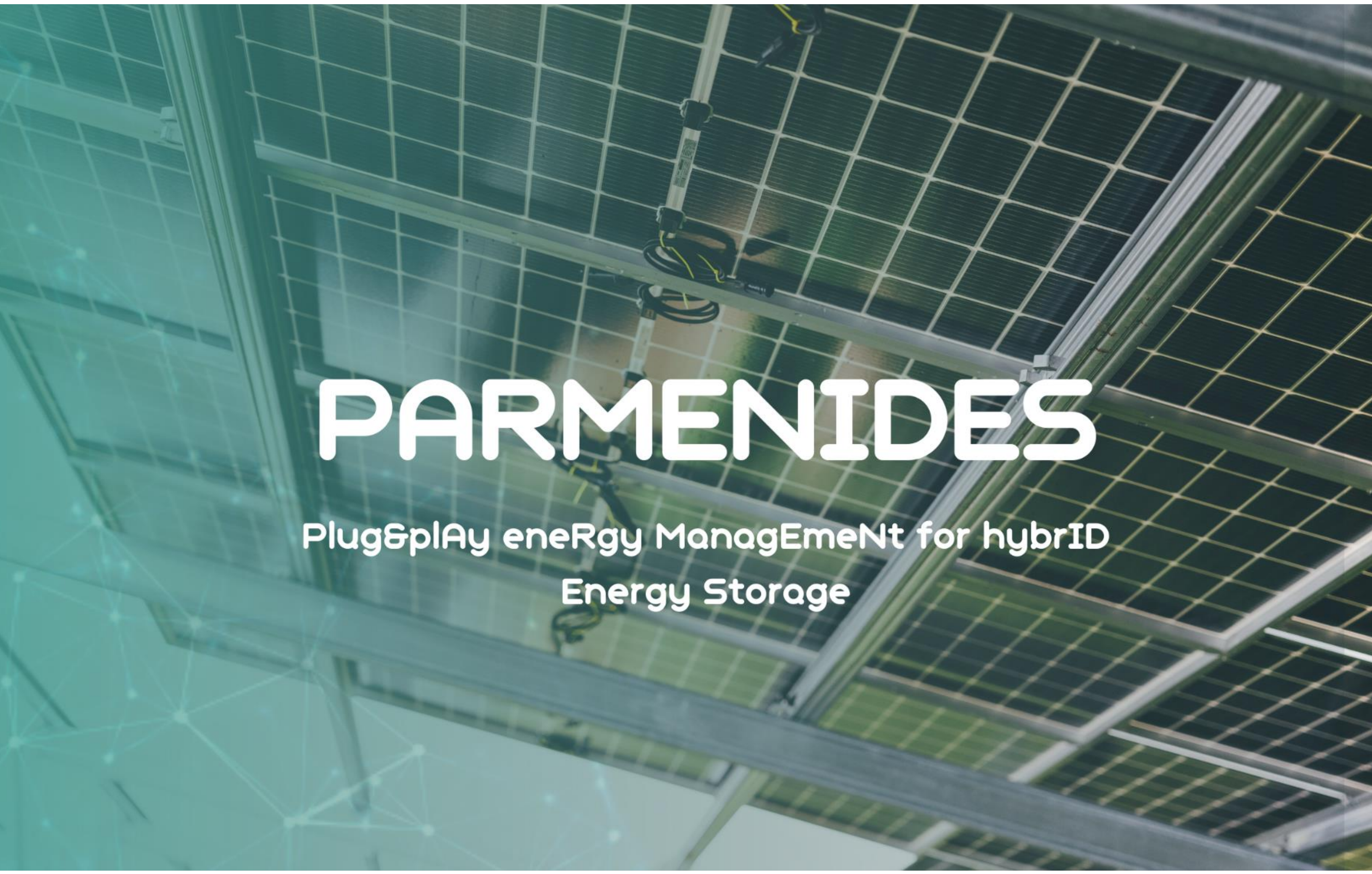

Deliverable D3.2

Interoperability framework and semantic interoperability

Work Package 3

Disclaimer

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PARMENIDES

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1. Executive Summary

This report describes the work performed within the task 3.2 of the PARMENIDES project regarding the interoperability framework and semantic interoperability, focusing especially on developing the PARMENIDES Energy Community Ontology (PECO). PECO allows representation of all entities relevant for the optimization of energy system within the renewable energy community (REC), putting a special emphasis on PARMENIDES pilot regions and use cases, and paying special attention to grid support. In addition, PECO allows representation of module interfaces for the purpose of early stage interoperability testing in the VLab environment. The intent of the ontology is to remain general enough to make it possible to apply PECO in other European countries. PECO is modelled in Protégé and is inspired and aligned with established ontologies for modelling of energy systems and buildings such as SAREF, Brick and BOT. PECO was developed following the LOT methodology, with stages explained in detail in the document. Theoretical underpinnings are described, with practical instantiation examples given to convey the use intent. Finally, the document describes the usage of PECO as part of the semantic interoperability layer used by the knowledge sharing agents, specifically focusing on the message and information exchange between the Energy Management System (EMS4HESS) and the Information and Configuration System (ICS). The ontology source file in turtle (.TTL) format is available in the Annex of this document as an OWL source, as well as on the world wide web.

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2. Abbreviations

Acronym	Description
AC	Alternating current
API	Application Programming Interface
BRP	Balance Responsible Party
CEC	Citizen energy community
CSV	Comma-separated values
DC	Direct current
EC	Energy community
ECM	Energy community member
EMS	Energy management system
EMS4HESS	Energy management system for hybrid energy storage system
GBP	Generic business processes
GTR	Grid tariff reductions
HEMS	Home energy management system
HESS	Hybrid energy storage system
ICS	Information and configuration system
LOT	Linked Open Terms
MQTT	Message-queuing transport protocol
ORSD	Ontology requirements specification document
PECO	PARMENIDES Energy Community Ontology
POD	Point of delivery
PVT	Photovoltaic-thermal
REC	Renewable energy community
RED	Renewable Energy Directive
REST	Representational state transfer
SM	Smart meter
VLab	AIT Virtual laboratory
WWW	World-wide web

3. Introduction

