



JRC TECHNICAL REPORT

Blockchain in the Energy Sector

*WP3 - Use cases identification
and analysis*

Nai Fovino, I.

Andreadou, N.

Geneiatakis, D.

Giuliani, R.

Kounelis, I.

Lucas, A.

Marinopoulos, A.

Martin, T.

Poursanidis, I.

Soupionis, I.

Steri, G.



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Contact information

Name: Igor Nai Fovino
Address: Via E. Fermi 2749, TP 580, 21027 Ispra(VA), Italy
Email: igor.nai-fovino@ec.europa.eu
Tel: +(39) 0332 785809

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Contents

Abstract	1
1 Introduction	2
2 Smart metering	4
2.1 Actors	5
2.2 Interactions	6
2.3 Technical requirements	9
2.4 Societal challenges	10
3 Energy Communities	11
3.1 Peer to peer energy exchange (micro-grid)	12
3.1.1 Actors	13
3.1.2 Interactions	13
3.2 Community shared balance storage	14
3.2.1 Actors	14
3.2.2 Interactions	15
3.3 Peer to grid	15
3.3.1 Actors	15
3.3.2 Interactions	16
3.4 Technical Requirements	16
3.5 Societal challenges	17
4 Flexibility	18
4.1 Actors	19
4.2 Interactions	20
4.3 Technical requirements	21
4.4 Societal challenges	21
5 Mobility	22
5.1 Car-Wallet and Payments	22
5.1.1 Actors	23
5.1.2 Interactions	23
5.2 Technical Requirements	24
5.3 Other potentially interesting scenarios (not subject to tests in WP 5)	24
5.3.1 Fleet Management & Energy Optimization	24
5.3.2 Autonomous Vehicles, Predictive Maintenance and features	25
5.3.3 Smart insurance	26
6 Certification of origin	27
6.1 Actors	27
6.2 Certificate of origin for consumed energy	28

6.3	Certificate of Origin for Prosumers	28
6.4	Certificate of Origin for Prosumers with BESS.....	29
6.5	Certificate of Origin for Energy Communities as Consumers	30
6.6	Certificate for Origin for Energy Communities with RES and BESS	31
6.7	Certificate of Origin for EV	32
6.8	Interactions	32
6.9	Technical Requirements	32
6.10	Societal challenges	33
7	Energy Regulatory Packages	34
7.1	Clean Energy Package and digitalization	34
7.2	Regulatory framework for Smart metering.....	35
7.3	Regulatory framework for energy communities	36
7.4	Regulatory framework for Flexibility.....	38
7.5	Regulatory framework for Certificate of Origin	41
8	ICT Regulatory Framework	43
8.1	General Data Protection Regulation	43
8.2	ePrivacy Directive and proposal	44
8.3	RED Directive	45
9	Blockchain Considerations.....	46
9.1	Smart metering	46
9.2	Energy Communities	47
9.3	Flexibility	49
9.4	Certification of Origin	51
9.5	Mobility	51
10	Conclusions.....	53
	References.....	54
	List of abbreviations and definitions	57
	List of boxes.....	59
	List of figures	60
	List of tables	61

Abstract

In this report, we analyse from a technical and legislative point of view the most promising applications of Distributed Ledger Technology to the electrical energy sector, as they were selected from the previous work performed in the AA between DG ENER and DG JRC, called Enerchain. Namely these use cases are smart metering, energy communities, flexibility services, certification of origin, and electro mobility. The outcome of the analysis is a short-list of conceptual applications of DLT to various trending topics and research areas in the energy sector. In this report we also describe the related energy regulatory packages, and ICT regulatory framework and discuss our blockchain considerations.

1 Introduction

In early 2019, DG ENER and DG JRC have signed an Administrative Agreement (AA), called ENERchain, in order to explore the area of “Blockchain Technologies in the Energy System”. The purpose of this AA is to investigate the applicability of blockchain technologies to the power sector assessing the actual potential of reaching greater accuracy, security, flexibility and money savings, which the technologies theoretically promise to bring.

In this report, we analyse the most promising applications of Distributed Ledger Technology (DLT) to the electrical energy sector. These applications were selected mainly on three steps. The first one was a literature review to assess the efforts and progresses of the research community, and it is presented in WP1. The second one was a survey aimed at better understanding the point of view of the industry and various other stakeholders. A questionnaire was designed and disseminated in 2019, and the numerical outcome of the survey as well as an analysis of the open-ended questions is presented in WP2. The third one was the use of the TIM (Tools for Innovation Monitoring) tool developed by JRC. This tool allows to search various publications and online content for specific topics using a keyword-based search engine.

The outcome of the analysis is a short-list of conceptual applications of DLT to various trending topics and research areas in the energy sector, which indeed correspond to the candidate use cases taken into consideration for actual implementation. However, this selection is not the final step, as the proposed use cases need to be assessed in order to verify their actual feasibility and concrete advantages that the DLT technology can bring in those specific cases. Therefore, only few of the technologies presented in this short list will be selected for further analysis and deeper research. This selection is guided by a qualitative assessment aimed at optimizing the relevance of the envisaged research output.

The landscape analysis consisted first in a systematic review of the initiatives applying DLTs to energy sector in the period leading to Q1 2020. This revealed the state-of-the-art in the DLT industry in the energy sector at the global level, with special emphasis on the European context, and allowed to identify four main categories of use cases:

1. General research efforts and multi-purpose DLT initiatives. This category includes research initiatives exploring the overall potential of DLTs, to DLT solutions addressing multiple types of applications in the energy sector.
2. DLT solutions for the control of industrial process for the production, distribution and accumulation of energy, especially electrical power. This includes grid management applications, flexibility services, metering, e-mobility, IoT and smart devices to manage the infrastructure of the electrical power grid.
3. DLT initiatives for new business models and financial applications in the energy sector. This category relates to applications such as billing, imbalance settlement, wholesale and peer-to-peer energy.
4. Use of DLTs for certification of asset ownership, proof of origin, green certificates and carbon credits trading. The fourth category focuses on the use of DLTs for the authentication, verification and certification processes of energy related assets, from electrical power produced to the devices producing it.

After the literature review, a survey was delivered to members of the EU Smart Grids Task Force [1]. The goal of the survey was to directly asking practitioners in this field to share

insights on their experience of developing DLT for the energy sector, and it was useful to highlight, among the other things, the challenges to be addressed for a successful adoption of DLT in the energy sector, such as for example scalability and privacy issues.

On the basis of the landscape analysis, for the purposes of this report it was possible to identify the most promising domains of application of DLT in the energy sector. In particular, five different use cases have been selected for further analysis and experimentation:

- Smart metering
- Energy communities
- Flexibility services
- Certification of origin
- Electro mobility

In general, these use cases are the most technically meaningful for appropriately testing and exploiting the potential of DLTs in their respective context. In addition, some of them represent the vast majority of cases in the landscape analysis (energy communities, with 40 projects), can count on an appropriate regulatory framework for compliance (e.g., flexibility services), or they were inquired to provide scientific evidence to further inform policymaking (Certification of origin, Smart metering, Electro mobility).

We analyse all five use cases from a technical and legislative point of view. In particular, chapter 2 describes smart metering which is the basis for all other use cases. Chapter 3 describes the three types of energy communities, while chapter 4 the flexibility use case. Chapter 5 analyses the mobility use case and chapter 6 the certification of origin. In chapter 7 we analyse the relevant energy related policies for all use cases and in chapter 8 the data protection related applicable policies. Since our focus is on blockchain and DLT, chapter 9 summarises how blockchain technology could satisfy the technical requirements set by the various use cases.

2 Smart metering

One of the most critical enabler components of a smart grid are the smart meters, which are electronic devices that register real-time consumption and generation of electricity, in a household or an industry, and send the data to the electricity retailer for monitoring and billing. Thus, smart meters play a key role in the smart grid, since they can provide useful information about the consumption and the consumer profile, which can lead to load prediction and load peak reduction. Moreover, the energy provider can use such information for possible consumption control through load-shifting. On the other hand, the smart meters can be a useful interaction tool between the energy provider and the end user, via which the consumers can be actively involved in reducing their consumption [2]. Indeed, smart metering is considered to be crucial in enabling electricity customers not only to monitor their actual consumption, but also to interact with their energy provider, e.g. responding to market signals like price surges by shifting electricity consumption (load shifting) or selling electricity generated at home e.g. through solar panels to the market. It has also an important function in allowing the consumers to switch provider within a short timeframe, enabling a fair competition among energy retailers. Figure 1 shows the high level concept for smart metering applications as has been defined in [3].

In more detail, smart metering applications use either wired or wireless transmission medium to communicate with the appropriate entities. A popular wired technology deployed in the energy section is Power Line Communications (PLC), which refers to the use of the existing power lines for the signal transmission. A benefit of this technology is that there is no need for new infrastructure. PLC technologies can be classified into two categories: Broadband PLC (BB-PLC) and Narrowband PLC (NB-PLC) [3]. Two popular technological solutions for NB-PLC are the PRIME [4] and G3-PLC [5] specifications, which constituted the main basis for the standards proposed by ITU and IEEE [6].

Different wireless techniques can be used depending on the type of signal transmission examined, like the ZigBee [7] or cellular wireless technologies. In general, there are two links for transmitting data from the smart meter to the control centre: the first link carries data from the smart meter to a data concentrator whereas the second link connects this data concentrator to the data centre [8]. In the rest of the report, we refer to these links for smart meter data communication as “first” and “second” link.

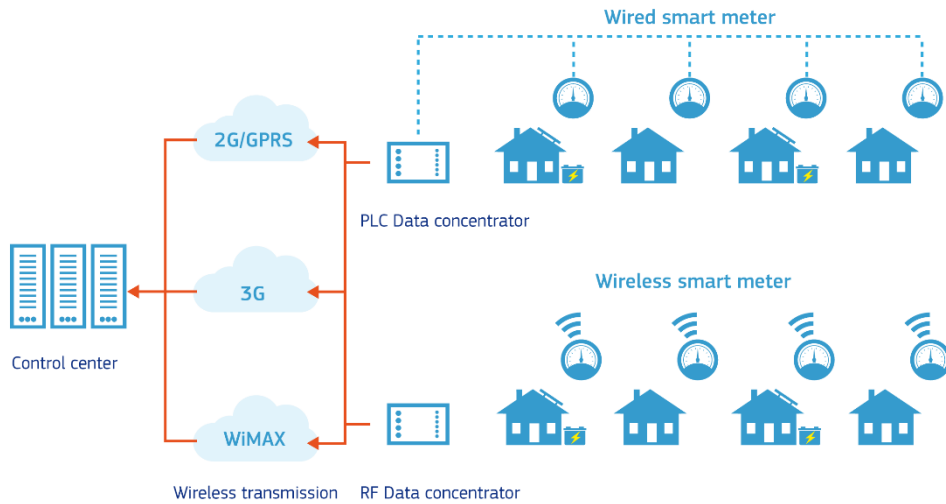


Figure 1. AMI—Communication from the smart meters to the utility system with several technological solutions

Smart meters enable directly or indirectly many applications in the smart grid framework, among others: Demand Side Flexibility/Demand Response; energy management; remote load scheduling; distribution grid monitoring. Moreover, they are necessary for consumers' empowerment, through consumptions awareness enabling them to be actively involved in the smart grid. For the above reasons, a thorough smart metering roll-out is seen as an important step towards innovating the electricity grids and markets and has been the object of several policy interventions at European level.

2.1 Actors

Smart metering applications involve different actors, since smart meters are the basic element for numerous smart grid applications. Table 1 gives an overview of the actors that can interact with Advanced Metering Infrastructure systems (AMI) [9]. These actors can be systems, devices or physical persons.

Table 1. Actors description in the context of AMI.

Actor	Description
Actor A	External actor (Smart Grid Market Role) interacting with the system functions and components in the home or home automation network through the energy management communication channel. Examples of such market roles are the Energy Provider, the Energy Services Provider, the aggregator, etc.
Actor B	External actor (Smart Grid Market Role) interacting with the system functions and components in the home or home automation network through the metering communication channel. This actor is responsible for collecting metering data. Examples of such market roles are the DSO, metering company, etc.

Consumer	Person(s) that consume electricity measured by smart meter
Customer Energy Management System – CEMS	Exchanges information with smart meter to control devices at home
Energy Management Gateway (EMG)	Gateway interacting with CEMS and Actor A
Head End System - HES	System collecting smart meter data to forward them to the hierarchy for processing
Home Automation End Device – HAED	Device interacting with the CEMS and controlling a (non-smart) appliance in home
Local Network Access Point – LNAP	Point interacting with the smart meter for data transmission
Meter Data Management System – MDMS	System that processes smart meters data
Neighbourhood Network Access Point – NNAP (also seen as Data Concentrator)	Point interacting for data transmission
Simple External Consumer Display - SECD	Display showing to end-customer information, i.e. his/ her consumptions
Smart Appliance	Appliance within home that interacts with the CEMS
Smart Consumer Application	Application that enables the end-customer to interact with the Actor A (i.e. giving consent for DR programs)
Smart Meter	Core element

2.2 Interactions

According to CEN/CENELEC [10], some of the above actors and their interactions can be summarized in Figure 2.

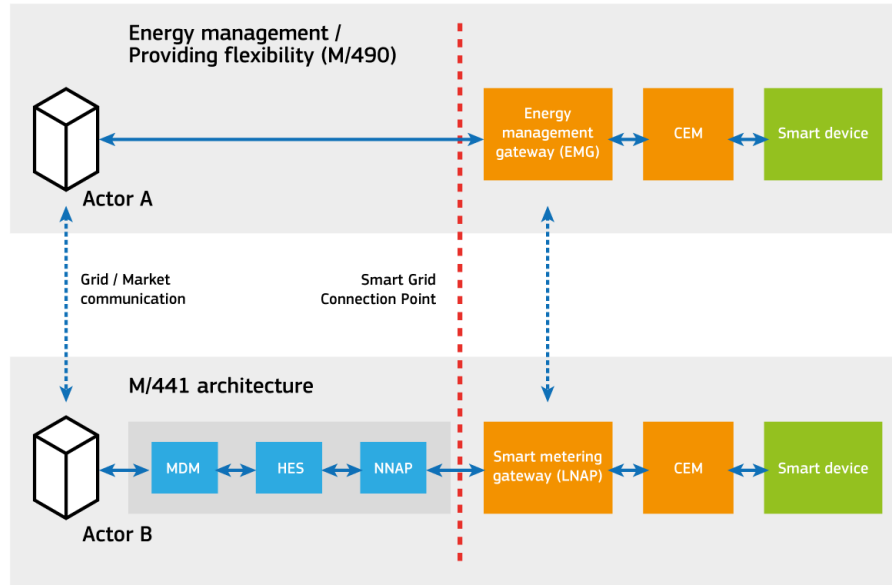


Figure 2. Energy management functional architecture [10]

In order to depict the interactions of the majority of the actors depicted in Table 1, we created the Message Sequence Chart (MSC) that can represent sequential interactions (Figure 3). This MSC can represent remote load scheduling applications or Demand Side Flexibility applications.

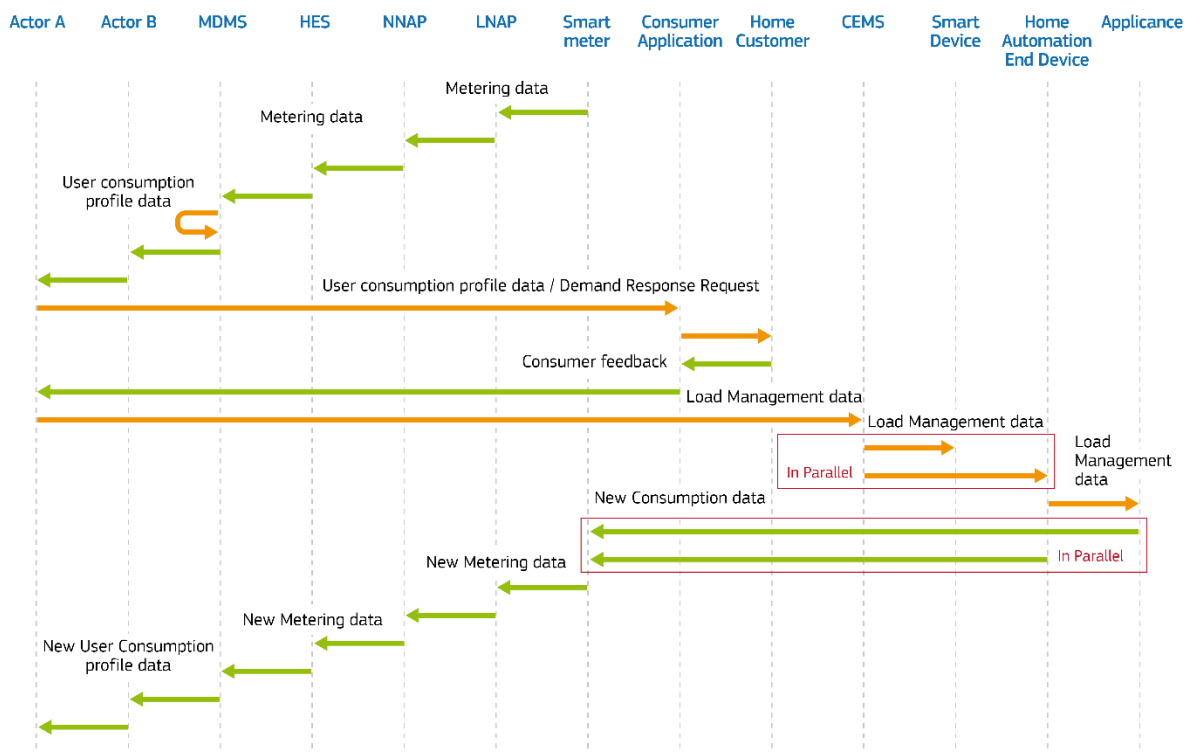


Figure 3. Message Sequence Chart showing interactions between actors for DSF actions [9].

