectures (Intel & ARM). It is designed for embedded systems and has a small footprint.

OpenMUC can be used to implement anything from simple data loggers to complex SCADA systems. The aim is to shield the application developer from the details of communication protocols and data logging technologies. The framework is used in various smart grid projects to readout smart meters, control CHP units, monitor PV systems or control electric vehicle charging. Therefore, many communication protocol drivers from the energy domain are included. Due to the open and modular architecture many more applications can be realized using OpenMUC.

OpenMUC features:

- Easy application development — shielding the developer from communication protocol coding
- Simple and flexible configuration — parameters can be dynamically configured in various ways
- Communication support out of the box — popular protocols are included, plug-in interface to add new drivers
  ○ Existing drivers: Modbus TCP, Modbus RTU, Modbus RTU/TCP, IEC 61850, IEC 60870-5-104, IEC 62056-21, DLMS/COSEM, KNX, wired and wireless M-Bus, eHz meters/SML, REST/JSON, SNMP, CSV
- Data logging in many formats — plug-in interface to new data loggers
  ○ Existing logger: ASCII, SlotsDB (binary)
- Web user interface configuration and visualization
  ○ Existing WebUI: Channel Access Tool, Channel Configurator, Data Exporter, Data Plotter, Media Viewer
- Data servers — to connect remote and local non-Java applications
  ○ Existing server: Modbus TCP, REST/JSON
- Modularity — drivers, data loggers, etc. are individual selectable components
- Embedded systems ready — designed to run on low-power devices (e.g., x86 and ARM systems)
- Open-source software — licensed under the GPLv3

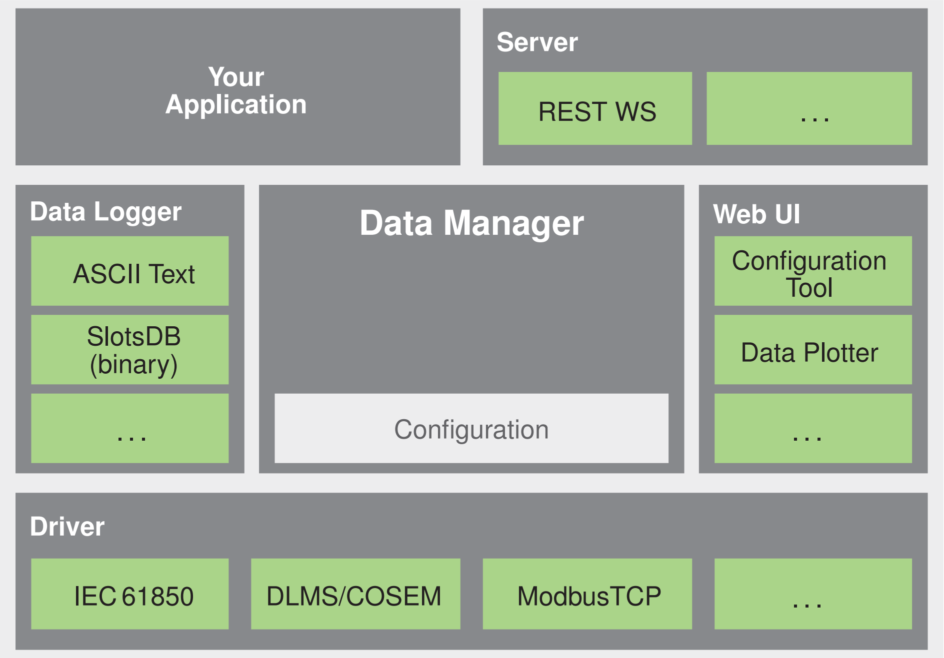

Figure 5.1: OpenMUC Architecture [21]

The boxes shown in figure 5.1 are implemented as OSGi bundles that run independently in the OSGi environment. Except for the Data Manager are all modules optional to support light weight customised solutions.

↪ *OpenMUC demo app:* A simple demo app is provided to demonstrate how channels and their records can be accessed from an application. The app reads data from channels of the CSV driver, calculates new values from them and writes them to other channels. The app can be used as starting point to create own OpenMUC application.

OpenMUC is offered by the *Smart Grid ICT* group at the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany. The group is part of the business area *Energy Systems Technology* covering Smart Grid Technologies:

- ○ Grid integration of distributed energy appliances, (e.g., PV, BESS, heat pumps, CHP, EV)
- ○ Secure information transmission, communication technologies and protocols
- ○ Energy management gateways, embedded systems
- ○ Supervisory Control and Data Acquisition (SCADA)
- ○ Monitoring and smart metering systems

Third parties are encouraged to create their own customized systems based on OpenMUC, which is licensed under the GPL. Individual licenses are sold on request.

5.5.3 Nymea

nymea is an open source IoT platform offering an *Open IoT Stack*. It provides a collection of tools, libraries and services to build connected devices that scale from highly specific IoT use cases to fully featured smart home platforms, including cloud connectivity. **nymea** consists of three parts: *nymea:core, nymea:app* and optional *nymea:cloud*. Using plug-ins for many tasks, a large variety of building block setup combinations is possible. With *nymea:core* and *nymea:app* a powerful smart home solution can be set-up that does not require powerful hardware or fiddling with configuration files. **nymea** strives to simplify communication for connected products.