PARMENIDES Energy Community Ontology (PECO) aims at establishing a common vocabulary for semantic interoperability at the level of the data model and of the information layer in the context of Renewable Energy Communities (REC) in Europe. This is achieved by describing the energy community (regarding the excess energy allocation method, internal energy prices etc.), its energy community members, their assets (electrical and thermal energy generation assets and energy storage assets, such as PV or batteries)and properties thereof (static and dynamic), as well as the relationships between them (based on assets ownership and on system topology). Such abstractions allow real-time communication and data exchange between the devices and interfaces that are part of the project pilots, e.g., the Grid Capacity management System (GCM) and the Energy Management System (EMS) for the purpose of optimizing the production and consumption of energy community's and energy community members' systems to achieve predefined optimization objectives.

Section 2 of this deliverable provides a general background chapter on the use of ontology and on the specific goals of PECO, both within the scope of the PARMENIDES project and at a European level. A classification of the domains covered by PECO is given, distinguishing between: community members and community itself, energy assets, flexibility signals (grid perspective), and prosumer targets (user perspective). Moreover, this section also covers information on the transpositions of the Renewable Energy Directive in European countries, which have been taken into account while developing the ontology in order to make PECO general enough to be instantiated not only in PARMENIDES pilot regions, but also in different REC at the EU level. Therefore, flexibility actors and incentivization schemes are defined, in accordance with the definitions provided by BRIDGE, as well as the tariff schemes which could take place in pilot regions, depending on the direction of the energy flows. Moreover, a detailed classification of the type of assets covered by PECO and their properties (static or dynamic) is provided. Special emphasis is given to the energy assets, and in particular to the storage technologies, which are also grouped under the PARMENIDES novel definition of Hybrid Energy Storage System (HESS). Finally, the use of the AIT Virtual Lab (VLab) is introduced, with specification on how PECO models this tool for the purpose of the PARMENIDES project.

Section 3 focuses on the methodology used for the development of PECO, as well as its implementation, which follows the Linked Open Terms (LOT) methodology, and consists of four phases: ontology requirements specification, ontology implementation, ontology publication and ontology maintenance. This document describes each phase of development of the ontology, by providing both theoretical background and hands-on examples with sketches and instances based on PECO modelling. Collection of ontology requirements specifications is done via collecting the competency questions as well as collection of all the documents relevant for involved partners. This development step has been essential for collecting pilot-specific information with domain experts. Moreover, a special focus has been given to pilots´ assets and topology (also in relation to the use cases).