This figure shows that information from smart meters is collected firstly at data concentrator level (LNAP), travels higher in the hierarchy and is finally collected by the actors that control

the metering and energy channels. In order for flexibility programs to be realised, a signal needs to be sent to the customer in order to ask his/her permission for participation to the program. Once the customer agrees, a signal is sent to CEMS, which can program the function of the electrical devices in automatic way. After the devices are programmed and the new consumption pattern is realised, the new data is sent to the smart meter and the flow of data restarts.

In case interoperability is examined, it is important to use the SGAM framework (Smart Grid Architecture Model), which depicts the five interoperability layers. The SGAM facilitates the testing procedure for interoperability purposes. For reasons of completeness, we depict the actors described above, on the SGAM component layer. This way, we represent how the actors are placed on SGAM and how they interact, thus providing information for interoperability testing purposes. Figure 4 shows this representation.

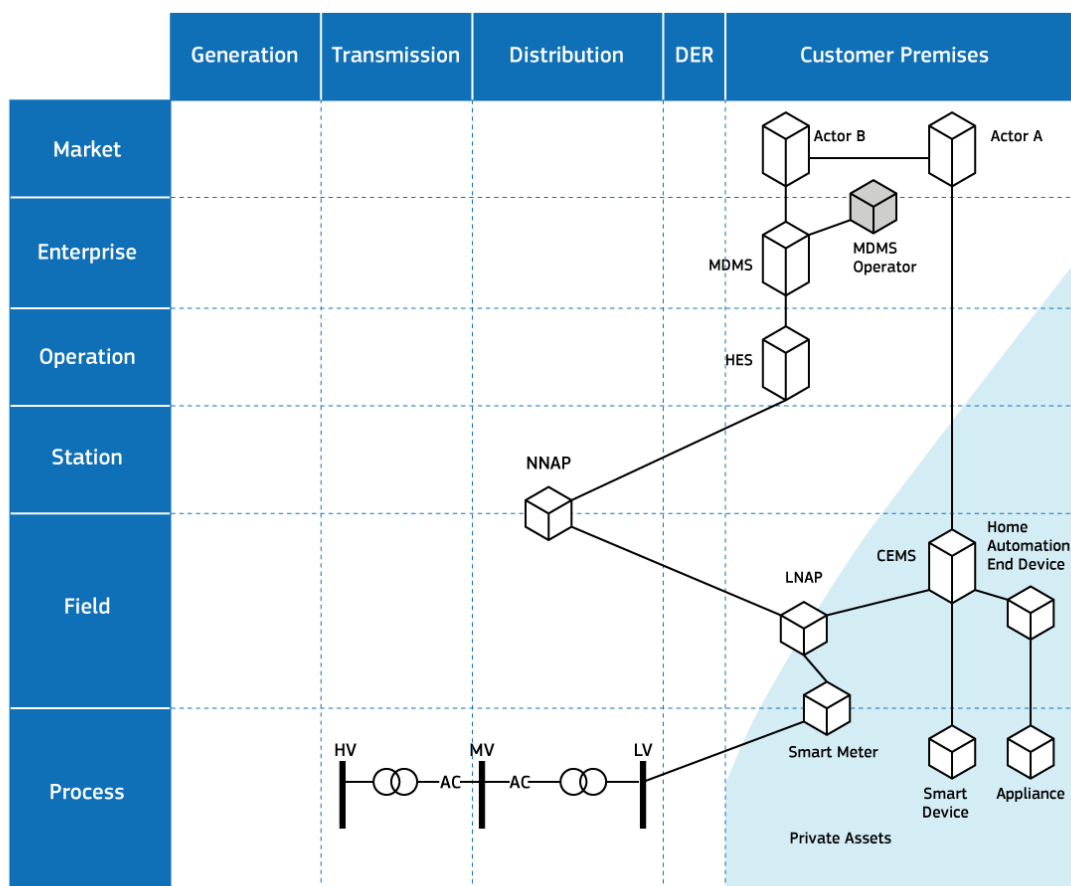


Figure 4. Representation of Actors in the SGAM framework and their interactions [9]

Please note, that the representations (SGAM framework and MSC) can be simpler depending on the application that is necessary to analyse. For instance, if we are interested only in the simple interaction between a smart meter and a data concentrator (NNAP), then Figure 5 can be used for the SGAM representation.

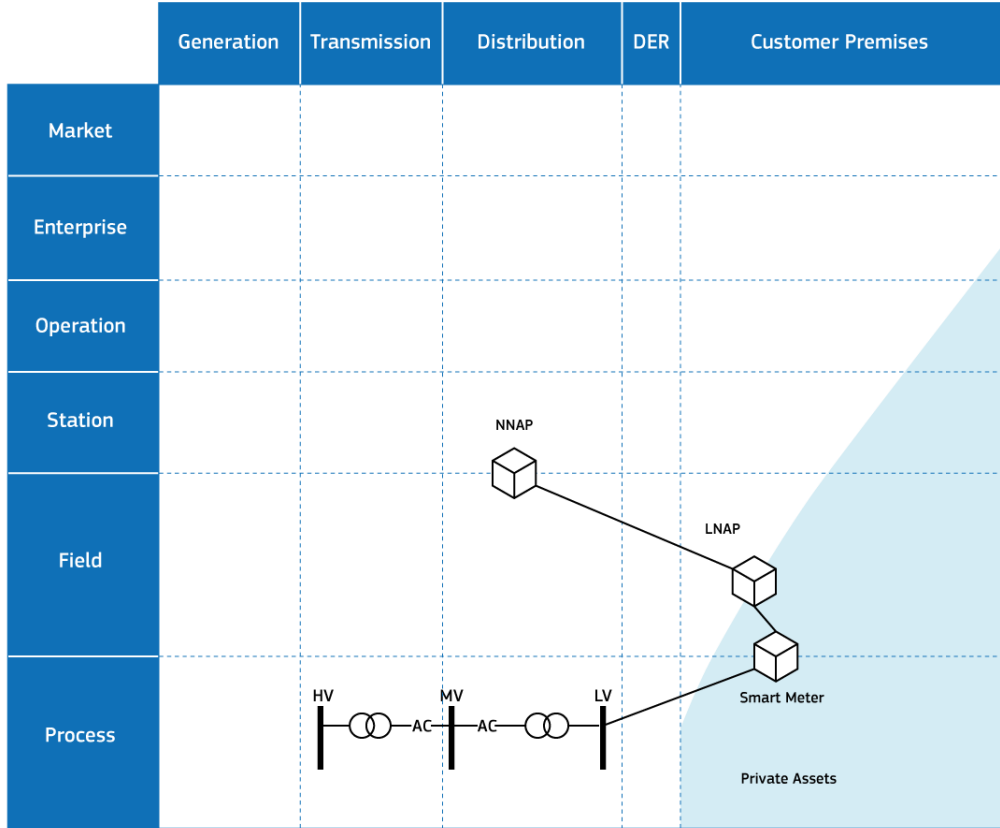


Figure 5. Representation of Actors for the simple interaction between a smart meter and a data concentrator [11]

2.3 Technical requirements

Providing accurate and timely measurements is essential for the reliability of any energy system. Thus the integrity (SM-T-R1), and authenticity (SM-T-R2) of the smart meters' data must be guaranteed. The frequency, the way and the information communicated between the involved entities vary depending on the use case. However, it should be stressed that users' privacy (SM-T-R3) could be violated when high frequency granularity smart metering data is enforced [12].

The hierarchical smart metering architecture (SM-T-R4), which AMI requires, should be supported. In fact, the LNAP communicate the data collected from smart meters are sent to NNAP, and then to HES who shares them with the appropriate actors.

In this point it should be mentioned that several communication technologies can be used for smart metering applications. For example, we can have wired or wireless technologies that entail various options in terms of protocols, standards, and technological solutions. For instance, if a smart meter uses a specific technology, then the whole (smart metering) system is built to support this technology. Hence, all the components (i.e., LNAP, NNAP) should be compatible, otherwise system components are not able to exchange the corresponding information. In order to support multiple protocols at least add-ons should be deployed and configured to the required components. Therefore, network interoperability (SM-T-R5) should be guaranteed in order to eliminate the gap between the different available technologies.

2.4 Societal challenges

When dealing with smart meters, there are also societal challenges entailed. Smart metering acceptance is an important issue and, in many occasions, people are sceptical with smart meters installation at their homes. Reasons for being opponent can vary, and some of them are listed as follows:

1. Fear for health implications due to radiations
2. Fear for personal data misuse => consumption data can reveal information about when people are present or not at home, thus being subject to thefts
3. Lack of trust between consumer – energy provider (see point 2)
4. Fear of system hacking – data theft
5. Lack of knowledge of new technologies and limited capability to handle smart meters, home devices, etc.

All the factors listed above are important and can result in significant opposition from the public. This can result in hindering smart metering roll-outs. Examples of opposition can be found in the UK and the Netherlands [13], [14]. Specifically in the Netherlands, the option to deactivate the communication module was given to customers in order to tackle with opposition.

3 Energy Communities

The energy distribution network has traditionally been considered a “natural monopoly” because the infrastructure required to carry electric energy to the final user is such a large and complex investment that is not considered economical to replicate. The same used to apply to energy production. Few large power plants were operational and the technology and investment needed to operate such infrastructure was off-limits for most citizens and companies. As a result, the electric market initially evolved as a fully integrated network. A single operator would take care of all the aspects of the energy cycle and the consumer would have to comply with the rules set forward by the monopolistic operator and later on by the legal regulations put in place by states and local administrations.

Market liberalization however has started to de-couple the production of energy from its transport, transformation and conditioning. The IoT revolution has made network-connected energy metering economical for the average household and small business types. Another important factor is the availability of small-scale energy generators (photovoltaic, wind turbines, renewable thermal, co-generation etc.) that operate across Europe. The final and most recent enabling factor is the availability of powerful and inexpensive energy storage. Li-Ion and Li-Po batteries have recently become very popular due to their decreasing cost and increasing capabilities in terms of energy density, power density, durability and reliability. Moreover, the recent boom of electric powered vehicles has brought as a by-product the availability of ample storage capacity to the household.

This entire technological advance has led to the creation of a new actor in the energy domain, the prosumer. The prosumer concept combines the traditional role of energy consumer with that of energy producer and storage capability. In order for the prosumer to reap the benefits of independence, flexibility and economical gains promised by current technological revolution, a new paradigm shift is needed both technically and most importantly from a new policy and regulatory framework point of view. To this direction, energy communities have been proposed in [15] providing an alternative approach for energy exchange. An energy community can be defined as a group of energy prosumers that agree to locally exchange electrical energy via a common power bus, in which each prosumer can operate a number of power nodes.

Depending on the needs, the configuration different architectures can be deployed. For the scope of this research, we have identified three types of possible networking solutions for the electric communities of prosumers:

- a) peer-to-peer energy exchange,
- b) community shared balance storage,
- c) and peer-to-grid paradigms.

A fundamental difference between an independent peer-to-peer community and a peer-to-grid configuration is that in the first case peers have to manage a regulated access to the power bus, since they cannot rely on a third party that would guarantee a proper level of quality on the main (synchronisation, voltage frequency, load balancing, etc.). The shared storage concept is a particular case of peer-to-peer where all the metering and regulated access to the main bus are managed by a centralized unit capable of storing and dispatching energy to the community members. In the following paragraphs, all three typologies are described in detail.

3.1 Peer to peer energy exchange (micro-grid)

The peer-to-peer electricity community is a use case where a group of prosumers exchange electricity among themselves in an autonomous fashion. The community is autonomous in terms of electricity production, management of the internal operations and exchanges. Although the community can be completely independent and disconnected from a network operator (island model), in most of the cases it would still connect to a main grid in order to interact with it or with other communities.

Figure 6 displays the physical structure of a community. Electrical nodes connect with each other through a common electricity bus. Exchanges to and from the bus are recorded by a smart meter that are placed at the interfaces of each node's infrastructure (household, farm, factory etc.) to the rest of the network. Further meters owned by a node might be installed on the main line for verification purposes.

The purpose of the energy community is to offer to the end user the maximum flexibility in sourcing its energy needs. Energy efficiency and economic efficiency are the key parameters to be optimized in this case.

Energy efficiency is obtained by allowing prosumers to trade energy locally within a geographically limited area. This leads to greater efficiency as electricity does not have to travel long distances but it is kept, as much as possible, confined in a local grid. Interaction among equal peers is fundamental for managing and scheduling energy transactions and for metering and accounting for such transactions. The whole community in turn can rely on an external TSO or DSO for backup, last resort destinations and for managing load balancing and energy security. The community can interact with the outer world through this external link. The same link is needed for connecting multiple communities, aggregate them and replicate the same structure at a bigger level, similar to a fractal symmetry.

Economic efficiency derives from the possibility of having local exchanges among peers in the community (or in different interconnected communities), which can trade their own energy production and offer it at prices and conditions more convenient to those of a traditional operator. Prosumers can also create or access various energy venues for maximizing market efficiency.

A simple set of rules defines the behaviour of the energy community:

- Energy community has a limited number of nodes sharing a common main frequency and a common power bus
- Each node can generate, consume, and store energy
- Each node declares a maximum power for both injection and withdrawals as well as a maximum energy storage capacity for the battery
- Each node provides metering on all interfaces to the common bus
- Some nodes provide redundant power measurements

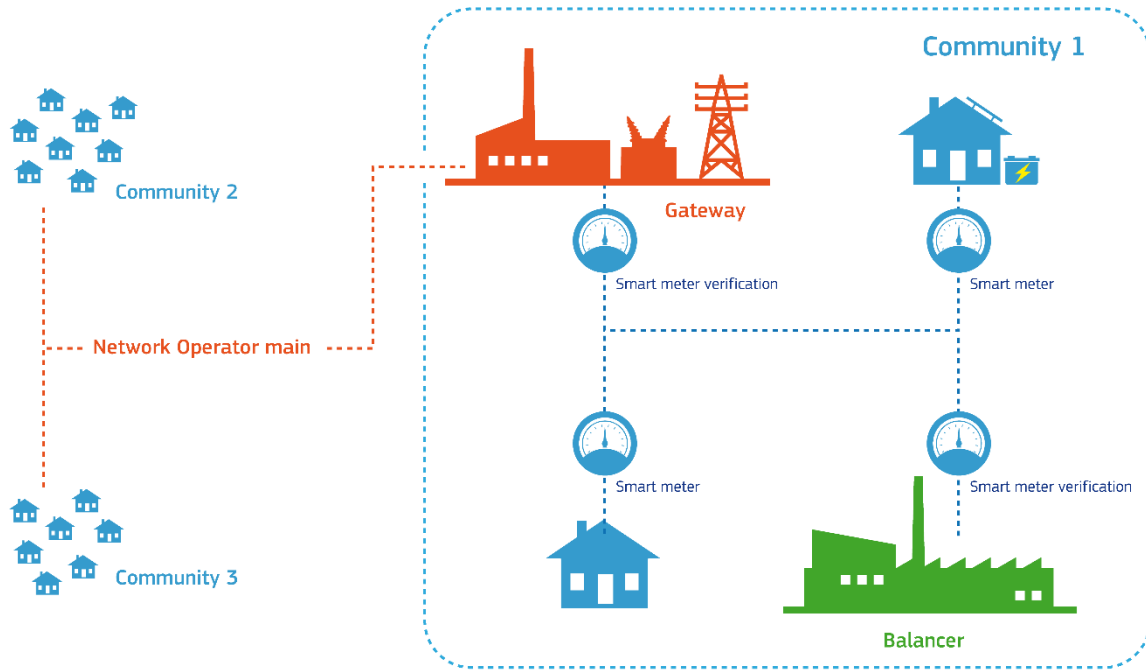


Figure 6. Structure of a peer-to-peer electricity community and possible interconnection with a Network Operator and other communities.