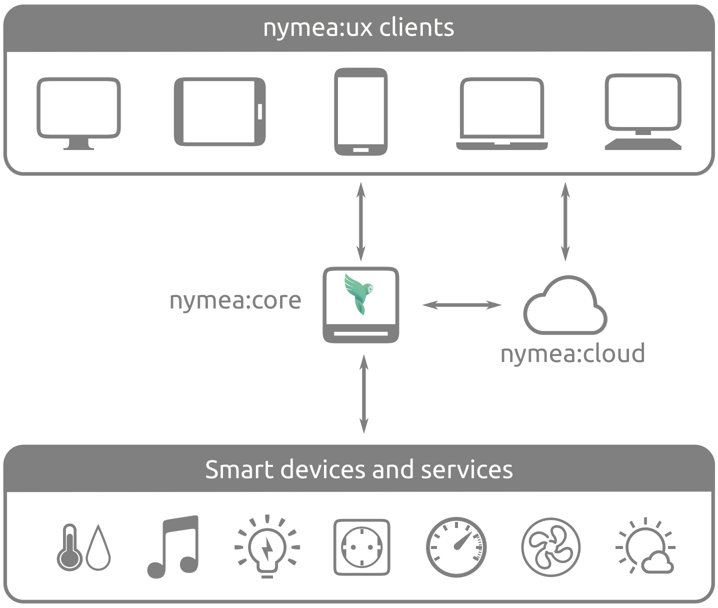

Figure 5.2: **nymea** system overview [© **nymea** – reproduced with permission]

IoT applications often require to interact using low level hardware interfaces like I2C, GPIO, One-Wire and networking protocols like MQTT, COAP, ZigBee, Bluetooth and more. **nymea** enables app developers to interact with devices from a remote JSON-RPC API instead of typing low level C code to implement the required interface drivers. Many interfacing tasks are readily handled out of the box. Hardware/Protocol abstraction layers for easy plug-in development available: [`https://nymea.io/documentation/overview/features`][51]

- Bluetooth
- NFC
- CoaP
- 443 MHz radio

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[51] The nymea platform is evolving and so are the interfacing means. Listing them is limited to a snapshot showing an excerpt.

- WiFi/Ethernet/Internet connected devices/services
  (e.g., HTTP REST APIs usable with minimal code effort)
- ZigBee (WIP)
- MQTT
- Any other transport protocols can be used hand-crafted in a plugin
- All libraries available in Linux available to use

Everything is designed in an offline-first approach, which results in fast reaction times, full control over personal data, and products do not become useless when a cloud provider shuts down the service. The local-first approach assures that everything can be done without cloud connection, which evidently keeps all data in the local network, where it belongs, i.e., within the owner's premises. IoT devices, especially inside homes, need not be cloud connected all the time.

The **nymea** edge software is modular and can be expanded with new functions, sensors and cloud integrations via plug-ins. The core modules of the software are open source, so every software integrator can make new integrations.

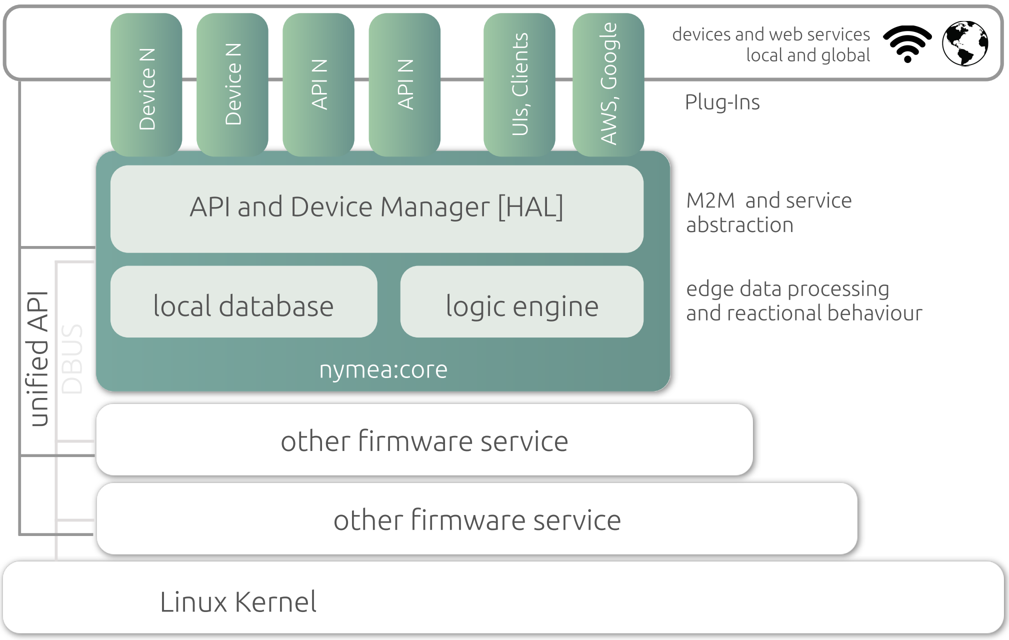

Figure 5.3: Modular **nymea** edge stack [© **nymea** – reproduced with permission]

Data privacy and operation reliability are prime. Independence from cloud vendors and not requiring an always-on internet connection are add-on benefits. Using 100% free and open source software saves royalty expenditures. Dedication to open-source, transparency, and openness is considered the better way to convince customers.

5.6 Good practice examples, common recommendations, and general ideas

Note that here in Vol.1 of the Technical Framework all content is informative only. Necessary operation, safety and security measures shall be specified in Vol.2 to be binding. Only when specified within IES Integration Profiles, requirements become mandatory and considered for conformance testing. All the examples outlined in this section are suggestions only.

5.6.1 Grid-access limits

The most basic and rather inevitable good practice is power limiting. Both, inserting and draining power to and from the grid, needs to be locally limited for safety reasons. Commonly, this is achieved by fuses. They protect the electricity conducting resources, i.e., wires and transformers, from overheating and eventual melting or exploding, respectively. Fuses respond rather slow to minor limit violations, which fits because overheating also accumulates rather slow. However, many customers along a supply line, or more generally within a region, may exceed their limits slightly for an extended time. These individually minor violations can sum up to considerable stress on up-grid resources, causing congestion that needs to be attended to.

Common practice is to enact access limits that render critical overload rather unlikely and of short duration, mostly. To achieve that, the access limits (i.e., the grid-edge bottlenecks) need to be smaller the more volatile the consumption pattern of a customer is and the more persistent limit violations commonly are.[52] The drawback is that rigorously set limitations prevent most rare events but cause underutilised resources, most of the time. They also limit the potential of demand side power management (DSM). Setting these access boundaries is balancing resource economics versus system safety.

In an ideal case, power loads would not fluctuate and every energy demand is fulfilled by an individually planned and granted energy flow, precisely routed from the power source (generator) to the appliance, which consumes the power exactly as it is produced and transported across grid resources. Such an energy system would not need local access limitations as the protection of resources could be integrated in the power routing process. However, this approach also implies that in case the power cannot be safely routed to the demanding appliance, the requested energy is not provided and thus, the appliance not always enabled to perform an intended task.