Section 4 summarizes the position of PECO within the system architecture and specifies its role in the semantic interoperability layer used by knowledge sharing agents, specifically focusing on the message and information exchange between the Energy Management System (EMS4HESS) and the Information and Configuration System (ICS).

Finally, in the Annex sections, the full ontology source is available as OWL file (Annex 1), and the detailed review of the transposition document for the Renewable Energy Directive in European countries is provided (Annex 2).

3.1. Acknowledgment

Authors would like to thank and acknowledge the whole scientific ontology-development community. Ontology development is truly a discipline where one stands on a gigantic number of scientists' and practitioners' shoulders.

Furthermore, we would like to acknowledge our PARMENIDES project colleagues and contributors who were very patient when we were asking what sometimes seemed like identical questions over and over to try to understand intricacies of some terms and concepts. We hope we captured those correctly, and if not, there is always an ontology maintenance phase.

4. Domain, scope and intent of the ontology

4.1. Background

Ontologies are used to semantically represent domain knowledge in a machine-interpretable way through a common vocabulary. Gruber defines them as an explicit representation of the domain, e.g., its classes (group of elements of the domain which could be univocally identified under the same name and which share certain properties), assets (elements of a class), attributes (properties of elements and/or classes) and their interrelationships (dependencies between elements of the domain, expressed with predicates), which are written according to a formal logic-based specification [1]. This allows machines to reason about assertions given in the domain model (i.e., facts as logical statements) and to build knowledge based on a domain model (instance-level assertions).

An example of possible relationships between assets and their properties is provided with an excerpt of SAREF ontology in Figure 1 [2]. Here, a certain Device (e.g., asset from PECO: “Heat Pump”) could have a Profile (predicate: hasProfile) which is described as a dynamic property (hasTimestamp, e.g., property from PECO “Nominal Power”).

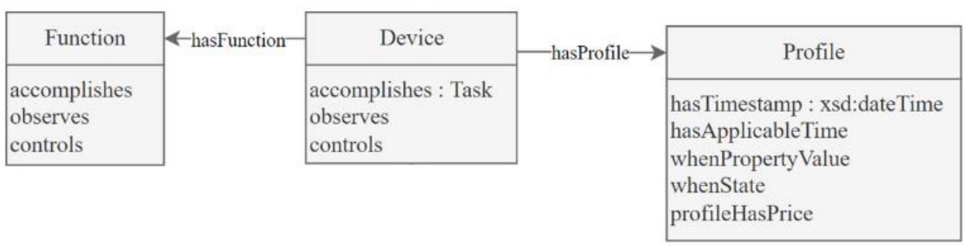

Figure 1: Excerpt from SAREF ontology [2]

In the case of the PARMENIDES project, PECO´s major contribution is to enable interoperability at the level of the data model and of the information layer, by generating an abstraction of the physical members of the ECs (energy community members), their assets (electrical and thermal energy generation assets and energy storage assets, such as PV or batteries), their properties (static and dynamic), as well as the relationships between them (based on assets ownership and on system topology). Such abstractions allow real-time communication and data exchange between the devices and interfaces that are part of the project pilots, e.g., the Grid Capacity management System (GCM) and the Energy Management System (EMS).