3.1.1 Actors

The actors involved in this use case are:

Prosumer nodes. It can be a household, a commercial facility, an industry, etc. It is capable of consuming electricity and possibly to produce it with renewable sources or store it. A node is composed of a power subsystem and a data processing node controller subsystem.

Energy communities. As prosumers get together to form a community, several communities can participate in a bigger energy network that includes a variety of actors

Distribution System Operator. The DSO can act as an external energy balancer, dispatcher or lease metering capacity to the community.

Transmission System Operator. The TSO can connect two or more energy communities or a community with an external power network. It does not intervene in the internal operations of a community.

Smart Meters. All actors identified in the smart metering use case are also applicable here.

3.1.2 Interactions

The node controller subsystem collects continuously information from its own smart meters and from the common verification smart meters. The power subsystem physically connects to the common power bus to either inject or withdraw electric power. The node controller then broadcasts to all other community nodes its smart meters readings flagged with the direction of power flow. Once the power transfer terminates, the node controller proposes a transaction in the current block. The transaction contains two timestamps, node id, direction flag, and total energy. A verification is then performed, any node controller in the community can be the verifier. The node that produces the highest number of readings from the smart

meters is the validator. It employs a control equation based on the electrical network topology to validate the amount of energy exchanged. Once the validation conditions are fulfilled the other node controllers can either approve or disapprove the transaction. In the former case a further monetary transaction can then be triggered by a smart contract. Additional interactions are required in case of a non-approved transaction, a periodic settlement of imbalances and disapproved transaction can be used for compensating such misalignments.

3.2 Community shared balance storage

An energy community that shares a centralized neighbourhood battery for energy storage and dispatching for the community needs, the battery storage acts as a balancing (buffer) unit. Whenever there is excess of generation in the community the battery charges and whenever there is an excess of consumption it discharges. The monitoring of the incoming and outgoing energy is done through the community members' meters, whose power sum must be equal to the net value of the storage unit meter at all times. As an example, if House A generates and injects in the system 5 kW of PV power and house B consumes 4 kW, then the net value of power in the battery storage meter must be 1 kW. This measure ensures anti-fraud cooperation and verifies that the energy balance would approximate always to zero considering the limitation of the instruments' precision measurements. The high level architecture for this configuration is presented in Figure 7.

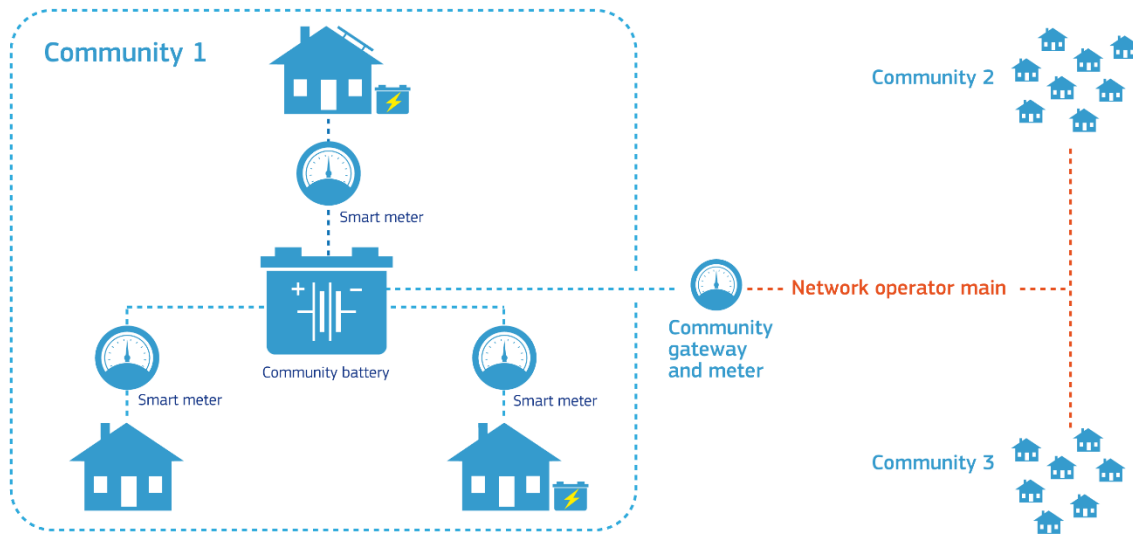


Figure 7. Structure of a shared storage electricity community and possible interconnection with a Network Operator and other communities.

3.2.1 Actors

The actors in this use case are:

Prosumers: It can be a household, a commercial facility, an industry, etc. It is capable of consuming electricity and possibly to produce it with renewable sources. A node is composed of a power subsystem and a data processing node controller subsystem.

Central storage: The central storage is a common shared infrastructure that can in turn interact with external TSO and DSO.

Smart Meters: All actors identified in the smart metering use case are also applicable here.

3.2.2 Interactions

The prosumer power node physically connects to the common power bus to either inject or withdraw electric power. The central battery collects continuously information from all smart meters

3.3 Peer to grid

The peer to grid use case refers to the scenario where a prosumer exchanges energy with a DSO or other peers via the DSO energy grid. This setup is presented in Figure 8.

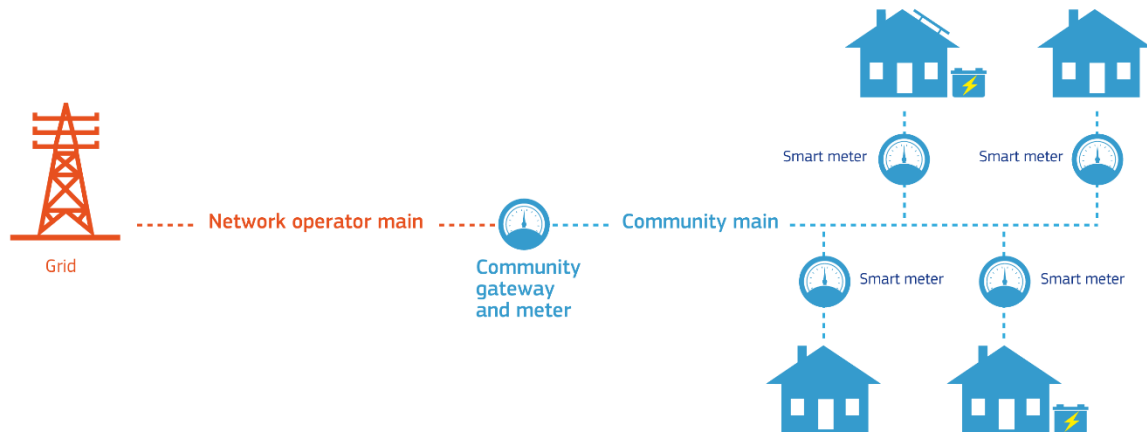


Figure 8. Structure of a peer-to-grid electricity community and possible interconnection with a Network Operator and other communities.

This is the simplest energy community scheme and it partially corresponds to an existing situation in many European countries. The subsidized prices of photovoltaic systems have allowed many households to install solar roofs or other forms of photovoltaic generators. If at any given time the energy produced is greater than the energy consumed locally, the extra amount generated goes back to the main grid. In such a case there is no need for:

- (a) coordination between the consumer and the grid operator, other than a fixed rigid maximum power allowed.
- (b) energy balancing or power quality management as the grid operator takes care of that, and
- (c) for local storage of energy and limited usefulness for intelligent load management

There are two basic payment schemes in this use case. In the first one, the peer is paid (feed-in tariff) every predefined period for the total energy that was injected to the grid. In the second scheme (net metering), a balance of the energy injected with the one consumed by the peer is calculated. Then the peer will need to pay for the excess, if any.

3.3.1 Actors

In this use case there are the following actors:

Prosumer nodes. It can be a household, a commercial facility, an industry, etc. It is capable of consuming electricity and possibly to produce it with renewable sources or store it. A node is composed of a power subsystem and a data processing node controller subsystem.

Distribution System Operator. The DSO can act as an external energy balancer, dispatcher or lease metering capacity to the community.

Transmission System Operator. The TSO can connect two or more energy communities or a community with an external power network. It does not intervene in the internal operations of a community.

Smart Meters. All actors that apply to the smart metering use case, are also applicable here.

3.3.2 Interactions

The node controller subsystem collects continuously information from its own smart meters and the DSO collects continuously information from the common verification smart meters.

The node power subsystem physically connects to the common power bus to either inject or withdraw electric power. The node controller then broadcasts to all other community nodes and to the DSO its smart meters readings flagged with the direction of power flow.

The DSO monitors and verifies the correctness of the information. In fact, DSO employs a control equation based on the electrical network topology to validate the amount of energy exchanged.

3.4 Technical Requirements

For the provision of energy communities use cases at large scale, without loss of generality, the system should be able to handle a large number of participants (ENC-T-R1), a high throughput of transactions (ENC-T-R2) and the handling of any *sensitive-personal* data according to the underlying policy framework (ENC-T-R3). In fact, the key requirements for an energy community to properly function are:

- a) **Trust** (ENC-T-R4): A key aspect for energy distribution is the need to establish trust among the different participants and components. In a case of a fixed contract with a single grid operator trust might be considered as guaranteed between the involved parties. However, in the case of energy communities, there is a high need to trust multiple entities (i.e., prosumers, DSO, TSO, etc.). Moreover it should be noted, the trust and reliability of the metering systems are of paramount importance since they are providing the actual values for all the supported functionalities.
- b) **Regulated access to the power bus** (ENC-T-R5): This aspect is crucial for a change in the paradigm, and it includes the aspects of stability, power quality, reliability and economic conditions. These are the technical requirements that can allow prosumer access to the energy spot-market or allow them to trade energy locally.
- c) **Transparency and Security** (ENC-T-R6): It is technically possible to fine-tune the behaviour of various power-consuming appliances in order to balance the local energy grid or to take advantage of energy abundance or scarcity. It is also possible to set aside a percentage of the total available energy and lease it to the community or to a third commercial partner. These potential benefits need transparency and security in order to be available to the energy community.

- d) **Direct data exchange and verifiability** (ENC-T-R7) for all the supported functionalities. Depending on the energy community service, the constant monitoring of physical parameters such as voltages and loads in the context of the provided services might be required.
- e) **Measurement noise** (ENC-T-R8) for the smart metering systems should be kept under control and below certain limits.
- f) **Management of the community main and access to it** (EN-T-R9): when independent from a network operator, peers have to manage their own main electricity bus. This includes:
 - ensuring electricity quality in the network (e.g. voltage peaks, frequency, etc.);
 - coordinating the access of peers that want to inject or take electricity (e.g. via a booking systems or fixed timeslots);
 - providing a balancing system towards an external main (managed by a classical network operator) and/or other communities (to make sure that excesses of production can flow to the external or additional energy can be imported when needed).
- g) **Ensuring robustness against malicious peers or faulty meters** (EN-T-R10): in order to correctly track the energy exchanges, it is fundamental that readings about energy injected or withdrawn by any of the peers are true.

3.5 Societal challenges

Cost of the infrastructure. The setup and installation of the additional equipment needed to participate in the community (in house electricity generation, IT infrastructure for node controller, smart meters, and energy storage technology) could be considered too expensive compared to the promised benefits and represent a barrier for the majority of people, which would still depend on a traditional energy supply.

Trust in the energy community and technology divide. Many users could perceive the use of any ICT system as a technological barrier, or could have a lack of trust in the energy community infrastructure in general. Therefore, there is the need to promote and highlight the actual benefits of building innovative technologies in energy sector with focus to energy communities in order to increase trust, and it is fundamental that the whole system is user-friendly.

4 Flexibility

Two customer market intermediaries, aggregators and citizen energy communities, are defined in the 2019 Clean Energy Package (CEP) [16], with provisions on their regulatory framework, roles, and duties aiming to group the energy generation or consumption of several consumers. In this context, an aggregator is acting as an energy service provider which has the capacity to manage consumers' electricity needs and provide demand-side flexibility to the grid. Aggregation can be carried out by traditional energy service providers such as suppliers, or by new entrants such as independent aggregators. In practice, when consumers engage with an independent aggregator, they have one contract with the supplier and a separate one with the aggregator.

The procurement of demand response (DR) services is already a reality throughout Europe but explicit DR is still only in some European countries, as illustrated in Figure 9. The system operators currently request flexibility services to large units (mainly industrial actors) to vary their loads according to an identified need. This can be done directly or most typically through an aggregator actor that has a large portfolio of assets and coordinates the events, load triggering and settlements by taking a small fee for the service. Until now, the task of managing a few hundred loads has been manageable with traditional tools, such as SCADAs, direct meter reading and transparent access of portals or platforms between aggregators and TSOs.

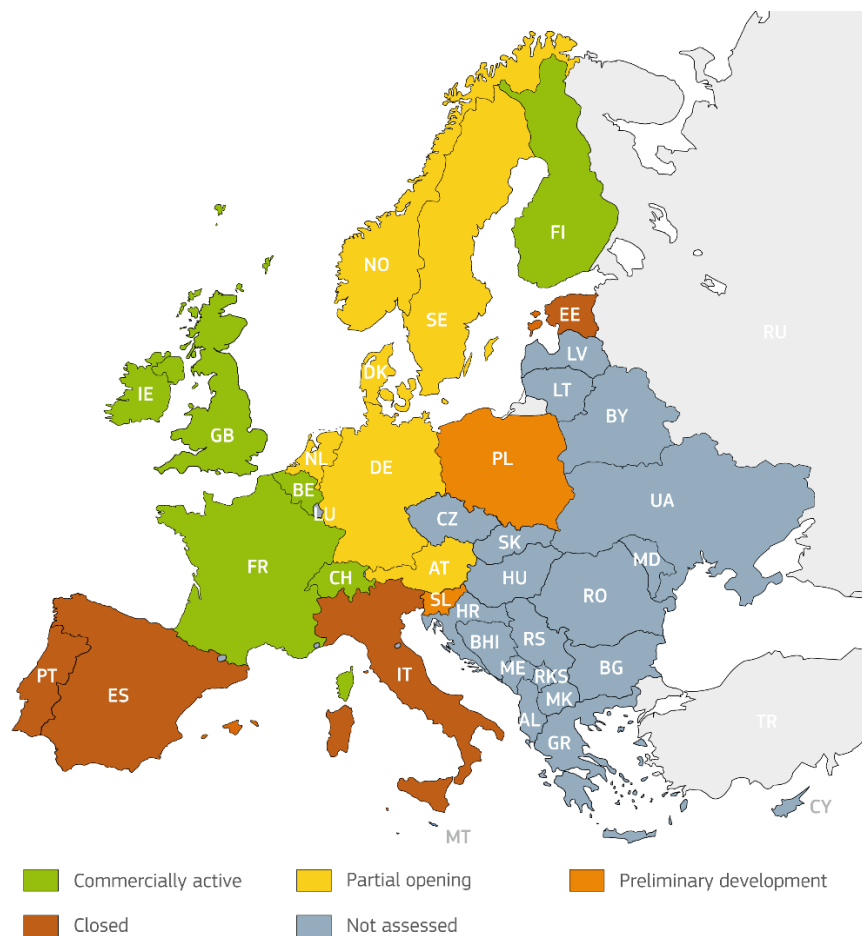


Figure 9. Map of Explicit Demand Response development in Europe today [17]

In European markets, there are few examples of independent electricity aggregators engaging with commercial or residential consumers. However, with the emergence of consumer empowering, new technologies and the adequate regulatory framework, residential flexible electricity consumption will become more commercially attractive for aggregators and vice-versa. This will mean a higher order of magnitude when it comes to contract management, data exchange and settlements between all participants.

TSOs are typically the entities supposed to request DR services, as they are in charge of assuring the grid stability. However, the CEP describes the participation of DSO on this task as well and defines the conditions under which DSOs may acquire flexibility services without distorting the markets for such services. It includes clear provisions that will enable DSOs to manage local grid issues and enhance the security of supply (SoS) through flexibility procurement. Figure 10 shows the high-level architecture and actor interaction.