5.6.2 Autonomous power-state aware operation

Smart edge devices, the foundation of a smart grid, can use far more information to make local decisions than simple fuses. Metering the power quality at a customers access point these devices (Smart Meters) can detect over- and under-voltage and grid-frequency deviations. In addition, they may also measure the power angle, i.e., the relation of active power to reactive power related to the phase offset between the voltage and the current, indicating whether the reactive power is inductive or capacitive.

Intelligent power assets within customer premises, in particular rectifiers inserting power from local generation, can than adjust their power output to the measured power quality in order to mitigate power quality issues.[53] The topic of integrating high amounts of Distributed Energy Resources in the low voltage distribution grid is the topic of many studies, proposing different means to smoothly insert the power, commonly based on autonomous insertion control. See for example the open access published comparison by Kui Luo and Wenhui Shi [22].

◊ **P(U)-control:** Executes active power (P) curtailment as a function of the voltage (U) at the grid access point. The inserted power is confined by the voltage level at which it may be inserted. If the voltage at the grid access

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[52] Industry customers often pay grid-fees based on their peak load, which triggers them in a friendly, economics based manner to avoid peaks. Private customers pay grid tariffs in relation to their consumption; their load pattern is not metered, and thus, unknown. Empirical load patters are used to predict their consumption behaviour. Deviations, for example due to heat pumps and EV-charging, indirectly challenge grid stability: such applications render the empirical load patterns unrealistic and the load-planning systematically tainted.

[53] *Grid codes*, sometimes also called *network codes*, specify the required grid support. Support in excess of what is required by law, shall be considered as *ancillary service*, that in a way needs to be (pre-)ordered, on demand requested, and equitably remunerated.

point exceeds a set threshold, the inserted power is reduced until the threshold is again met. This response has to occur irrespective of what causes the threshold violation.

◊ **Q(U)-control:** Inserts reactive power (Q) as a function of the local grid voltage. Positive or negative (inductive or capacitive) reactive power is inserted to either decrease or increase the local voltage, respectively. A drawback of this algorithm is that due to the smaller voltage deviation closer to the transformer the prosumer further away need to contribute more reactive power than those close to the transformer.

◊ **PF(P)-control:** This scheme forces the insertion of power with a certain power factor (PF), i.e., at a certain power angle Φ, where $PF = \cos(\Phi)$, that depends on the actually inserted power (P). Thereby, all prosumer contribute reactive power equally. A disadvantage is that reactive power is inserted also when it may not be needed, i.e., independent of the voltage level, causing unnecessary grid losses.

◊ **Combinations:** E.g., $P(U)+Q(U)$ and $P(U)+PF(P)$ have as well been evaluated and proposed. However, the basic schemes are far from perfect, and even combinations thereof cannot achieve the optimal power flows, which result from solving the complex power flow optimisation across an entire LV-grid.

◊ **Frequency control:** The heavy rotors of common synchronous power generators store a huge amount of kinetic energy. Its derivative, the inertia of the rotating mass, provides the power that counteracts any frequency deviation between the grid and the rotating mass, limited by the robustness of bearings and the conducting capacity of the electric wiring. If these limits are reached the generator needs to be disconnected, which may trigger a cascading failure leading to a severe black-out.

Common PV-rectifier perform grid-synchronised power insertion, which does not provide any inertia. Instead, switched rectifiers are non-linear loads that cause distortion of the sine waveform, reflecting harmonics of the grid frequency into the grid. These harmonics cannot be compensated alike the positive or negative power angles introduced by inductive and capacitive loads. Smart rectifiers, so called *synchronverter* [23], if coupled with a sufficiently sized energy buffer, e.g., a capacitor bank or fast and powerful battery, can provide virtual inertia [24]. Their impact is still to be investigated, and economic viability appears achievable for upscale systems.

Implementing such a decentralised autonomous power ingress control scheme is often demanded by law, at least for bigger generation assets. Commonly, it is a good idea to have them, even if used as fallback operation mode only, where customers are primarily managed by a Community Energy Management System: If communication with the Community Energy Management System occurs over a public IT infrastructure, connectivity cannot be assumed always present. Thus, the local operation of smart energy assets needs to persist even when IT connectivity is lost, i.e., by switching to some safe fallback operation mode.

5.6.3 Dynamic power ingress and egress curtailment

Grid code based power insertion and absorption limits are rather static. To achieve a little flexibility, i.e., alignment of the actual power consumption to production and distribution economics, the switched low-price energy was introduced long time ago. Independent supply lines are not needed, commonly only the power meter is switched on and off in accordance with the utilisation of production and distribution capacities. Appliances that need not be powered all the time are connected to the switched low-price meter and therefore support the utility in the supply stabilising attempt by enabling remote altering of the current demand (Demand Side Management – DSM).

Similar can smart power generation devices, e.g. smart PV-rectifier, adjust the power insertion according to received control messages, e.g., switch the insertion control scheme according to the relevant grid code. In case the power generation is not equipped with a control interface, or when the device does not respond correctly, the DSO may cut the power insertion entirely when locally too much power is currently inserted (production curtailment). Commonly, every prosumer with a production capacity that exceeds a defined insignificance threshold is required by regulations (grid codes) to execute insertion curtailment whenever requested to.

However, plain on-off control causes wide spreading power control ripples across many grid levels when too many loads or generators are simultaneously cut off. Grouping of customers can help, but the optimal group depends on the cause for the interaction and because latter varies, there cannot exist any perfect grouping. The optimum for control quality is cause sensitive control of each switch individually.

In the near future, this approach may be extended by predicted schedules, and consequentially introduced dynamically adjusted power ingress limitation as presented at the 2020 ISGT-Europe conference [25, 26]. Thereby can also the systemic unfairness of curtailment in respect to the prosumer's position along the supply strand be addressed [27].