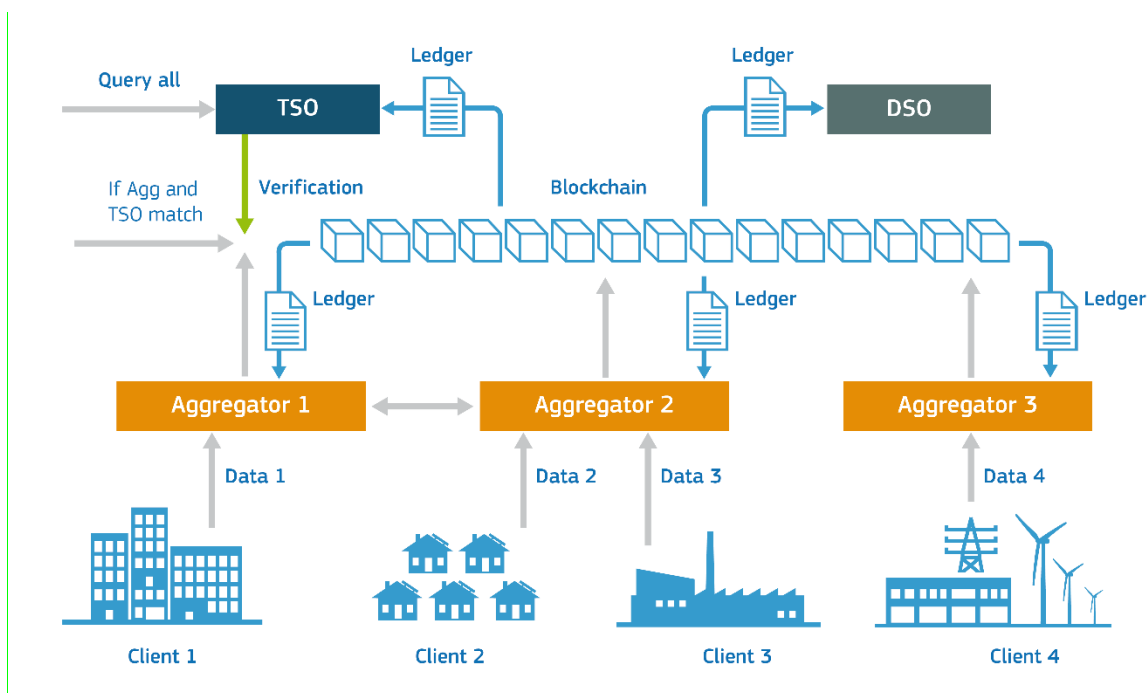


Figure 10. Explicit DR hierarchical structure of data sharing between actors

4.1 Actors

Aggregators: An aggregator is an energy service provider which can change the electricity consumption of a group of electricity prosumers and provide demand-side flexibility to the grid.

Prosumers: It can be a household, a commercial facility, an industry, etc. It is capable of consuming electricity and possibly to produce it through solar panels or wind turbines. Two or more prosumers connected with each other form a community.

TSO: The Transmission System Operator is an organization responsible for operating and maintaining the high voltage grid. It is also responsible for developing the transmission system in a given area and its interconnections with other systems. It is the responsible entity for the stability, quality and reliability of the electricity provided assuring a continuous balance

between demand and supply. It makes use of different mechanisms to do so, such as the balance market, ancillary services or even capacity mechanisms.

DSO: The Distribution System Operator transport electricity on high-voltage (some levels in some MS), medium-voltage and low-voltage through the distribution systems with a view to its delivery to customers, but does not include supply. The commercialization/supply is done by the retailers. DSO are however able to put in place mechanisms to solve congestion constraints.

Smart Meters: All actors identified in the smart metering use case are also applicable here.

4.2 Interactions

Figure 11 presents the UML sequence diagram that depicts the interactions between the involved actors for the flexibility use case. In a typical operation an aggregator has buckets or portfolios of assets of different characteristics such as power, energy, ramping up/down time, which are made available to the TSO. Upon a request by the TSO with a specific amplitude and duration (which is specified in a market bid/offer), the Aggregator rechecks the availability of flexibility of its assets and the delivery occurs by setting the loads/assets to a desired/allowed level. This is achieved by a device which acts directly on the asset's programmable features. Many of the assets have discrete levels of settings. This is a feature which is often identified as standardisation gap, and will be useful for smaller devices (to be DR ready). However larger devices, either have a continuous nature of adjustment such as a storage system or if they are discrete, these levels are sufficiently large to cause a sudden consumption reduction/increase.

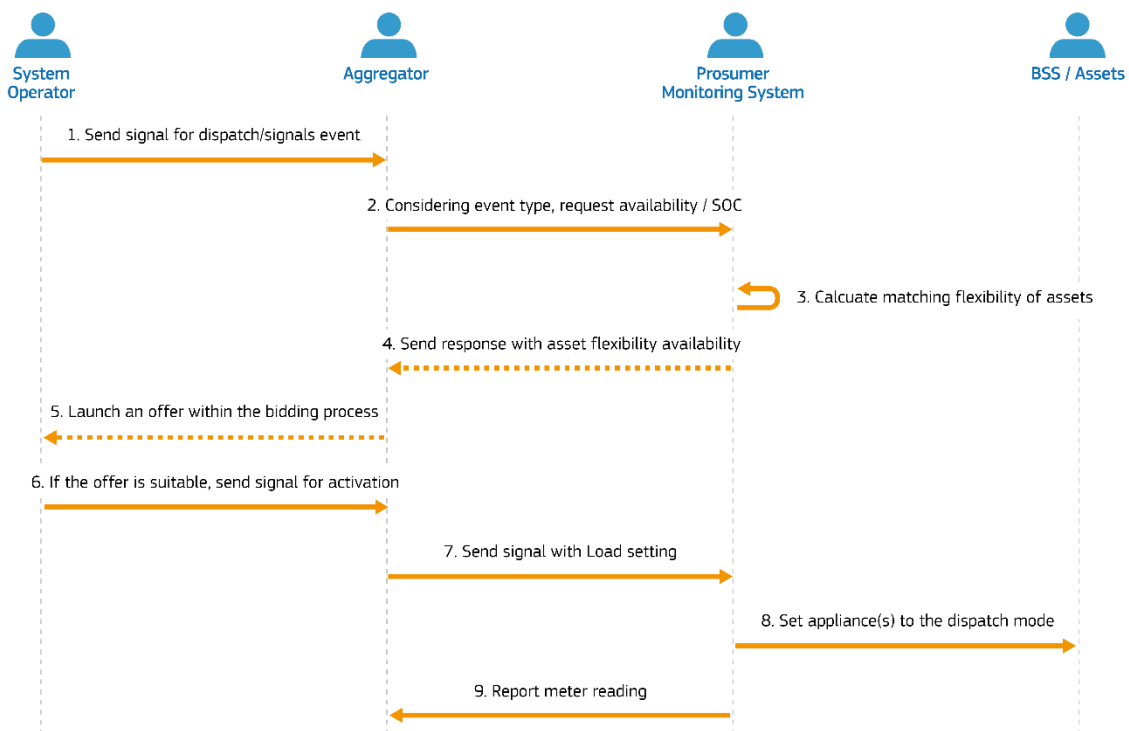


Figure 11. UML sequence diagram for the “Automated DR services

After the event takes place the TSO must confirm that the reduction was actually performed and imbalance prices must be determined. However, if this is done for example through a balance energy market considering current approaches it is not a straightforward procedure. In fact, the service providers/parties are first billed for imbalance charges approximately one month after the settlement day, for which the charges were incurred. The systems carry out subsequent reconciliation runs over the next 13 months, which update the imbalance charges by replacing any estimated data with actual metered data. For the relationship between the TSO and an aggregator, an open and transparent interaction between platforms is required. This is how the TSO ensures that the assets were ordered according to a certain event. However, this is unlikely to be effective when the number of loads and events increase.

4.3 Technical requirements

An automated demand side response (DSR) mechanism for providing flexibility services is driven by some generic business objectives such as:

- **Increase customer base and adoption rates** by providing a secure platform (FL-T-R1). Security concerns amongst DSR end-users is a significant barrier for adoption of such services. Providing a secure way to communicate and deploy control strategies to assets as well as audit transactions (FL-T-R2) should give adoption rates a boost.
- **Increase the efficiency of the aggregation service** by enabling autonomous, computer to computer contracting (FL-T-R3). As the DSR services and market become more dynamic, there is an increased need for automation of decision making for allocation of flexibility services to the best paying markets, however in the absence of an audit trail this can be risky.
- **Secure data share mechanism** (FL-T-R4) that enables all the involved entities to provide the underlying services

4.4 Societal challenges

The involvement of prosumers and citizens in the electricity market could unleash a trend of efficiency and a smarter use of energy. Even though no major changes to personal life would be made with large scale explicit DR, some technological adaptations would have to be carried out. The system to trigger a load adjustment would have to be installed for example. Close to real time readings would be required, as well as information disclosed, which could be very intrusive, showing individual's behaviour and consumption patterns. Levels of comfort would have to be agreed upon with the aggregator and the cost of infrastructure to bear is so far unclear.

Moreover, the financial compensation for such services are expected to be negligible and some doubts exists on how citizens could be engaged without "significant" incentives. Social platforms with scoring mechanisms, offering complementary discounts in services could be introduced to promote the participation. Main challenges enabling large scale demand response refer also to establishing reliable control strategies and market frameworks so that the demand response resources can be used optimally. In the end its success and adoption will depend on the business models developed and partnerships that companies will put in place.

5 Mobility

Transport accounts for a quarter of the EU's greenhouse gas emissions, and still growing. To achieve climate neutrality ambitions stated in the EU's Green Deal, a 90% reduction in transport emissions is needed by 2050. Road, rail, aviation, and waterborne transport will all have to contribute to the reduction. Achieving sustainable transport means putting users first and providing them with more affordable, accessible, healthier and cleaner alternatives to their current mobility habits.

Automated and connected multimodal mobility will play an increasing role, together with smart traffic management systems enabled by digitalisation. The EU transport system and infrastructure will be made fit to support new sustainable mobility services that can reduce congestion and pollution, especially in urban areas. The Commission will help develop smart systems for traffic management and 'Mobility as a Service' solutions, through its funding instruments, such as the Connected Europe Facility. The demand for data capturing by automotive manufacturers is creating a shift in the traditional mobility business model. To capture this data, vehicles are starting to have their own digital identity. For instance, the transactional data from re-fuelling at a gas station is currently on a credit card, but soon will be housed on a digital wallet owned and operated by a car. This car could generate its own income through a service model and pay for its own fuel, maintenance, and other services.

5.1 Car-Wallet and Payments

For the scope of this report, we analyse below a specific use case comprising a car-wallet and payments to either direction, i.e. V2G or G2V. The use case refers to an EV connected to a V2G charging station (CS) (Figure 12), which charges/discharges in a smart way, based on a price signal. We assume that the Distribution System Operator faces an issue in its distribution grid, where the charger is connected, for example congestion, over/under-voltage, etc. To mitigate this issue the DSO can utilize the flexibility of a V2G connected EV by sending a price signal (or a power profile) that will trigger the car to either charge or discharge at a specific power level. Assuming that the V2G CS is installed in an office building parking lot, the signal from the DSO has to go through the Energy Management System (EMS) of the building or an aggregator, which along with the building energy consumption might operate multiple CS in the parking, towards the specific CS that the EV is connected to. In case the EV charges, a payment will be done to the aggregator/retailer, while if the EV discharges the aggregator will reimburse the EV owner. For the payment a digital wallet is used and a DLT holds the records of the balancing transactions.

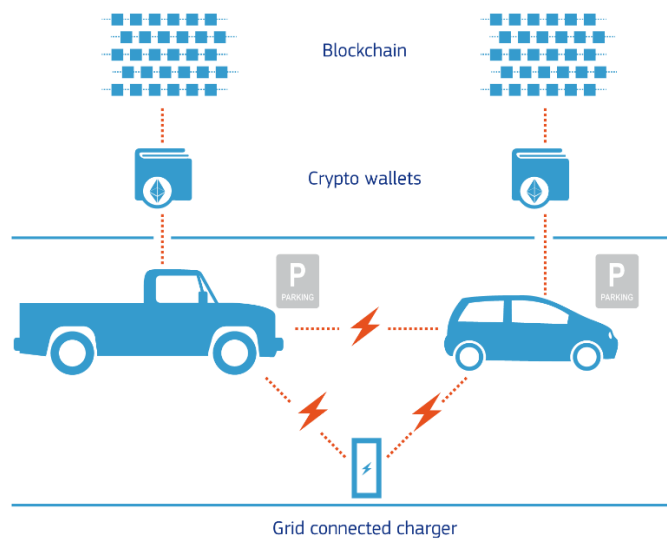


Figure 12. General architecture of car-wallet payments

5.1.1 Actors

The actors in the above described use case are:

DSO: This is the Distribution System Operator, or grid operator or network operator. He is responsible for operating and maintaining the distribution grid. He can send price or capacity profiles via a common two-way information exchange model, e.g. OpenADR. In this case he implements an OpenADR Virtual Top Node (VTN), with all necessary messages: polling, registering, sending events (both push as well as pull), optIn/-Out and reporting and custom DR programs.

An **aggregator** is an energy service provider which can change the electricity consumption of a group of electricity consumers/assets such as an EV and provide demand-side flexibility services to the grid.

CS: This is the V2G charging station, implementing OCPP 2.0 and supporting ISO 15118.

EV: This is the Electric Vehicle that supports ISO 15118.

5.1.2 Interactions

The interactions among the actors are illustrated in Figure 13.



Figure 13. Actors' interactions in a car-wallet payment scenario

The EV is connected and charging with the max available power. At some point, the DSO forecasts a possible issue on the distribution transformer serving the EV charging station and in order to resolve it, he tries to manage the local load, i.e. the EV charging/discharging. The

DSO sends via OpenADR a new power profile to alter the charging power or switch to discharging. The EMS receives the trigger and sends further a signal to the CS via OCPP to alter the charging power or switch to discharging. The CS communicates via ISO 15118 with the EV and changes the charging, accordingly.

5.2 Technical Requirements

Since the mobility use case heavily relies on the vehicle's wallet to operate, the wallet's protection is of utmost importance. The wallet is in practice a collection of private keys that enables its owner to prove that various addresses are his/hers. As a result, the secure storage (M-T-R1) and access to these keys is fundamental (M-T-R2). Moreover, Internet connectivity is needed when performing a transaction (M-T-R3), especially when using public payment systems (e.g., Ethereum).

From an architecture point of view, if each vehicle is required to be a node in a blockchain network, that would imply a network with a huge number of nodes. However, that is not necessary from an operational point of view. The vehicles could simply carry the wallet and the charging stations could be the nodes of the blockchain network. This would seem more feasible from a scalability point of view (M-T-R4), as it would significantly reduce the necessary number of nodes in the system.

5.3 Other potentially interesting scenarios (not subject to tests in WP 5)

The scenario presented in the previous two sections will be, in agreement with DG-ENER, subject of tests in workpackage 5. However, for sake of completeness, additional potentially interesting use-cases are presented in the following. Their implementation will not be assessed in this study, but briefly illustrated here to give the idea of possible other uses of blockchain in this particular context

5.3.1 Fleet Management & Energy Optimization

Currently, DLT enables secure communication of data between entities. This technology allows for a smarter understanding of an entire fleet, leading to an increase in performance of AI powered fleet management and energy optimization. An example can be a freight company who is interested in optimizing their fleet through a technique called platooning.

Platooning: the digitalization and networking of automated vehicles is a key element in the increase of efficiency. Cars need to communicate with each other to, for example, buy data for the optimization of their operational strategy. At the so-called platooning, several vehicles drive behind each other in very close distance. Safety is ensured by the communication of the involved vehicles and the real-time exchange of sensor data. The reduction of the distance between the vehicles leads to significant savings in terms of consumptions due to reduced wind resistance of the following vehicles. In general, these savings need to be passed on to the leading vehicles as well. Without having any savings itself, this vehicle leads the platoon, detects and bypasses potential dangers and shares its sensor data with the other vehicles. With a smart contract on blockchain technology, the payment process could be securely automated with real-time data. In addition to this, transportation infrastructure could negotiate with the vehicles on the streets in order to optimize the traffic situation. Thus, it would be possible, that such a platoon buys a green wave as a premium product to further increase energy savings and reducing traffic volume. Besides the payment function, blockchain technology could help validating the sensor data communication.

5.3.2 Autonomous Vehicles, Predictive Maintenance and features

DLT can be used to provide the means for autonomous vehicles to perform activities inherent to being autonomous. Such services include road usage (driving through tolls), refuelling, recharging (EV's), parking, and ultimately paying for these services through an integrated DLT-enabled digital wallet, with a distributed ledger of profit and loss statements available to all involved parties to assess, in real-time, the profitability of that fleet. Another use could be in temporary vehicle functions. In the automotive industry it is common that extra equipment in cars needs to be bought with the initial order. A later upgrade is mostly unavailable or involves a great deal of expenses. Blockchain technology could enable the temporary activation of extra equipment. Therefore, the vehicles need to be fully equipped ex-factory. Users then can unlock various extra features for a limited period of time via a smart contract, directly when they need it. For example, if the user is on a long highway trip, he could unlock cruise control for the length of his journey, which he wouldn't need in his daily routine. Besides additional income through the unlocking of the extra equipment, automakers too can achieve economies of scale through the plus built in components. In this scenario, blockchain technology enables secure payments and the safe and unmanipulable unlocking of extra equipment via a smart contract. Revenues can be achieved with carsharing, expenses emerge by repairs or charging. The advantage for the customer is the omission of the payment and accounting process, especially in corporate fleets. The vehicle itself can publish a detailed record of all transactions at the end of the month, bills are being paid instantly. With blockchain technology and artificial intelligence, vehicles can maintain themselves for the first time in history. This opens completely new possibilities of vehicle ownership. Incentives to buy a car could vanish, because of the high availability of P2P-carsharing via blockchain and the decrease of individual costs for mobility. As soon as the incentives decrease, the number of cars on the street would also decrease. This is the point where blockchain once again gets into the game.