5.6.4 Grid-state awareness – introducing a Grid Traffic Light system

The power routing to a region is performed based on the assumed average power demand per customer. The actual power demand varies and therefore will in general deviate from the average assumed. Across many customers the deviations may level out, but that is not always the case. Congestion occurs where the total demand across a region reaches a level that cannot be handled easily, i.e., that overloads the up-grid resources.[54]

Responsible for mitigating any critical situations is the grid operator. In Figure 5.1 the required and potential actions of the Distribution System Operator are assigned to traffic light colours. Depending on the course of the current power issue, either too high voltage (upper limit) or too low voltage (lower limit), occurring from too low or high local load in respect to the energy provided to a region respectively, the Distribution System Operator is intended to respond accurately. Which actions a Distribution System Operator may and can actually execute depends on the local Distribution System Operator's situation awareness and control capabilities, which commonly are determined by regional regulations and policies on what Distribution System Operators are required and allowed to perform.

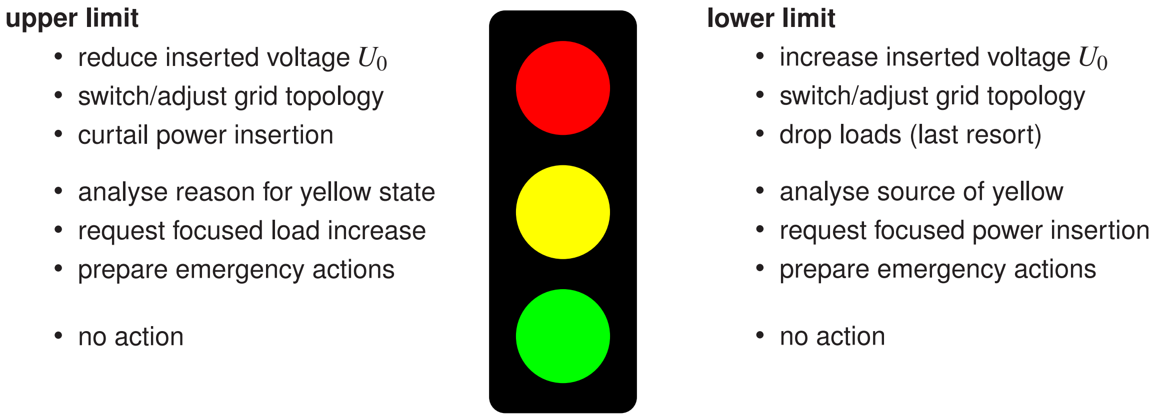

Figure 5.1: Grid Traffic Light – required Distribution System Operator actions

On the other hand, the affected entities, i.e., the active customers, will prepare themselves for Distribution System Operator actions. Most effectively, if they are informed on the current grid state as shown in Figure 5.2. They may take actions to prepare their systems for possibly harsh actions of the Distribution System Operator, e.g. ingress curtailment and disconnection from the grid. They may confine the effective grid access limits to reduce the potential power volatility. To further calm the grid situation active customers may empower the Distribution System Operator to control parts of their supply and demand, i.e., can offer their flexibility as ancillary service for an adequate reimbursement[55]. Vice versa, active customers will optimally utilise the local resources whenever the grid state empowers their Energy Management Systems to perform freely, i.e., selfish, individually and cooperative within an Energy Community.

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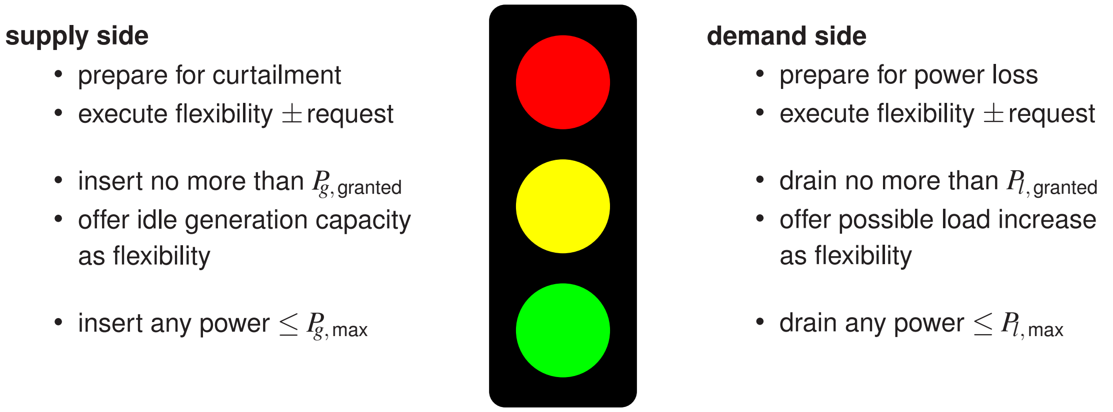
[54] The local resources, i.e., the wires along the supply lines, might also be overloaded, but we assume that this problem is sufficiently solved by local fuses. DSO interaction is assumed to be triggered by power balancing issues, i.e., unexpected lasting peaks, rather than congestion of individual grid resources due to dimensioning issues.

[55] If grid safety related ancillary services are sold to the Distribution System Operator, the sellers need to make sure that they can fulfil the promised generation and/or load change. If execution as offered cannot be assured, the reimbursement will be minor. The consequence for not delivering what was actually offered shall exceed compensation by magnitudes because non-performing is an issue of public safety.



supply side

- prepare for curtailment
- execute flexibility ± request

- insert no more than $P_{g,\text{granted}}$
- offer idle generation capacity as flexibility