Theoretically, vehicles can be kept as independent firms. After X years and the successfully paid off investment the car doesn't need to make profit anymore due to missing stake- and shareholders. Therefore, it could offer individual mobility at net cost price. The advantages of blockchain technology in this scenario can be summed up as the following: the vehicle becomes a financial entity; missing trust is replaced by blockchain technology. The self-owning car is able to make transactions and maintain itself. Thus, the effort for accounting and payment processes decrease and new possibilities of vehicle ownership arise. The self-owning car can start transactions with many different parties. Blockchain as a single source of truth matters less in this scenario. As at least one party is a machine, trust can't be existing in the process. The self-owning car is an open ecosystem, which everybody can participate in. With the implementation of different accounting features, the self-owning car is a decentralized database, which functionalities are not in the focus. Different payment scenarios and smart contracts as well as a huge degree of freedom in the decision-making process mark this use case. A real-time system is essential to the self-owning car. Kilometre database could also be a possibility. By continuously uploading data into the blockchain, a transparent, anonymous and manipulation proof database for kilometres driven can be established. The upload of data can be done either in the repair shop or autonomously by the vehicle itself. As a result, odometer fraud can be prevented. With the aid of a blockchain certificate, it can be proofed that the mileage shown in the odometer in the car equals the real driving data.

5.3.3 Smart insurance

Impact on insurance companies, in predicting driving behaviour and fit auto premiums according to driving style, and not on average performance, could be a major application of DLT in the transportation sector. A vehicle black box enables the exact documentation of the vehicle status. Blockchain technology enables the unmanipulable and transparent logging of the vehicles' sensor data in a decentralized network. With regard to coming autonomous vehicles, this unimpeachable documentation of a blockchain black box could help to resolve the circumstances of an accident. In theory, blockchain technology could enable insurances to be unbound to the vehicle due to the logging of sensor data. The insurance could be taken along into other vehicles like a user profile, for example in carsharing.

Insurances consider in their rates neither driving style, travel time, route nor frequency, although this data is available real-time in most cases due to connected cars. In a smart contract, this data could be processed inside the car and implemented into the insurance plan. In such a smart insurance, various clauses relying on data from the car can be implemented and are activated by certain triggers. Thus, pre-paid or usage-based tariffs can be realized on a secure data basis from the car or respectively the blockchain black box. Another promising scenario is located in freight traffic. Depending on location and route, there are various risks, like robbery or vehicle or freight damage due to bad roads. With a smart contract, the insurance plan could be adjusted according to the real-time risks. A smart insurance is usually a multi-party process with few participants. The circle of participants is limited to insurance company and reinsurer, owner and driver. All parties trust the data from the blockchain black box, which represents the single source of truth. Furthermore, there is no trust between the parties. In this open ecosystem, every vehicle can start collecting data in a blockchain black box, which the insurance company can access to provide the smart contract. In the presented use case smart insurance, the focus lies on the decentral database functionality. Payments and smart contracts are implemented as well. Vehicles are becoming autonomous entities with a limited degree of freedom. Real-time functionalities are not in the focus. Technology readiness level is to be evaluated as low.

6 Certification of origin

According to the EU-wide energy framework [18], energy production from renewable sources needs to cover at least 32% of the final energy needs of the consumers. The share of renewables in final energy use is only expected to grow having as an ultimate goal, if technologically possible, to cover 100% of the final energy needs from renewables.

Although the share of renewables in the energy mix is increasing, it is not clear to the end-user whether this energy originates from renewable sources or not. The traceability of energy injections from energy producers being them renewable or not is an important aspect for the electricity transmission and DSO.

Towards this direction smart metering roll-out that is taking place in EU Member States makes it easier to periodically collect energy consumption and renewable production readings, in an automatic way. However, the process that should be followed for the certification of energy for production and consumption is related to the studied use case. In this section we report on the following use cases:

- Certificate of origin for the energy consumed
- Certificate of Origin for Prosumers
- Certificate of Origin for Prosumers with BESS
- Certificate of Origin for Energy Communities as Consumers
- Certificate for Origin for Energy Communities with Renewable Energy System (RES) and Battery Energy Storage System (BESS)
- Certificate of Origin for EV

6.1 Actors

A generic list of actors found in all use cases are the following:

Consumers: The traditional actor for whom the whole electricity system was conceived and developed. It can be a household, an enterprise, an industry and, in general, anyone having a contractual agreement with a DSO.

Prosumers: It can be a household, a commercial facility, an industry, etc. It is capable of consuming electricity and possibly to produce it through solar panels or wind turbines.

Energy Communities: An aggregation of energy consumers and/or prosumers that merge, either virtually or physically, in order to form a community.

Aggregators: An aggregator is an energy service provider which can change the electricity consumption of a group of electricity prosumers and provide demand-side flexibility to the grid.

EVs: This is the Electric Vehicle that supports ISO 15118 “Road Vehicles: Vehicle to Grid communication interface”.

DSO: The Distribution System Operator distributes electricity on voltage (some levels in some MS), medium-voltage and low-voltage through the distribution systems with a view to its delivery to customers, but does not include supply. The commercialization/supply is done by

the retailers. DSO are however able to put in place mechanisms to solve congestion constraints.

6.2 Certificate of origin for consumed energy

In this **trivial use case**, a consumer already in contract with a DSO is upgraded to a consumer equipped with a smart meter. No local renewable generation is present. In this case, in predefined time intervals, the smart meter readings for energy consumption can be collected by the DSOs. The big picture of the interactions between the consumer and the DSO is clear and unambiguous (Figure 14). This information can be further processed triggering settlements between the consumer and the DSO, while a certificate of origin for the energy consumed, i.e. imports from the electricity system, is issued periodically.

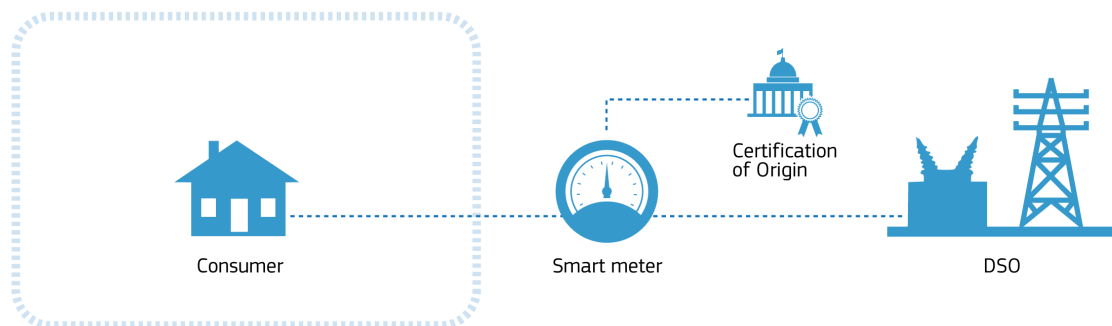


Figure 14. Consumer as Actor

If the energy mix of a country is known with a granularity of 1min (or 15min or 30min or 1h), in near real time terms, then an additional added value of this use case could incorporate dynamic pricing of electricity consumed. The prerequisite here is to collect the smart meter readings for consumption with the same periodicity the granularity of the energy mix is updated.

In such a scenario individualized pricing schemes can be developed according to the time intervals of consumption at the consumer premises with respect to what the energy mix, and thus respective system costs, is during the same intervals. This use case is trivial in the sense that the source of energy consumption is always the electricity system and certificates of origin of the energy used is unambiguous. When no consumption is present during a time-interval no certificate is issued.

6.3 Certificate of Origin for Prosumers

This use case resembles the situation where a consumer is equipped with RES production attached to his premises. Smart metering is a sine qua non prerequisite both for consumption and production metering. In this use case, no BESS is present.

Depending on the **type of contract** that the prosumer has with the respective DSO, the **certification of origin** of consumption and production can take place in a different way. This is because, in some EU Member States the legislative framework allows **self-consumption** of the energy produced by prosumers' RES system, while in others not. When self-consumption is not allowed, schemes such as Feed in Tariff and/or Net Metering are present, among others. The type of scheme utilized may have an impact on the determination of the process that will

lead to the issuance of a Certificate of Origin of production and/or consumption. Figure 15 presents a generic prosumer under contract with a DSO.

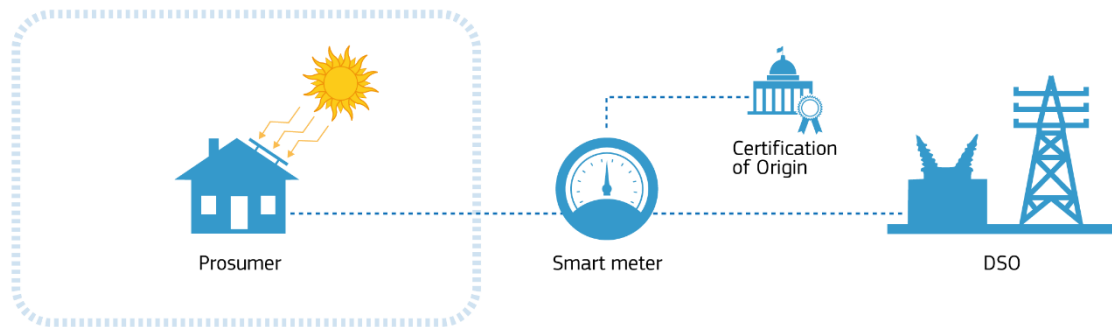


Figure 15. Generic Prosumer

Considering that a self-consumption is allowed then a consumer consumes energy as usual. What changes is the source of the energy consumed. Predefined time intervals (e.g. 1min or 15min) are utilized for monitoring the consumption as well as production by the RES. During the time intervals where RES production exceeds the consumption two Certificates of Origin are issued. One for the amount of energy that was self-consumed and one for the amount of energy that was injected to the grid. The amounts registered in the certificates are complementary; they sum up to the total amount produced by the RES system. When, during an interval, the RES production is zero and consumption is present, the amount needed is imported from the electricity system. A respective certificate for the amount imported is issued. When, during an interval, RES production exists but it is less than the consumption then two certificates are issued. One for the amount of RES energy that was self-consumed and one for the amount that was imported in order to meet the demand needs. When, during an interval RES production exists and consumption is zero then a certificate is issued for the amount exported to the electricity system. When there is neither RES production nor consumption no certificate is issued.

In case that self-consumption is not allowed the energy injected by the RES system is self-consumed when consumption is present, it cannot be accounted as such due to legal reasons. In this case, the load demand and RES production curves can be treated as two discrete entities. The energy consumed, at different time intervals, is considered to be imported from the electricity system and RES production is considered to be exported to the electricity system. During any given interval two certificates are issued, one for the imports from the electricity system for covering energy demand needs and one for the exports to the electricity system.

6.4 Certificate of Origin for Prosumers with BESS

In this case, the prosumer is equipped with a BESS system at his premises. The utilisation of such a system allows the prosumers to decrease the cost of prosumer's electricity. Figure 16 presents a generic prosumer equipped with a BESS system at his premises.

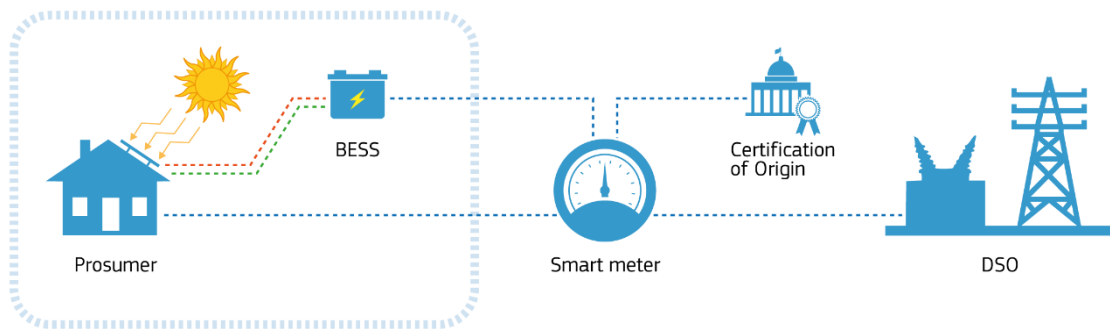


Figure 16. Generic Prosumer equipped with BESS

This use case makes sense, if only **self-consumption** of locally produced energy is **allowed**. In this case, during the time intervals that the renewable production is greater than consumption (not equal to zero) then a portion of the production is used for self-consumption and the rest is used for charging the BESS and exporting any remaining energy after charging the BESS. A maximum of three certificates of origin is expected, i.e. one for self-consumption, one for charging the BESS and one (when applicable) for the exports to the electricity system. During a time interval where renewable production is present and consumption is zero then two certificates of origin are expected, i.e. one for charging the BESS and one (when applicable) for exporting the excess amount to the electricity system. During a time interval where renewable production is zero and consumption is present then a maximum of two certificates of origin is expected, i.e. one for BESS discharging in order to meet the needs consumption and one (when applicable) for import of energy from the electricity system in order to meet excess needs that the BESS cannot cover. During a time interval where renewable production is present but the consumption need exceeds the production then the renewable amount is self-consumed and the rest is covered by the BESS. If remaining consumption exceeds what the BESS can provide the residual amount is imported from the electricity system. A maximum of three certificates of origin is expected, i.e. one for self-consumption, one for BESS discharging and one (when applicable) for import from the electricity system. When, during a time interval, neither renewable production nor consumption are present then no certificate of origin of supply or demand is issued.

If self-consumption is not allowed: the capital investment needed for the acquisition of the BESS system cannot be justified and no return on such investment can be rationally expected. This case can be reduced to the case of prosumer without BESS, having the electricity system acting as the “battery” to which energy can be exported or from which energy can be imported according to the needs of the prosumer.

6.5 Certificate of Origin for Energy Communities as Consumers

This use case can be reduced to the trivial case of the consumer that was described above. The key difference is the fact that the community consists of a number of consumers who can either be geographically bounded e.g. the total number of consumers after the MV/LV substation (secondary substation) that defines the boundaries of the community or can be a community formed by distant users virtually through online platforms (given that legislative framework allows and online platforms exist). A lot of research work is performed on whether and through which means **aggregators** could provide such services. Such communities of pure consumers could potentially form in order to benefit from discounts in the electricity price for

the energy imported while offering e.g. enhanced capacity for controllability to the aggregator and/or the DSO. On the other hand, when forming the energy community on the basis of the structure of the physical power system, the components of the energy conversion chain should be taken into account. Figure 17 presents an energy community with strict boundaries that are defined by the electricity distribution system [19].

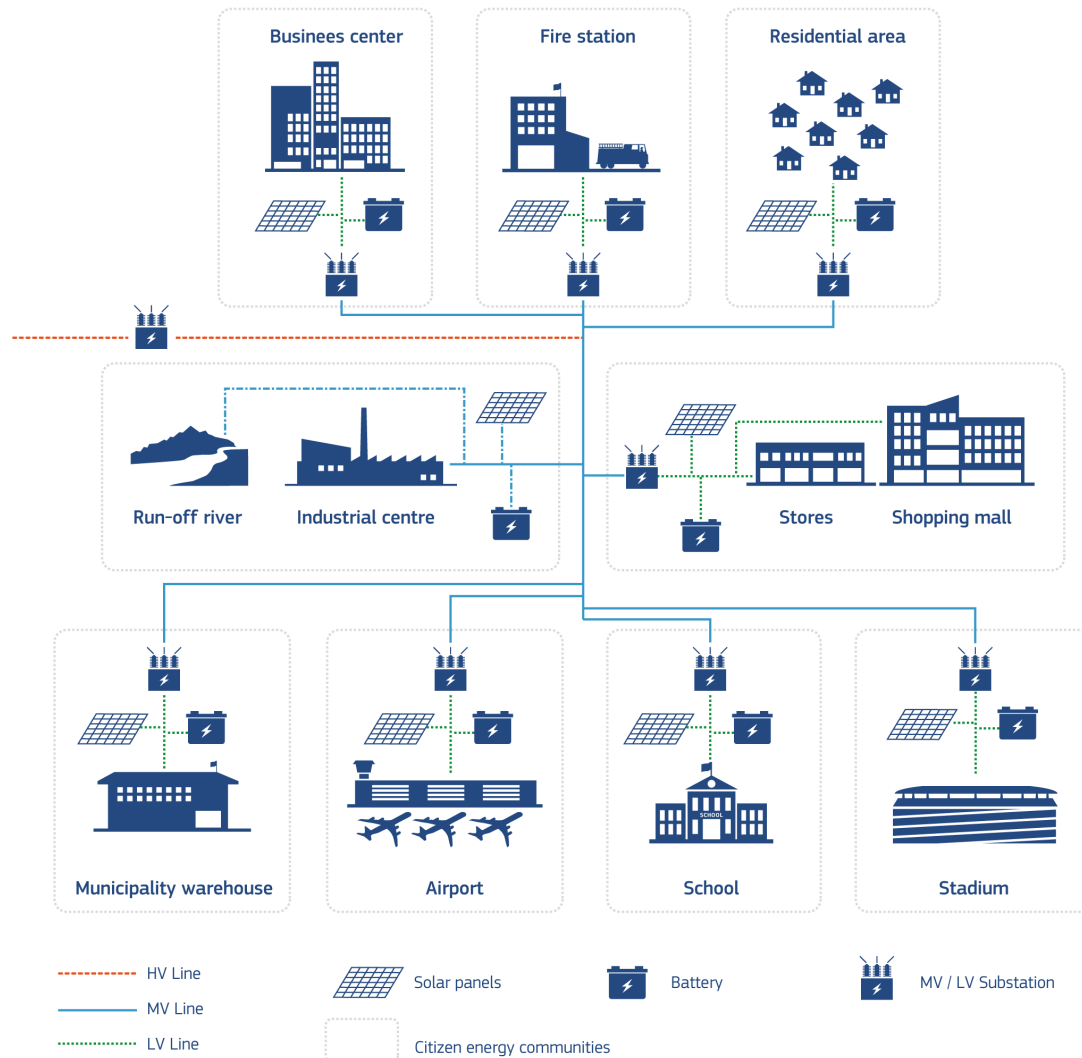


Figure 17. Energy community formed by consumers to an MV/LV substation

6.6 Certificate for Origin for Energy Communities with RES and BESS

This use case can be directly linked to the use case of Certificate of Origin for Prosumers with RES (and BESS, if available) given that the community is geographically bounded and acting as a single entity, i.e. having a RES (and BESS, if available) installation for collective production of renewable energy within the energy community.

If the legislative framework allows then the corresponding amount of energy can be self-consumed. The excess is always injected to the electricity system and relevant certificates of origin for consumption, self-consumption and injection to the electricity system are issued. If the community is not geographically bounded but a virtual merger has taken place, then each

actor of the virtual community may act either as a pure consumer or as a prosumer equipped or not with BESS. In this case, what was already described for the prosumer with or without BESS can be used as well.

6.7 Certificate of Origin for EV

The emerging role of EVs in modern societies will require the certification of the origin of services offered by or provide to EVs as well. From the energy point of view, EVs act as BESS systems and thus can be charged or discharged according to the needs of a diverse range of actors including consumers, aggregators, DSOs.

6.8 Interactions

Below, the interactions for the use case of a Prosumer equipped with BESS are presented. We have chosen to only present the interactions for this use case since the rest of the use cases are either simpler or can be reduced to this one. It is assumed that self-consumption is allowed. The situation regarding the issuance of Certificates of Origin for a potential reality of the Certificate of Origin for Prosumers with BESS is presented in Figure 18. Similar message sequence charts can be derived for the rest of the use cases. The entities present are the following: Prosumer's Smart Meter, Prosumer's Monitoring System and Certificate of Origin Issuance Authority (CoOIA). The following notions apply: RESp: RES production, C: Consumption, TC: Total Capacity of the BESS system, RC: Remaining Capacity of the BESS system.

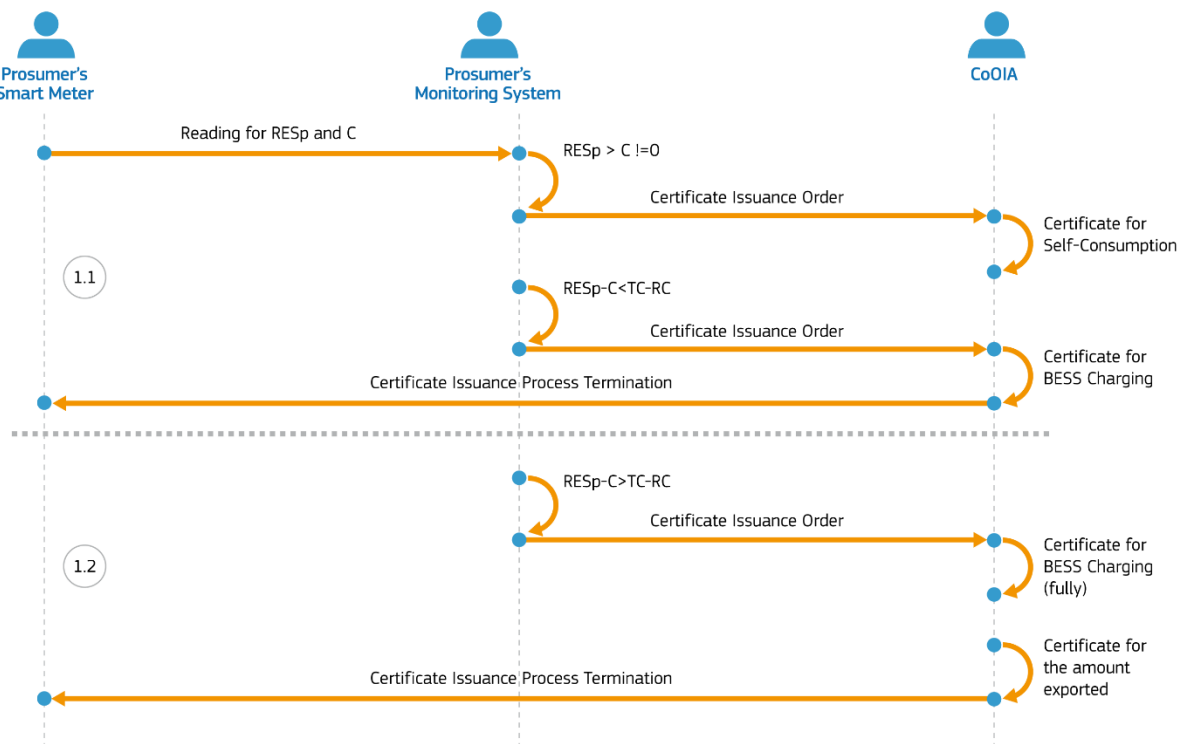


Figure 18. MSC for the use case of a Prosumer with BESS where self-consumption is allowed and rest production exceeds consumption.

6.9 Technical Requirements

Technical requirements needed for the realization of Certification of Origin include:

- **Full scale deployment of smart metering technologies** (CO-T-R1), since without the guarantee of such developments it will be impossible to collect meter readings, in near real time, attribute these readings to relevant actors coordinate interactions and issue certificates of origin for consumption and/or production
- **Data sharing** the involved entities should exchange the provided data at the predefined time frames (CO-T-R2)
- **Data security should be guaranteed** (CO-T-R3)
- **Validation of certification of origin** (CO-T-R4) all the involved entities should be able to confirm the validity of a certificate of origin

6.10 Societal challenges

The societal challenges identified as relevant to the Certification of Origin use case include:

- **Capital investments** for the deployment of the needed infrastructure
- **ICT literacy of people** at whose facilities new developments in the ICT domain, such as blockchain technology, are deployed

7 Energy Regulatory Packages

This section provides a general analysis of the current regulatory framework put in place by the European Commission for the energy sector including legal and governance considerations paving the way for selection, deployment and analysis of experimental use cases.

7.1 Clean Energy Package and digitalization

The political guidelines for the new European Commission (2019-2024) propose a European Green Deal that puts Europe at the forefront to become the world's first climate neutral continent [20]. In fact, following the agreements achieved internationally in Paris 2015 summit [21], the European targets regarding climate and energy are set in 2019 for clean energy under the context of Clean Energy Package [16]. In particular, the CEP consists of the following energy related legislative and policy acts:

- the Energy Performance in Buildings Directive 2018/844,
- the Renewable Energy Directive 2018/2001,
- the Energy Efficiency Directive 2018/2002,
- the Energy Union and Climate Action Governance Regulation 2018/1999,
- the Electricity Directive,
- The Electricity Regulation,
- the Risk-Preparedness Regulation,
- the Regulation for the Agency for the Cooperation of Energy Regulators (ACER)

The starting point for the analysis is the EU framework on climate and energy, whose agenda includes the following EU-wide 2030 targets and policy objectives:

- At least 40% cuts in greenhouse gas emissions, from 1990 levels,
- At least 32% share for renewable energy,
- At least 32.5% improvement in energy efficiency [18].

Combined with these developments in the regulatory legal and governance framework for the energy sector the European Parliament approved a resolution on October 3rd 2018 on 'Distributed ledger technologies and blockchains: building trust with disintermediation' [22]. That could imply that the above mentioned targets can be supported by new ICT technologies like DLTs. In fact, blockchain and DLTs can be potential solutions for many of the operational aspects addressed by the Regulation EU(2019)/943 and Directive EU(2019/944). These can be observed in data security and sharing, interoperability, scaling services to engage citizen participation, how different actors may interact in a trust less way and taking advantage of the digitalization of the energy sector allowing new products and services to be created.

As a final consideration, it is worth to mention extensively paragraph 2 and 2a in order to appreciate the general landscape that the Directive (EU) 2018/2001 draws in terms of rationale endorsed by the European Parliament in the last legislature about the use cases deploying of DLT in the energy sector:

- Paragraph 2. Underscores that DLT can transform and democratize the energy markets and allows citizens in trust-less and open networks to sell, certify, track and measure the energy that is exchanged in a peer-to-peer mode, especially when produced in decentralised systems;
- Paragraph 2a. Highlights how beneficial DLTs can be in terms of protection, trust and inalterability of data that are ubiquitously collected through distributed networks of environmental sensors (polluting particulate, CO2 emissions, noise, radioactivity, seismicity, etc.).

At the light of the developments in policy on energy and DLT in the previous EU Parliament legislation summarised above, regulatory frameworks, laws and governance structures are advancing in a direction that supports the formation of a new landscape in the energy sector promoting decarbonisation, decentralization and sustainability.

7.2 Regulatory framework for Smart metering

The main legislative provision addressing smart metering was included in the so-called "Third Energy Package" approved by the Council and the European Parliament in 2009 and binding for all European countries¹. These latter have to ensure that at least 80% of electricity consumers in their territory are equipped with smart metering systems by 2020.

According to the new Directive 2019/944 [23] smart meters characteristics can be summarised to the followings:

- Coupled with energy management systems
- Its costs should be shared also by consumers
- If no roll-out, the decision and its supporting Cost Benefit Analysis (CBA) should be reviewed at least every 4 years
- Pre-existing smart meters to be substituted within 12 years from the Directive

As far as the smart metering functionalities are concerned the following should be taken into consideration:

- SM measures actual consumption and provide such information (both non-validated near to real time and validated historical consumption) to consumers (SM-P-R1)
- SM complies with cybersecurity, privacy and data protection legislation (SM-P-R2)
- SM accounts for the generation inputted in the grid by self-generators/prosumers
- SM data are portable: they are consumers' property, who can transfer them to third parties (SM-P-R3)
- SM capabilities in terms of reading and monitoring consumption are communicated prior or at the time of the installation
- SM measures consumption/generation at the same time resolution of the relevant electricity market

¹ Annex I.2 to the Electricity Directive (2009/72/EC).

The newly adopted Clean Energy Package entails specific requirements for smart meters. Member States are required to perform a CBA on which a smart meter roll-out decision is based. There are differences with respect to the smart meter roll-out status of different Member States [24]. Thus, some Member States are advanced in terms of smart metering roll-out whereas other are not. In some cases, advanced smart meters are used, that target at customers' empowerment, whereas in many occasions first generation smart meters are used that do not interact with end-customers that much.

From a policy perspective, there are timelines for Member States to proceed with their CBAs and further on with smart meter roll-outs. However, at the time being, the differences among Member States imply that ***advanced smart metering applications cannot be adopted in countries where the smart meter policies have not been implemented***. Therefore, there is no homogeneity in European countries when talking about smart metering applications due to (partly) lack of policy implementation.

7.3 Regulatory framework for energy communities

The relevant regulatory framework for energy communities, is composed by the Regulation 2019/943 and Directive 2019/944 for the internal market in electricity [23]. Moreover, energy communities can be subdivided in three distinct categories:

- (a) peer-to-peer energy exchange,
- (b) peer-to-main grid exchange and
- (c) microgrids in remote locations such as islands.

Relevant regulations for these cases are summarized as follows:

- Peer to Peer: Articles 21 and 22 on the Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources allow the exchange of energy on a peer-to-peer basis in infrastructures such as microgrids.

Article 22 clearly states that Member States (MS) ensure that final customers, in particular household customers, are entitled to participate in a renewable energy community, provided that for private undertakings, their participation does not constitute their primary commercial or professional activity.

Moreover Member States shall ensure that renewable energy communities are entitled to: (a) produce, consume, store and sell renewable energy, including through renewables 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.

- Peer-to-main grid: Resolution P8_TA-PROV(2019)0227 [25] concluded the legislative process with the enactment of the following points contained in the Directive (2016/0380(COD)) that will positively impact on consumer-centered electricity markets and energy communities. It establishes rights for consumers to act individually or form groups in order to take advantage of price oscillations in the energy provided by main grid operators. In this way, consumers can save on their bills, while grid

management and the market gradually adapt to the need to integrate renewable energy within the legacy grid infrastructure.

The Directive enables all willing citizens to become 'active customers' in the electrical power market. Therefore, they have the right to consume, stock and sell the energy that they produce back to the main grid. In these regards, active customers must be put in the condition to know in near-real time the trend of their electricity consumption and production. In this way, they can sell back to the grid their surplus when it is more profitable for them. In turn, active customers can enter into dynamic electricity contracts, i.e. contracts that price electricity in relation to the oscillations of daily electricity prices. Under this Directive, all energy suppliers with more than 200.000 costumers shall offer dynamic pricing in their contracts.

- Micro grids in remote locations such as neighbourhoods and islands: energy communities have now the right to share internally the energy that they produce and control their microgrids. These microgrids can be formed by production units located in different places and connected through ICT solutions such as DLT and virtual net metering devices. In the latter case, energy communities in the European Union have the right to pay their bills by accounting for the energy produced by their assets (e.g. solar parks or wind farms) even if such assets are located far from where they reside. The EU directive on internal markets also establishes the rules for self-consumption and for districts to be their own distribution system operator which give way to microgrid management by communities. It clearly states that consumers should be able to consume, to store and to sell self-generated electricity to the market and to participate in all electricity markets by providing flexibility to the system, for instance through energy storage, such as storage using electric vehicles, through demand response or through energy efficiency schemes. It further hints innovative tools saying that "New technology developments will facilitate those activities in the future".

Moreover, as stated in Article 21 of P8_TA-PROV(2018)0444, MS shall ensure that renewables self-consumers, individually or through aggregators, are entitled:

- a) to generate renewable energy, including for their own consumption, store and sell their excess production of renewable electricity, including through renewables power purchase agreements, electricity suppliers and peer-to-peer trading arrangements, without being subject: (i) in relation to the electricity that they consume from or feed into the grid, to discriminatory or disproportionate procedures and charges, and to network charges that are not cost-reflective; (ii) in relation to their self-generated electricity from renewable sources remaining within their premises, to discriminatory or disproportionate procedures, and to any charges or fees;
- b) to installing and operating electricity storage systems combined with installations generating renewable electricity for self-consumption without liability for any double charge, including network charges, for stored electricity remaining within their premises;
- c) to maintaining their rights and obligations as final consumers.

The directive does provide also some clarifications regarding the injection of renewable energy into the grid. Member States should for example apply non-discriminatory and

proportionate charges and fees to renewables self-consumers, in relation to their self-generated renewable electricity, remaining within their premises in one or more of the following cases:

- a) if the self-generated renewable electricity is effectively supported via support schemes, only to the extent that the economic viability of the project and the incentive effect of such support are not undermined;
- b) from 1st December 2026, if the overall share of self-consumption installations exceeds 8% of the total installed electricity capacity of a Member State, and if it is demonstrated, that it represents a burden on the long-term financial sustainability of the electric system, or creates an incentive exceeding what is objectively needed to achieve cost effective deployment of renewable energy, and that such burden or incentive cannot be minimised by taking other reasonable actions; or
- c) if the self-generated renewable electricity is produced in installations with a total installed electrical capacity of more than 30 kW. Such clarifications also apply to buildings. The directive also considers at a city context and hence calls for the attention of MS to ensure that renewables self-consumers located in the same building, including multi-apartment blocks, are entitled to engage jointly in activities referred to above and that they are permitted to arrange sharing of renewable energy that is produced on their site or sites between themselves, without prejudice to the network charges and other relevant charges, fees, levies and taxes applicable to each renewables self-consumer. Member States may differentiate between individual renewables self-consumers and jointly acting renewables self-consumers.