- insert any power $\leq P_{g,\text{max}}$

demand side

- prepare for power loss
- execute flexibility ± request

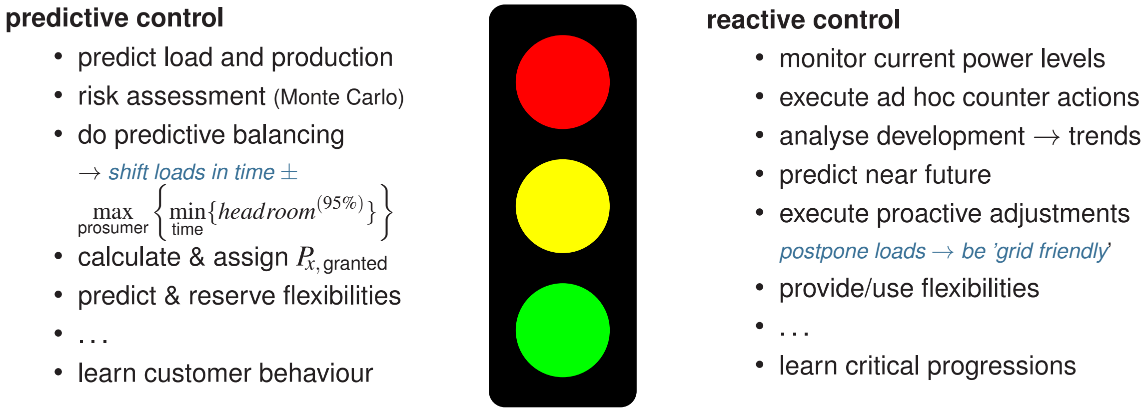
- drain no more than $P_{l,\text{granted}}$
- offer possible load increase as flexibility

- drain any power $\leq P_{l,\text{max}}$

Figure 5.2: Grid Traffic Light – expected prosumer actions

To prevent critical situations, Energy Management Systems may introduce pro-active control base on the knowledge of planned (scheduled) load and production, and on experience, i.e., learned behaviour patterns and typical state progression. The prime intention of using state prediction is the reduction of the probability to experience red-light situations. According tasks are listed in Figure 5.3, i.e., on the left side. On the right side we find the response actions of a Member Energy Management System taken on behalf of a prosumer (active customer).

The prime feature that an Energy Management System can add is load limiting and shifting. In response to a grid state change only a posterior load can be altered. Within an Energy Community the individual Member Energy Management Systems can also perform ahead of time load balancing, thereby coordinating predicted local loads and supplies to optimally utilise all the local resources. Along with this supply to demand matching task, the objective shall include red-light prevention. A basic approach thereto is maximising over all community members (and maybe also other clients in between along supply lines) the minimum headroom over time between predicted power level (voltage) and the upper and lower voltage limits allowed. Staying maximally away from limits reduces the probability of limit violations due to the inevitable prediction uncertainty resulting from unpredictable load and production fluctuations.



predictive control

- predict load and production
- risk assessment (Monte Carlo)
- do predictive balancing
  → *shift loads in time* ±
  $\max_{\text{prosumer}} \left\{ \min_{\text{time}} \{ headroom^{(95\%)} \} \right\}$
- calculate & assign $P_{x,\text{granted}}$
- predict & reserve flexibilities
- ...
- learn customer behaviour

reactive control

- monitor current power levels
- execute ad hoc counter actions
- analyse development → trends
- predict near future
- execute proactive adjustments
  postpone loads → *be 'grid friendly'*
- provide/use flexibilities
- ...
- learn critical progressions

Figure 5.3: Grid Traffic Light – possible Energy Management System actions

Achieving optimal energy distribution and production utilisation within an Energy Community does not naturally correltate with supporting grid stability. Therefore, the Traffic Light System introduces the opportunity to perform situation aware control.[56] Whereas in a green light situation the Energy Community may perform selfish and shall optimise energy flows to the benefit of its members, the same system can be used to support grid stability during red light periods, allowing the local Distribution System Operator to control local power production and demand, without

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[56] Subsection 5.6.4 is provided to indicate how an Energy Community and its members can include the grid state in the control of energy flows among members. This option is mentioned here-and-there throughout Vol.1 of the Technical Framework on Local Energy Communities.

trading or buffering any energy on its own behalf. During yellow light phases the objective shall be returning to green light with minimal effect on the individual energy customers. Meaning that all customer needs shall be fulfilled, only the added benefits from cooperation in an Energy Community shall be exchanged for returning to green light.

Table 5.1 summarises the responsive tasks of the different entities involved in maintaining the stability and safety of the local distribution grid. Here, where active customers are expected to cooperate in Energy Communities, we assume that on demand, i.e., when the grid state changes from green to yellow, these can adjust their power insertion and draining to lower levels than physically determined by access-point fuses. This load reduction is intended to increase the headroom needed to cover an unpredicted power level deviation that most probably causes the yellow grid state. Thereby, continuing from the yellow into a red grid state should at least be postponed if not entirely prevented.

Table 5.1: Grid state responsive tasks of the different entities involved

actual/reactive	**red**	**yellow**	**green**
DSO	act immediately	analyse & prepare	monitor & learn
prosumer	respond reliably	behave within limits	act on your own
EMS	support DSO	offer flexibility	monitor & perform

To perform the tasks mentioned in Table 5.1 best, the response to state changes can be pre-planned. The according preparatory task of the different entities involved are listed in Table 5.2.

Table 5.2: Tasks required to be prepared for individually adequate grid state responses in accordance to Table 5.1

ahead/predictive	**red**	**yellow**	**green**
DSO	plan & prepare counter actions	analyse issues & predict trends	delegate local control to EMSs & prosumer
prosumer	deliver promised flexibility	make flexibility offers & sell them	optimise self-consumption
EMS	implement reliable response actions	confine own actions & exec. adj. schedules	execute planned schedules

To reduce the likelihood of leaving the green state where an Energy Community can freely perform to maximise the benefit for its members, some grid state responsive control within the Energy Community can be beneficial also within the green grid state. In good cooperation with the local Distribution System Operator, the Energy Community members might be granted some free extra access capacity to distribute energy among themself in exchange for actively supporting grid health[57].

↪ ***Plan and prepare alternative schedules for different grid states.*** Depending on the grid's current state (green|yellow|red), which the Distribution System Operator communicates, the planned schedules are more, less or not *aggressive* concerning the load on individual grid segments. In case the Distribution System Operator has a capable grid monitoring tool, the traffic-light system might be applied section wise to improve both, local grid stability and local resource utilisation.

A grid friendly behaviour of Energy Communities may be implemented based on signals from the local Distribution System Operator or based on grid state prediction via the autonomous interpretation of the power quality (Voltage, $\cos\phi$) measured at the Energy Community members' access points (Smart Meters). In consequence might an Energy Community offer this monitoring feature also to a Distribution System Operator in case that does not have the required means for distributed power quality monitoring at the low voltage level.