7.4 Regulatory framework for Flexibility

A way in which citizens can become active customers is to take part to energy management schemes. They can do so by offering their load flexibility to the market or enter into contact with an energy aggregator. Aggregators can increase/decrease or limit electricity consumption of consumers according to total electricity availability on the grid. An aggregator can also operate on behalf of a group of consumers producing their own electricity by selling the excess electricity that they produce [26]. Whereas individually prosumers cannot reach the minimum power to be bid/offered to the market, they associate with other small prosumers through the means of an aggregator which manages the assets in an optimal way.

By increasing the number of renewable power systems connected to the electricity grid, balancing power between generation and load is a progressively challenging task, for both long-term and short-term balance. Demand Side Management (DSM) is a method for balancing supply and demand in power systems with a high share of variable renewable energy generation. Demand Response strategies are gaining more attention in power system operations lately, driven by growing interest in the smart grid concept, decrease in cost of sensors and general electronics, IoT, large bandwidth and protocols. Demand Response is defined as:

“the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including time-variable electricity prices or incentive payments, or in response to acceptance of the final customer's bid, alone or through

aggregation, to sell demand reduction or increase at a price in organised markets”, as defined in Commission Implementing Regulation (EU) No 1348/2014.

Demand Response empowers consumers to adjust their use of energy related devices and resources to specific time periods by providing control signals and/or financial or social incentives. Demand Response is divided into the following categories [27]:

- (a) In Explicit Demand Response schemes (sometimes called “incentive-based”) the aggregated demand side resources are traded in the wholesale, balancing, and capacity markets. In this scenario consumers receive direct payments to change their consumption (or generation) patterns upon request, triggered by, for example, activation of balancing energy, differences in electricity prices or a constraint on the network.
- (b) In Implicit Demand Response (sometimes called “price-based”), consumers choose to be exposed to time-varying electricity prices that reflect the value and cost of electricity in different time periods. They respond to wholesale market price variations or in some cases dynamic grid fees. Introducing the right to flexible prices for consumers (provided by the electricity supplier) does not require the role of the aggregator.

The directive hence states that both paths can be followed when offering flexibility to the grid. Either through an aggregator or directly. What is not explicitly stated is that an aggregator may sell also through another aggregator, which may happen in the case where an aggregator procures flexibility in order not to incur in an imbalance itself. In this case we can sum up three types of flexibility provision possibilities:

- (a) Electricity consumer provides flexibility through an aggregator
- (b) Electricity consumer provides flexibility directly to the market
- (c) An aggregator provides flexibility to another aggregator

Moreover, regarding business models, it is important to distinguish that aggregators may be classified into independent aggregators or aggregators which are part of a retailer. Whereas the latter may incorporate financial settlements and management within its activities, the first only focuses on DR and interacting with the markets. In this case the exchange and access to information is crucial to the well-functioning of the aggregation activity and which is foreseen in the CEP (2019) 944. This care has a goal of removing any market strength from vertically integrating retailing and aggregation activities.

Even though Demand Response is widely seen as an important instrument to handle flexibility in electricity systems, there are various requirements that should be met considering the different policies:

According to the Directive (EU) 2019/944 the European Commission aims to better link wholesale and retail electricity markets by “taking advantage of new technology, new and innovative energy service companies” that should enable consumers to participate in the energy transition considering near real time information sharing (FL-P-R1). This should be done by the “creation of a market framework that rewards flexibility and innovation”. The European Commission is aware that a “lack of real-time or near real-time information provided to consumers about their energy consumption has prevented them from being active participants in the energy market and the energy transition. By empowering consumers

and providing them with the tools to participate more in the electricity market, including participating in new ways, it is intended that citizens in the Union benefit from the internal market for electricity and that the Union's renewable energy targets are attained”.

- (a) One major precondition for consumer participation in flexibility schemes is the availability of smart meters and the corresponding services (FL-P-R2)
- (b) One of the main barriers for including small- and medium-sized loads into the demand response market is the absence of a unique and clear definition of independent aggregators as an important market participant. Article 13 of the directive specifies the role of aggregation: *“Member States shall ensure that all customers are free to purchase and sell electricity services, including aggregation, other than supply, independently from their electricity supply contract and from an electricity undertaking of their choice. [...] Member States shall ensure that, where a final customer wishes to conclude an aggregation contract, the final customer is entitled to do so without the consent of the final customer's electricity undertakings. Member States shall ensure that final customers are entitled to receive all relevant demand response data or data on supplied and sold electricity free of charge at least once every billing period if requested by the customer.”* (FL-P-R3)
- (c) The directive further clarifies that “Member States may require electricity undertakings or participating final customers to pay financial compensation to other market participants or to the market participants’ balance responsible parties, if those market participants or balance responsible parties are directly affected by demand response activation. Such financial compensation shall not create a barrier to market entry for market participants engaged in aggregation or a barrier to flexibility. In such cases, the financial compensation shall be strictly limited to covering the resulting costs incurred by the suppliers of participating customers or the suppliers’ balance responsible parties during the activation of demand response. The method for calculating compensation may take account of the benefits brought about by the independent aggregators to other market participants and, where it does so, the aggregators or participating customers may be required to contribute to such compensation but only where and to the extent that the benefits to all suppliers, customers and their balance responsible parties do not exceed the direct costs incurred. The calculation method shall be subject to approval by the regulatory authority or by another competent national authority”.
- (d) For more elaborated demand response, implicit or explicit, applications where load control is included, further functionalities are necessary. The most important of these functionalities are **data availability and exchange (standardisation), data management and interoperability** (FL-P-R4). This is stated as: *“Smart metering systems shall accurately measure actual electricity consumption and shall be capable of providing to final customers information on actual time of use. Validated historical consumption data shall be made easily and securely available and visualised to final customers on request and at no additional cost. Non-validated near real-time consumption data shall also be made easily and securely available to final customers at no additional cost, through a standardised interface or through remote access, in order to support automated energy efficiency programmes, demand response and other services”* (Art. 20, (a)). Smart meters should be “interoperable and able to deliver

the desired connectivity of the metering infrastructure with consumer energy management systems in near real-time” (Art. 21, (b)).

- (e) As explained in the previous section a dissemination of demand response service providers and the promotion of Aggregators, especially independent ones, raises different challenges. Among others is how can TSO’s confirm that a DR was delivered, in particular when dealing with independent Aggregators, and assure data integrity and confidentiality (making sure data is true and original and without individual data being shared). So far, for dispatch and control purposes the system operator may request for example a single point of dispatch. This requirement is easily met, since larger loads are located under the same dispatch node. However it also states that “an alternative method in which the total output of the combined loads can be monitored” (FL-P-R4) can be used.
- (f) As the CEP states using system flexibility services will require extensive cooperation and clear boundaries between TSOs and DSOs. This aims to ensure an efficient data exchange on the activated flexibility resources and to avoid a double activation from a DSO and a TSO of the same flexibility source. According to article 32(1), *“distribution system operators shall exchange all necessary information and coordinate with transmission system operators in order to ensure the optimal utilisation of resources, ensure the secure and efficient operation of the system and facilitate market development”* (FL-P-R5).
- (g) In addition, for the access flexibility resources, article 53(2) of the E-Regulation states that ‘transmission and distribution system operators shall cooperate in order to achieve coordinated access to resources such as distributed generation, energy storage or demand response that may support particular needs of both the distribution system and the transmission system. The E-directive is clear when it states that information regarding the flexibility services should be shared between several parties (TSO, DSO, Aggregators, consumers) (FL-P-R6).

To summarise, regulatory framework conditions for demand response will change dramatically in the coming years. Active consumers will increasingly be enabled to participate to flexibility markets. The market development will be actively pushed by flexible energy tariffs and by the broad establishment of new market participants, independent aggregators, whose role and responsibilities are defined in the directive and that will be further specified in national legislation. Finally, technical requirements such as the availability of smart meters with precise specifications and standardisation of data formats will ensure the interoperability of systems. Several challenges are presented as scalability, data sharing, data protection and authenticity, fast and digital financial settlements, service tracking and cost effective solutions.

7.5 Regulatory framework for Certificate of Origin

- (h) The main EU legislative documents covering the concepts of “guarantees of origin” and “self-consumption”, both of which were mentioned in the Certificate of Origin section of this document, are:
 - Directive (EU) 2018/2001 of the European Parliament and of the Council, of 11th December 2018, on the promotion of energy from the use of renewable sources [28]

- Directive 2012/27/EU of the European Parliament and of the Council, of 25th October 2012, on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC [29]

Other EU legislative documents that briefly cover the concepts of “guarantees of origin” and “self-consumption” are:

- Regulation (EU) 2018/1999 of the European Parliament and of the Council, of 11th December 2018, on the Governance of the Energy Union and Climate Action [30]
- Regulation (EU) 2019/943 of the European Parliament and of the Council, of 5th June 2019, on the internal market for electricity [31]

In [28], the concept of “guarantees of origin” is mentioned in paragraphs 55, 56, 57, 58, 59, of the explanatory memorandum, in Article 1 on the Subject Matter, in points 12, 13 of Article 2 on the Definitions and in Article 19 on Guarantees of Origin for energy from renewable sources. The concept of “self-consumption” is mentioned in paragraphs 50, 63, 66, 67, 68, 69, 72 of the explanatory memorandum, in Article 1, in points 14, 15 of Article 2, in paragraph 2 of Article 7 on calculation of the share of energy from renewable sources, in paragraphs 3, 4 of Article 15 on administrative procedures, regulations and codes, in paragraph 3 of Article 16 on organization and duration of the permit-granting process, in paragraph 1 of Article 17 on simple notification procedure for grid connections, in paragraphs 1, 6 of Article 18 on information and training, and in Article 21 on renewables self-consumption.

In [29], the concept of “guarantees of origin” is mentioned in paragraph 39 of the explanatory memorandum, in paragraph 10 of Article 14 on the promotion of efficiency in heating and cooling, and in paragraphs (a) and (b) of Annex X on guarantee of origin for electricity produced from high-efficiency cogeneration.

In [30], the concept for “guarantees of origin” is mentioned in Article 27 on reporting on 2020 targets and in Annex IX on additional reporting obligations. The concept of “self-consumption” is mentioned in Article 20 on integrated reporting on renewable energy and Annex I on general framework for integrated national energy and climate plans.

In [31], the concept of “self-consumption” is mentioned in Article 18 on the charges for access to networks, use of networks and reinforcement.

8 ICT Regulatory Framework

The wish to develop energy communities and prosumer energy systems has brought up major concerns on privacy. Indeed, when such systems will be deployed, informed customers will yearn for guarantees that their personal data processed by the systems, and thus their privacy, will not be threatened.

The European Union has also expressed many fears regarding data protection and privacy with the growing use of information systems for daily purposes. Worries are highlighted, from (involuntary) leak of personal data to theft, which can bring impersonation or ransomware attacks. To help in protecting European citizen's personal data, the EU published several laws that, generally speaking, address the main issues regarding privacy and security of these data in information systems. The most recent and impactful law is the General Data Protection Regulation (GDPR), published in 2016.

In this section, we present the three main EU laws related to privacy and security, namely the GDPR, the ePrivacy directive, and the RED directive. We then analyse the impact of the GDPR on the blockchain technology.

8.1 General Data Protection Regulation

The most important EU regulation on data protection and privacy for individuals in the last 20 years is the General Data Protection Regulation 2016/679 [32]. Its primary goal is to reshape the way personal data is handled by information systems, and unify it within the EU. The regulation became enforceable on 25 May 2018.

The strength of the GDPR is that it is a regulation, meaning that it becomes enforceable as law in all member states simultaneously. This is different from directives, which must first be transposed into a national law.

The following requirements of the GDPR are of particular interest in our study context.

- **Application:** The GDPR applies to any system that processes personal data, including closed systems. This means that, even if an information system is not connected to the Internet or a local area network, it must comply with all the requirements of the GDPR if it processes personal data. Note however that the GDPR does not apply to (a) activities outside the Union law, (b) personal or household activities, and (c) authorities that work for prosecution of criminal activities.
- **Responsibility:** The data controller² (and data processor if it processes the data on behalf of the controller) is responsible of data processing, meaning that it must put in place appropriate technical and organisational measures to ensure that this processing is performed in accordance with the GDPR (e.g., appropriate data protection policies).
- **Security of personal data:** The personal data that are processed by a system should be protected with appropriate technical and organisational measures such as encryption or pseudonymisation. These protection mechanisms should ensure confidentiality, integrity, availability and resilience of the data and/or of the processing system, and they should be regularly tested and evaluated.

² The data controller is the entity that determines the purposes, conditions and means of the processing of personal data, while the data processor is the entity that processes personal data on behalf of the controller.

- **Data protection by design and by default:** The data controller shall put in place data protection *by design* at the creation of the system that is processing personal data. This can be performed by implementing appropriate technical and organisational measures such as pseudonymisation or data minimisation. Additionally, the data controller shall put in place data protection *by default* by only allowing the processing of personal data that are necessary for the purposes of the system.
- **Data retention:** The duration of data storage, also called data retention, is not fixed nor limited by the GDPR. However, this duration should not be longer than necessary for the purpose of the system. It clearly depends on the context, and thus might not be the same for every situation.
- **Data portability:** Upon request, the data subject shall receive his/her personal data in a structured, commonly used and machine-readable format. Furthermore, the data subject shall be able to transmit those data to another data controller without any obstacle.
- **Consent:** The data subject shall give his/her consent to the processing of his/her personal data for the specific purposes given by the data controller in an intelligible and easily readable form. The data subject shall be able to withdraw his/her consent at any time.
- **Right to erasure/to be forgotten - right of rectification:** The data subject shall be able to ask that his/her personal data are erased from a system at any time. In the same vein, the data subject shall be able to rectify or modify his/her personal data without undue delay.
- **Right of access:** The data subject shall be able to access to his/her personal data that are being processed by the data controller. This means that (1) the data subject shall obtain confirmation by the data controller whether or not his/her personal data are processed, where and for what purpose, and (2) the data subject shall easily obtain a copy of these data.

8.2 ePrivacy Directive and proposal

The second most important EU law that is of concern for the study is the ePrivacy Directive 2002/58/EC [33]. It is a continuation of the Data Protection Directive of 1995, which was not dealing with electronic communications information, such as data traffic, spam, cookies. The directive has been amended in 2009.

In 2017, an ePrivacy proposal for a regulation has been presented and published [34]. Its goal is to replace the old ePrivacy Directive by clarifying definitions and requirements on electronic communications, such as exchanged data, user consent, cookies, opt-outs. In particular as explained by the EC [35], the key points of the proposal include (a) the application of the rules to new players (e.g., Facebook, WhatsApp), (b) stronger rules for all people and businesses, (c) privacy for communications content and metadata, (d) new business opportunities for telecom operators, (e) simpler rules on cookies, (f) protection against spams, either emails, SMS or calls, and (g) more effective enforcement of confidentiality rules.

The following requirements of the ePrivacy proposal are also of particular interest in the context of our study.

- **Confidentiality of electronic communications data:** Any interference with electronic communication data (e.g., listening, tapping, storing, monitoring) by persons other than the end-users shall be prohibited, except when permitted by the ePrivacy proposal. This means that the access to the data is strictly limited/restricted to the right people, and forbidden to the wrong people.
- **Limitation of processed data and consent:** A service provider may process electronic communications data, metadata and content only under specific circumstances. In particular for metadata and content, the end-users must have given their consent. Note that end-users should always have the possibility to withdraw their consent at any time.
- **Erasure and anonymity of data:** A service provider shall erase or make anonymous the electronic communications content and metadata once the communication is transmitted. This should be performed in accordance with the GDPR restrictions and requirements.
- **Special legislative requests:** A service provider shall establish internal procedures in case of legislative requests to access end-users' electronic communications data.

8.3 RED Directive

Finally, the Radio Equipment Directive 2014/53/EU [36] is the last EU law that is essential for this study. This comes from the fact that Helios relies on IoT technology.

The most important requirement of this directive is the following one:

- **Data protection and privacy:** A radio equipment should incorporate safeguards to ensure that the personal data and privacy of users are protected.

9 Blockchain Considerations

The concerns regarding blockchain usage are divided into two categories: (a) legal compliance, especially to data protection related policies, (b) specific technical implementations, mostly related to the transactions' duration, scalability of the system and to confidentiality of data.

For what concerns the data protection compliance, the biggest obstacle is that of the right to be forgotten. This is due to the fact that transactions and data on the blockchain are immutable and cannot be thus deleted. As a result one cannot choose to remove a fulfilled transaction. A workaround to this problem, is to not store in the blockchain data that may need to be deleted later on. Instead, a reference of such data is stored in the chain and the real data are stored and transmitted by other means. Therefore, in such cases it is possible to delete data that refer to a previously executed transaction.

The technical limitation of blockchain highly depend on the specific implementation and platform used, as the implementations' performances highly differ one from another. Nonetheless, cases that require extremely fast transactions (i.e., in terms of milliseconds) are not adequate for blockchain systems as their performance is much slower. Also scalability could be an issue, depending on how many transactions could be required per second and on how many active nodes should be part of the system. However, these obstacles are often solved in the design phase of the system and are mitigated by adapting or converting the logic of the developed solution to match the logic of a blockchain system.

9.1 Smart metering

Smart metering is considered a core service for any use case to be supported by blockchain technologies, as smart meters data would be distributed to all the involved parties. Blockchain by design provides data authenticity, integrity and immutability and consequently requirements SM-T-R1, SM-T-R2 can be satisfied. However, users' privacy (SM-T-R3) is platform independent considering that the smart meter data frequency collection could be adapted. If not another could be configured which would enable data aggregation in specific time frames in order to protect user's privacy.

With regard to the support of a hierarchical architecture SM-T-R4 where specific entities should share info among pre-defined entities permissioned blockchain systems can provide this requirement considering specific configurations.

The challenging aspect for smart metering is communication technologies interoperability (SM-T-R5) supported by smart meters. However, the underlying communication system could be transformed to a neutral technology if Internet Protocol (IP) is enforced over it. This way, smart meters data can be transferred 'easily' to any service that is built upon IP. Of course, it should be stress that all the current blockchain systems function over IP.

Considering the policy related requirements blockchain systems can support the provision of both non-validated near real time and historical consumption to consumers and fulfil this way the requirement SM-P-R1. Furthermore, a smart metering system that leverages on blockchain would support by design integrity and immutability of the stored data and would enhance the overall cybersecurity (SM-P-R2). However, the cybersecurity of the smart meter itself is not enhanced unless Trusted Platform Module (TPM) is introduced for supporting at hardware level cryptographic operations related to the blockchain functionality.

As far as the data portability (SM-P-R5) is concerned though definitions of the proper data structures are technology neutral, blockchain can support data integrity and authenticity on the transferred data, providing an easy way to providers to validate consumers data.

Table 2 overviews the policy and technical requirements of the smart metering use case and identify whether blockchain can support them.

Table 2. Overview of smart metering requirements and possible support by blockchain systems

Requirement	Description	Blockchain support
SM-T-R1	Smart metering data integrity	Yes
SM-T-R2	Smart metering data authenticity	Yes
SM-T-R3	Users privacy	Neutral
SM-T-R4	Hierarchical smart metering architecture	Yes
SM-T-R5	Network interoperability	Neutral
SM-P-R1	Smart metering measures actual consumption and provide such information to consumers	Yes
SM-P-R2	Smart metering complies with cybersecurity, privacy and data protection legislation	Enhance SM overall cyber security
SM-P-R3	SM data are portable: they are consumers' property, who can transfer them to third parties	Neutral

9.2 Energy Communities

Energy communities combine the use of smart meters in a closed environment where data and energy could be transferred transparently between all involved entities. An important requirement derives from the potential size of such network in terms of participants (ENC-T-R1). Each blockchain platform has different capacities; however, since a geographically confined and locally connected energy community allows for a limited number of nodes to be managed, the participants' size per se would not be an issue for any blockchain system. In addition, the interaction between the community and other communities, the TSO and the DSO can replicate the same local structure. The same applies for the expected throughput size (ENC-T-R2) as well.

For what regards data protection issues, blockchain is often criticised for not been able to comply with the latest data protection regulations (ENC-T-R3), such as the GDPR. This is due to the fact that blockchains are immutable and as a result data cannot be deleted from them, which contradicts one of the regulation's basic articles in case in which personal data are stored on it. However, depending on the use case and the requirements proper solutions can

be deployed i.e., data aggregation or other configuration should be consider, to bypass such obstacles. For instance, the most common solution can be to the use of non-personal data in the transactions that are recorded in the blockchain. Alternatively, the personal data are not stored in the chain directly, but instead only a trace of them (i.e., data cryptographic hash) is recorded on it as a proof of the accomplished transaction. In that case, the data are sent to the involved entities through alternative channels. This way the blockchain does not handle personal data and do not require to comply with GDPR, however, the data shared among the participants should be protected in the context of GDPR.

In scenario such as energy communities establishing trust (ENC-T-R4) between the participants is considered of high importance for system's success, as the involved entities might be unknown to each other. In this context, blockchain offer an alternative path of establishing trust due to its intrinsic properties to guarantee data integrity and records' immutability in a completely transparent way.

Regulated access to the power bus (ENC-T-R5, ENC-T-R9) can be supported by an access control scheme that would be deployed at the blockchain (i.e. through a smart contract), however, such a requirement should be complemented by other energy technical solutions.

As far as transparency and security (ENC-T-R6) is concerned, blockchain can support current regulation frameworks for data protection (see also ENC-T-R3) as by design it guarantees data integrity and records' immutability among all the participants. In addition, blockchain through its data sharing mechanisms and the deployed consensus mechanism can support the direct data exchange and verifiability (ENC-T-R7) requirement. Data verifiability is also enhanced in a blockchain as all the participants can share a common logic (i.e., business rules) so they can individually validate data and transactions correctness.

With reference to ensuring robustness against malicious entities (ENC-T-R10), blockchain can play a vital role as entities can collaborate through the appropriate consensus mechanisms to detect possible malicious activities.

Table 3 overviews the policy and technical requirements of the smart metering use case and identify whether blockchain can support them.

Table 3. Overview of energy communities' requirements and possible support by blockchain systems

Requirement	Description	Blockchain support
ENC-T-R1	Handle a large number of participants	Neutral
ENC-T-R2	A high throughput of transactions	Depends on the platform
ENC-T-R3	Handle <i>sensitive-personal</i> data according to the underlying policy framework	Requires adaptation at the business layer
ENC-T-R4	Enhance trust among the participants	Yes
ENC-T-R5	Regulated access	Yes

ENC-T-R6	Transparency and Security	Yes
ENC-T-R7	Direct data exchange and verifiability	Yes
ENC-T-R8	Measurement noise	Neutral
EN-T-R9	Management of the community main and access to it	Neutral
EN-T-R10	Ensuring robustness against malicious peers or faulty meters	Requires adaptation at the business layer/consensus mechanism

To summarise, blockchain technologies offer the possibility to decentralise the operations of electric communities, mitigate the need of a central trusted authority, allow the prosumers to sell and buy energy from several actors that do not necessarily trust or know each other while eliminating the dependency and constraints deriving from a single centralised operator. This facilitates a free market with consequent reduction of costs and possibility of making profits for the prosumer. Integrity of data and possibility to transact in a trust less environment are in fact crucial requirements for this type of use case.

9.3 Flexibility

To accomplish an efficient DSR mechanism for providing flexibility services a secure and cybersecurity resilient platform should be supported. In this sense blockchain provides secure by design services (data integrity, authenticity, data immutability, and data sharing) that support explicitly the requirements FL-T-R1 and FL-T-R4. In addition due to blockchain's intrinsic properties transaction auditability (FL-T-R2) can be achieved. Moreover, considering current event based mechanisms that are supported by blockchain implementations (i.e., Ethereum) a complete system automation (FL-T-R3) can be realised as well.

Considering the policy related requirements, as described in Section 6, the whole infrastructure should enable consumers to participate, providing near real time information to the participants (FL-P-R1). In fact, an appropriate blockchain scheme could enable secure consumers transactions with energy markets, providing information near real time. That means that near real time requirements should be defined.

As far as barriers for the conclusion of the aggregation contract are concerned (FL-P-R3), they might be eliminated in a more transparent way with the deployment of smart contracts, however the business layer functionalities should be defined in priori. In this context, also part of the interoperability issues (FL-P-R4) would be eliminated as all the rules at the business layer would be provided in a transparent and secure way.

Moreover, through the deployment of blockchain technology data availability (FL-P-R4), and data sharing (FL-P-R6) are enhanced in comparison to traditional centralised schemes. Besides, such a scheme in the energy domain goes beyond the tradition approaches introducing a complementary approach for monitoring loads (FL-P-R4) and enables a trusted well-defined cooperation between the involved parties (i.e., TSO and DSO) in order to develop an efficient system (FL-P-R5).

Table 4 overviews the policy and technical requirements and identify whether blockchain can support them.

Table 4. Overview of flexibility requirements and possible support by blockchain systems

Requirement	Description	Blockchain support
FL-T-R1	Increase customer base and adoption rates by providing a secure platform	Yes
FL-T-R2	Providing a secure way to communicate and deploy control strategies to assets as well as audit transactions	Yes
FL-T-R3	Increase the efficiency of the aggregation service by enabling autonomous, computer to computer contracting	Yes
FL-T-R4	Secure data sharing mechanism that enables all the involved entities to provide the underlying services	Yes
FL-P-R1	Electricity markets should enable consumers to participate in the energy transition considering near real time information sharing	Yes
FL-P-R2	One major precondition for consumer participation in flexibility markets is the availability of smart meters and the corresponding services	Neutral
FL-P-R3	One of the main barriers for including small- and medium-sized loads into the demand response market is the absence of a unique and clear definition of independent aggregators as an important market participant	Yes
FL-P-R4	The provided system should provide the following services: (1) data availability and exchange (standardisation), (2) data management and (2) interoperability	Yes
FL-P-R5	Flexibility services will require extensive cooperation and clear boundaries between TSOs and DSOs	Yes

FL-P-R6	Information regarding the flexibility services should be shared between several parties (TSO, DSO, aggregators, consumers)	Yes
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9.4 Certification of Origin

Certificate of origin relies mainly on smart metering functionality (CO-T-R1) that can enable consumers/prosumers energy metering in near real time and attribute these readings to the relevant actors (CO-T-R2) for the issuance of certificate of origin. Such data sharing requirement can be accomplished with the use of blockchain solutions. Furthermore, the generated certificate of origin should be protected against possible forgeries and all the involved parties must be able to confirm its validity (CO-T-R4). In fact, blockchain system can support protection against possible forgeries as the integrity and authenticity of the stored data are guaranteed and through its consensus mechanism all the participant nodes can confirm the validity of the stored data, with the immutability of the blockchain. Table 5 overviews the requirements and identifies whether blockchain can support them for the certificate of origin use case.

Table 5. Overview of certificate of origin requirements and possible support by blockchain systems

Requirement	Description	Blockchain support
CO-T-R1	Full scale deployment of smart metering technologies	Neutral
CO-T-R2	Data sharing	Yes
CO-T-R3	Data security	Neutral
CO-T-R4	Validation of certification of origin	Yes

9.5 Mobility

Protecting wallets is a well-known and important problem when dealing with blockchain systems. There are two high-level ways in which access to a wallet and one's keys is achieved (M-T-R2): (a) the user had direct access to the wallet and uses a protection mechanism only known to himself for utilising it, and (b) the wallet is hosted in a third party, which handles all the keys on behalf of the user, and is the one responsible for enforcing the appropriate security mechanisms. The access of the user to the third party is similar to the one of accessing an online service.

The biggest advantage of the first option is that there is no need to trust any other part, while the downside is that there are no recovery options should the user lose the access means to the wallet. On the other hand, account recovery is possible when using a third party wallet service, however there is the need to trust that party with one's private keys.

In either case, the actual wallet and the keys need to be stored encrypted in a secure location, having backups in place in case of loss (M-T-R1). Several techniques could be utilised to

achieve this, however analysing them in details is out of the scope of this report. What is important to ensure however is that the legitimate owner should always have access to the keys in order to perform transactions when needed.

In order to perform a transaction, connectivity to the Internet, or at least to the network that is utilised for the payment, is needed. This requirement (M-T-R3), is not blockchain specific but rather concerns general connectivity issues in the IoT domain.

Finally, in an expanding system, scalability could become an issue. Current blockchain systems have not been tested with millions of nodes as a system where vehicles being a node would require (M-T-R4). However, this design option could be mitigated by having the vehicles operating as clients, and the nodes being the charging stations. Such an option would dramatically reduce the network size and could prove to be operational.

Table 6 overviews the policy and technical requirements and identify whether blockchain can support them for the mobility use-case

Table 6. Overview of mobility requirements and possible support by blockchain systems

Requirement	Description	Blockchain support
M-T-R1	Secure storage of wallets	Yes
M-T-R2	Access control to the wallets and their keys	Yes
M-T-R3	Provide internet and/or network connectivity to the vehicles in order to perform necessary transactions	Neutral
M-T-R4	Scalability of the underline network in order to support the necessary number of nodes	Yes

10 Conclusions

In this report we analysed five different use cases of using DLT in the energy sector. We did so from a technical perspective, speculating on how the energy and DLT integration could work in practice, but also from a legal perspective by describing the applicable energy and ICT related legislations.

More specifically, for each use case we defined the actors and the interactions they have between them. Moreover, we set technical requirements that would need to be fulfilled for an energy-DLT synergy to be functional and operational. Finally, where applicable, we set the societal challenges, in case such a use case becomes reality.

We started our analysis from the smart metering use case, which is at the heart of every energy use case. We then analysed energy communities, and more in particular three sub-cases: peer to peer, community shared balance storage and peer to grid. Afterwards, we studied the flexibility and the mobility use case, to conclude our analysis with the certification of origin applied to all the previous ones.

Our report concludes with the blockchain considerations for all use cases, in which we describe how the various blockchain requirements set previously are fulfilled and what potential shortcomings may arise.

We believe that from the use cases described, the more meaningful in terms of logic and technology to be implemented in a blockchain environment are the flexibility and energy communities use case. Not only would it be beneficial for the participating actors, but it would also be technically feasible to do so. This is the reason that in our work that will follow, we will further investigate this assumption by implementing a prototype of both use cases in our laboratories. Our goal would be to prove that the energy and blockchain domain can coexist in practice and that it would be beneficial to do so.

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List of abbreviations and definitions

ACER	Agency for the Cooperation of Energy Regulators
AMI	Advanced Metering Infrastructure
BB-LPC	Broadband Power Line Communications
BESS	Battery Energy Storage System
CBA	Cost Benefit Analysis
CEMS	Customer Energy Management System
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CEP	Clean Energy Package
CoOIA	Certificate of Origin Issuance Authority
CS	Charging Station
DLT	Distributed Ledger Technologies
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
EMG	Energy Management Gateway
EMS	Energy Management System
EV	Electric Vehicle
G2V	Grid to Vehicle
GDPR	General Data Protection Regulation
HAED	Home Automation End Device
HES	Head End System
ICT	Information Communication Technology
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LNAP	Local Network Access Point
MS	Member State
MSC	Message Sequence Chart
NB-PLC	Narrow Band Power Line Communications
NNAP	Neighbourhood Network Access Point
PLC	Power Line Communications
RED	Radio Equipment Directive
RES	Renewable Energy System
SCADA	Supervisory Control and Data Acquisition
SECD	Simple External Consumer Display

SGAM	Smart Grid Architecture Model
SM	Smart Meter
SMS	Short Message Service
SoS	Security of Supply
TIM	Tools for Innovation Monitoring
TPM	Trusted Platform Module
TSO	Transmission System Operator
UML	Unified Modelling Language
V2G	Vehicle to Grid
VTN	Virtual Top Node

List of boxes

Box 1. This is a box title.....**Error! Bookmark not defined.**

List of figures

Figure 1. AMI—Communication from the smart meters to the utility system with several technological solutions	5
Figure 2. Energy management functional architecture [10]	7
Figure 3. Message Sequence Chart showing interactions between actors for DSF actions [9].	7
Figure 4. Representation of Actors in the SGAM framework and their interactions [9]	8
Figure 5. Representation of Actors for the simple interaction between a smart meter and a data concentrator [11].	9
Figure 6. Structure of a peer-to-peer electricity community and possible interconnection with a Network Operator and other communities.	13
Figure 7. Structure of a shared storage electricity community and possible interconnection with a Network Operator and other communities.	14
Figure 8. Structure of a peer-to-grid electricity community and possible interconnection with a Network Operator and other communities.	15
Figure 9. Map of Explicit Demand Response development in Europe today [17]	18
Figure 10. Explicit DR hierarchical structure of data sharing between actors.....	19
Figure 11. UML sequence diagram for the “Automated DR services	20
Figure 12. General architecture of car-wallet payments	23
Figure 13. Actors’ interactions in a car-wallet payment scenario.....	23
Figure 14. Consumer as Actor	28
Figure 15. Generic Prosumer	29
Figure 16. Generic Prosumer equipped with BESS	30
Figure 17. Energy community formed by consumers to an MV/LV substation	31
Figure 18. MSC for the use case of a Prosumer with BESS where self-consumption is allowed and rest production exceeds consumption.	32

List of tables

Table 2. Overview of smart metering requirements and possible support by blockchain systems	47
Table 3. Overview of energy communities' requirements and possible support by blockchain systems	48
Table 4. Overview of flexibility requirements and possible support by blockchain systems	50
Table 5. Overview of certificate of origin requirements and possible support by blockchain systems	51
Table 6. Overview of mobility requirements and possible support by blockchain systems	52

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