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[57] To qualify for serving the public good, requires a reliable, commonly certified, seamless and trustworthy monitored, and ultimately admissible execution of the energy and power management and control implemented at the community level and executed by common as well as individually owned member assets.

5.6.5 General safety and security advices

Safety and security measures result from common sense and regional regulation. General standards may include measures to assure required safety and security, but in many cases these need to be adjusted to fulfil local regulations. International recommendations and local regulations shall be referred to on a per use case basis.

Please suggest or contribute additions required to grasp the common principles and demand for safety and security. Feel free to recommend sources to be summarised or referred to. You are welcome to contribute paragraphs or subsections alike.[58]

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[58] Note that not all contributions can be included, and that some copy editing and shortening may occur version by version. Exemplary outlining of potential solutions is welcome, plain advertising and any confinement intended to promote a specific product (software, platform, hardware, or standard) will be generously neglected. Also exemplary solutions applicable for a minority of users that might misleadingly suggest common need or contradict common intentions shall not be included.

6 Content of Vol.2

Vol.1 covers the informative view, outlining business case(s) and potential functional requirements (Business Functions) of Local Energy Communities. Vol.2 of the Technical Framework focuses on the *normative* specification of specific *technical features* (Technical Use Cases). Therefore, Vol.2 is basically a collection of IES Integration Profiles, i.e., *harmonised* transactions and actor specifications (ABB_spec[59]), covering profile specific *security considerations, naming conventions, response times, execution protocols, state machines, data models and formats, encoding schemes, transport channels and media, etc.*

The harmonised technical features shall be specified to the point required to interoperably implement (realise) the here in Vol.1 defined Business Functions. In general, such normative specifications (restrictions) are necessary only for Business Functions that involve Meta-Actors (sub-systems) that may be developed and/or deployed by independent vendors.

The resultant harmonised specification of interoperability relevant features via IES Integration Profiles will be openly shared as required for true interoperability. Therefore, IES Integration Profiles shall neither disclose Meta-Actor internal implementation details nor restrict vendors in their freedom to choose implementation means, as long as irrelevant for the interoperability of the deployed Meta-Actors.

◊ **Vol.2 Introduction** shall summarise Vol.1 to the point required for implementation experts (i.e., software engineers) to roughly understand the general Energy Community aims followed by a brief description of Business Functions and their potential interoperability issues. The introduction closes with a table (or some other textual tool) that relates the Business Functions from Vol.1 with the IES Integration Profiles that Vol.2 is composed of.

◊ **IES Integration Profiles** result from strictly applying the Use Case Methodology specified in IEC 62559 [29]. Each IES Integration Profile shall be an individual document that can be used stand alone to interoperably implement a certain technical functionality. For example, how to remotely monitor the live measurements of a sensor in the field. Another IES Integration Profile could than specify how to record monitored data in a secure repository, and a third, how to implement secure authentication, authorisation and access control. All these exemplary profiles are per se independent but may be required together as (puzzle-)parts of some complex Business Function.

The examples given above for IES Integration Profiles are easy to understand and it should be clear that different flavours of these may be required for different Business Functions. For example, a simple sensor may not have the processing power to implement secure user authentication, authorisation and access control, such that this feature may be needed server based and in the field can only be achieved by a securely barred hardware interface (e.g., a locked hatch).[60]

If common practice or standards provide features that can be used in different flavours, than these features shall be specified once as a *Common Feature* providing all the usage flexibility they offer. Such Common Features can be addressed by IES Integration Profiles, reducing the specification effort within the IES Integration Profile to restricting the offered options to the single harmonised one best fitting the technical use case covered by the calling IES Integration Profile.

Figure 6.1 shows this modular, still use case specific, composition of technical specifications supported by the IES document templates.

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[59] According to the TOGAF (The Open Group Architecture Framework) Architecture Building Blocks (ABB) approach [28]

[60] Note that IES Integration Profiles are not restricted to software based solutions. Where necessary, interoperable hardware solutions shall as well be specified. Often the used hardware feature per se (here a hatch with a lock and a fitting key) is commonly known and needs no textual specification, such that a use case specific parametrisation in the IES Integration Profile is sufficient (e.g., specify the security class of the hatch and the lock). The same applies for commonly known software features. For example, the Internet Protocol (IP) needs not be specified, only the transport protocol (TCP, UDP, etc.) and if necessary also its flavour (Vegas, Reno, etc.) because latter implies the former.

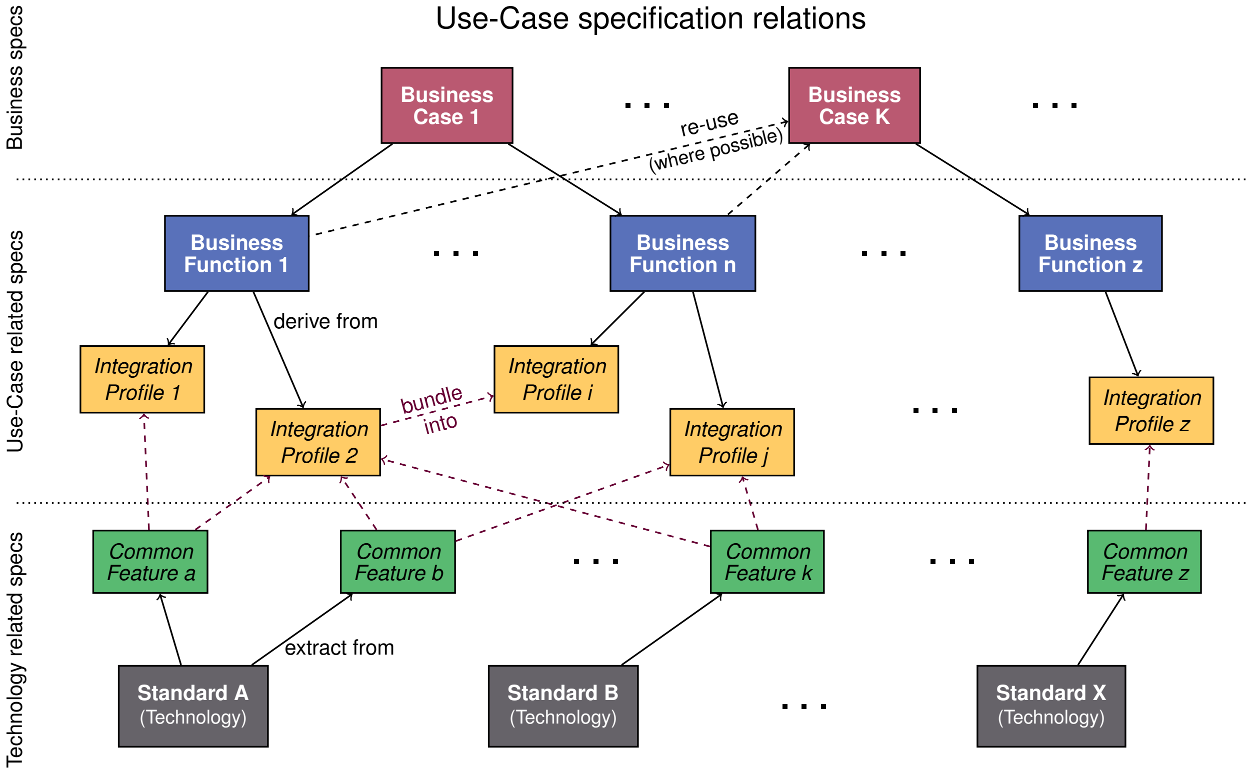

Figure 6.1: Use case centric still modular technical specifications composition supported by IES templates [30]

Abbreviations

Every abbreviation used anywhere in the Technical Framework and accompanying documents shall be included. Product and company names that only look like being abbreviations need not be included.

ABB	Architecture Building Block
ABB_spec	Architecture Building Block Specifications
ADU	Application Data Unit
AMD	AMenDment
AMI	Advanced Metering Infrastructure
APDS	Application Protocol Data Units
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BESS	Battery Electric Storage System
BF	Business Function
CAPEX	CAPital EXpenditures
CC	Creative Commons
CCTS	Core Components Technical Specification
CEC	Citizens Energy Community
CEP	Clean Energy Package
CF	Common Feature
CHP	Combined Heat and Power
CIM	Common Information Model
COAP	COnstrained Application Protocol
COSEM	Companion Specification for Energy Metering
CPA	Collaboration Protocol Agreement
CPP	Collaboration Protocol Profile
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSV	Comma-Separated Values
C/EMS	Community Energy Management System
DA	Data Attribute
DACH	Germany, Austria, Switzerland
DER	Distributed Energy Resource
DLC	Direct Load Control
DLMS	Device Language Message Specification
DO	Data Object
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
EDA	Energiewirtschaftlicher Datenaustausch
EDI	Electronic Data Interchange
EHV	Extra High Voltage level
ElWOG	Elektrizitätswirtschafts- und organisationsgesetz
EMS	Energy Management System
EnCo	Energy Community
ESMP	European Style Market Profile
EU	European Union
EV	Electric Vehicle
FPGA	Field-Programmable Gate Array
FSK	Frequency-Shift Keying
GNU	GNU's Not Unix!
GPIO	General-Purpose Input/Output
GPL	GNU General Public License
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HAL	Hardware Abstraction Layer
HEMS	Home Energy Management System
HDLC	High-Level Data Link Control
HTTP	Hypertext Transfer Protocol
HV	High Voltage level
I2C	Inter-Integrated Circuit
IBF	IES Business Function
ICT	Information and Communication Technology
ID	IDentifier
IEC	International Electrotechnical Commission
IED	Intelligent Energy Device
IEEE	Institute of Electrical and Electronics Engineers
IEM	Internal Electricity Market
IES	Integrating the Energy System
IETF	Internet Engineering Task Force
IHE	Integrating the Healthcare Enterprise
IIP	IES Integration Profile
IIT	IES Interoperability Testing
IMA	IES Meta-Actor
IopL	Interoperability Level
IP	Internet Protocol
ISBN	International Standard Book Number
ISO	International Organization for Standardization
IT	Information Technology
ITU	International Telecommunication Union
IUC	IES Use Case
JSON	JavaScript Object Notation
LD	Logical Device
LEC	Local Energy Community
LN	Logical Node
LN	Local Network
LV	Low Voltage level
L/GCI	Local Grid Control Instance
M/EMS	Member Energy Management System
MQTT	Message Queuing Telemetry Transport
MUC	Meta Use Case
MV	Medium Voltage level

OBIS	OBject Identification System
OFDM	Orthogonal Frequency-Division Multiplexing
OPEX	OPerational EXpenditures
OSGi	Open Services Gateway initiative
OSI	Open Systems Interconnection
OT	Operations Technology
PAN	Personal Area Network
PCC	Point of Common Coupling
PDU	Protocol Data Unit
PLC	Power Line Communication
PLC	Programmable Logic Controller
PPP	Public-Private Partnership
PSTN	Public Switched Telephone Network
PV	PhotoVoltaic
RDF	Resource Description Framework
REC	Renewable Energy Community
RES	Renewable Energy Source
REST	REpresentational State Transfer
RFC	Request For Comments
RPC	Remote Procedure Call
RTU	Remote Terminal Unit
R&D	Research and Development
SBB	Solution Building Block
SCADA	Supervisory Control And Data Acquisition
SES	Smart Energy System
SGAM	Smart Grid Architecture Model
SME	Small and Medium Business
SML	Service Modelling Language
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
TCP	Transmission Control Protocol
TE	Technische Einheit / Technical Entity
TF	Technical Framework
TSO	Transmission System Operator
UA	User Association
UBL	Universal Business Language
UCMR	Use Case Management Repository
UDP	User Datagram Protocol
UI	User Interface
UML	Unified Modelling Language
URL	Uniform Resource Locator
W3C	World Wide Web Consortium
WG	WorkGroup
Wi-Fi	trademark of the Wi-Fi Alliance
WPAN	Wireless Personal Area Network
XML	eXtensible Markup Language

Bibliography

[1] G. Franzl, R. Pasteka, and M. Gotschalk, *The IES Cookbook – Enabling interoperability the IES way – Edition 0.8*, CC-BY-SA, IES Austria, 01 2019, online, http://doi.org/10.13140/RG.2.2.13780.86409.

[2] L. Guise, “First Set of Standards,” CEN-CENELEC-ETSI Smart Grid Coordination Group, Tech. Rep., 2012, online, ftp://ftp.cen.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/FirstSetofStandards.pdf.

[3] M. Masi, T. Pavleska, and H. Aranha, “Automating smart grid solution architecture design,” in *2018 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)*, Oct 2018, pp. 1–6, online, http://dx.doi.org/10.1109/SmartGridComm.2018.8587457.

[4] CEN-CENELEC-ETSI Smart Grid Coordination Group – SG-CG/M490/K, *SGAM User Manual – Version 3.0*, 2014, online, ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/SGCG_Methodology_SGAMUserManual.pdf.

[5] Directorate-General for Energy, “Clean energy for all Europeans,” European Commission, 07 2019, online, http://doi.org/10.2833/9937.

[6] “Transactive Energy,” *IEEE Power and Energy Magazine*, vol. 14, no. 3, 2016, https://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=7452712.

[7] S. Thomas, M. Surampudy, and M. Knight, “Transactive Energy: Real World Applications for the Modern Grid,” Smart Electric Power Alliance, Tech. Rep., 2019, online, https://sepapower.org/resource/transactive-energy-real-world-applications-for-the-grid/.

[8] https://www.gridwiseac.org/about/transactive_energy.aspx, as of spring 2020.

[9] G. Franzl, A. Goranovic, S. Wilker, T. Sauter, and A. Treytl, “Initiating an IES based Technical Framework on Local Energy Communities,” in *25th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA 2020*. IEEE Industrial Electronics Society, 2020.

[10] M. Vadari, “The future of distribution operations and planning: The electric utility environment is changing,” *IEEE Power and Energy Magazine*, vol. 18, no. 1, pp. 18–25, 2020.

[11] http://pv-gemeinschaft.at/aufteilung/, as of spring 2020.

[12] E. M. Rogers, *Diffusion of Innovations*, 5th ed. Free Press, 2003, ISBN: 978-0-7432-2209-9.

[13] G. Franzl, “Energy Services Roles Grid,” CC-BY-SA-NC, 08 2019, online, https://doi.org/10.13140/RG.2.2.31032.70406.

[14] *IEC 61850:2016 - Communication networks and systems for power utility automation*, IEC Std., 2016.

[15] *IEC 60870-5-104 - Telecontrol equipment and systems - Part5-104: Transmission protocols - Network access for IEC 60870-5-101 using standard transport profiles*, IEC Std., 2006.

[16] ENTSO–E, “What are Network Codes?” online, https://www.entsoe.eu/network_codes/.

[17] Modbus.org, “Modbus application protocol specification v1.1b3,” 2012, http://www.modbus.org/docs/Modbus_Application_Protocol_V1_1b3.pdf.

[18] sunspec.org, “SunSpec DER Information Model Specification,” SunSpec Alliance, 2019, Document#: X99999, Status: Draft, online, https://sunspec.org/sunspec-der-information-model-specification/.

[19] Zigbee Alliance, “Zigbee Smart Energy 1.x,” online, https://zigbeealliance.org/solution/smart-energy/.

[20] DLMS User Association, “DLMS/COSEM overview,” online, https://www.dlms.com/dlms-cosem/overview.

[21] Fraunhofer Institute for Solar Energy Systems ISE, “OpenMUC: A Software Framework for the development of Monitoring and Control Systems,” online, https://www.openmuc.org/openmuc/.

[22] K. Luo and W. Shi, “Comparison of voltage control by inverters for improving the pv penetration in low voltage networks,” *IEEE Access*, vol. 8, pp. 161 488–161 497, 2020, online, https://doi.org/10.1109/ACCESS.2020.3021079.

[23] Q. Zhong and G. Weiss, “Synchronverters: Inverters that mimic synchronous generators,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1259–1267, 2011, online, https://doi.org/10.1109/TIE.2010.2048839.

[24] C. Vartanian and J. Alam, “Storage control for power system oscillation damping and inertia,” Jun 2020, online, https://resourcecenter.smartgrid.ieee.org/education/webinar-slides/SGSLW0134.html.

[25] K. Petrou, M. Z. Liu, A. T. Procopiou, L. F. Ochoa, J. Theunissen, and J. Harding, “Operating envelopes for prosumers in lv networks: A weighted proportional fairness approach,” in *2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, 2020, pp. 579–583, online, https://doi.org/10.1109/ISGT-Europe47291.2020.9248975.

[26] W. J. Nacmanson, M. Liu, and L. F. Ochoa, “On the role of pre-curtailed residential pv for primary frequency response considering distribution network constraints,” in *2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, 2020, pp. 769–773, online, https://doi.org/10.1109/ISGT-Europe47291.2020.9248917.

[27] M. Z. Liu, A. T. Procopiou, K. Petrou, L. F. Ochoa, T. Langstaff, J. Harding, and J. Theunissen, “On the fairness of pv curtailment schemes in residential distribution networks,” *IEEE Transactions on Smart Grid*, vol. 11, no. 5, pp. 4502–4512, 2020, online, https://doi.org/10.1109/TSG.2020.2983771.

[28] The Open Group, “Introduction to Building Blocks,” 1999, online, http://www.opengroup.org/public/arch/p4/bbs/bbs_intro.htm.

[29] IEC 62559-2:2015, “Use case methodology – Part 2: Definition of the templates for use cases, actor list and requirements list,” IEC, 2015, online, https://webstore.iec.ch/publication/22349.

[30] Smart Grids Austria, “Integrating the Energy System Austria (IES) – Downloads,” online, https://www.smartgrids.at/integrating-the-energy-system-ies/download.html.

All references used to prepare, extend, or amend the Technical Framework shall be listed; possibly with embedded link.