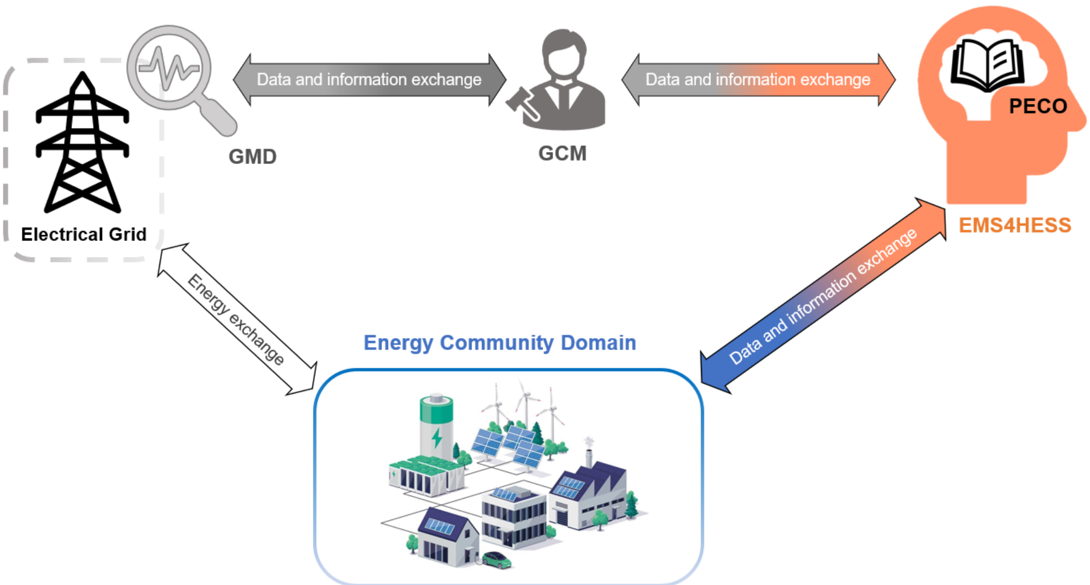

Figure 2: Sketch of PECO functionality and allocation within the context of PARMENIDES

As visible in Figure 2, PECO´s main function is to establish a common vocabulary to facilitate data and information exchange at two levels:

- EC Level: between the EMS and the smart meter, mediated by the Siemens Gateway. For instance, this data is related to the energy produced by the PV installation shared by the community, as well as the EC load, e.g., the energy consumed within a certain timeframe to run a heat pump.
- Grid Level: between the EMS and the GCM. In this case, the GCM is collecting and elaborating data with respect to the grid state and its stability, thanks to the information received by the grid monitoring device. Calculated setpoints for customer equipment are forwarded to EMS along with possible incentives.

According to Gruber, the most relevant design criteria to be adopted for a successful ontology development are:

- *Clarity*: ontologies must be able to effectively and objectively communicate the definitions of each term of the domain. In PECO this means, for example, defining formally and univocally the meaning of each asset class (e.g., "heat pump"). This implies the constructing axioms whose predicates are defined by all necessary and sufficient conditions. For example, "Heat pump *(asset class, e.g., Device)* hasProperty *(predicate)* Hot side temperature *(asset property)*".
- *Coherence*: ontology axioms must be logically consistent and do not contradict themselves.
- *Extendibility*: ontology should already envision the possibility to extend its use to larger domains, i.e., defining new terms for special uses, based on the existing vocabulary without revising existing definitions. For instance, PECO is intended to be general and applicable also in the context of other RECs at European level and to be further developed/extended, when needed. At the same time, it aims to reuse and/or align with established ontologies developed in the field of energy systems and building data models, i.e. SAREF [2], SAREF4BLDG [3], Brick [4] , BOT [5] and more general ones such as FOAF [6], QUDT [7], etc.

- *Minimal encoding bias*: representation choices should not be made purely for the convenience of notation or implementation, so that the ontology could be reused and implemented by knowledge-sharing agents with different representation systems and styles. For example, PECO aims to use a reusable and widely understandable vocabulary when assigning definitions to the elements of the domains, so that they can be easily adopted in the PARMENIDES pilots, but remain valid for instantiation in other RECs, and readable from other EMS, GCM and other communication systems.
- *Minimal ontological commitment*: ontology should be modelled in an essential way, i.e., requiring the minimal commitment to support knowledge sharing activities, but being in-depth enough to properly describe the system. This way, ontologies could be easily instantiated by third parties without major changes. PECO commits to this requirement by being used and instantiated in two pilots, different from each other's for classes within the domain, regions, topology, modeling objectives, and extension.

4.2. Domain and scope

The main objectives of PECO could be distinguished between PARMENIDES-specific goals and more general objectives related to the enhancement of flexibility strategies for energy communities at European level. These are schematically summarized in Table 1.

Table 1: Project and EU objectives of PECO

Objective	Description	Applicability	Innovation
(1) Enable interoperability between knowledge-sharing agents by means of domain abstraction and creation of common vocabulary	PECO allows interoperability at EC Level (between the EMS and the smart meter, mediated by the Siemens Gateway) and at grid level (between EMS and GCM) at the three pilot regions defined by the project.	Project-objective	To the best of our knowledge PECO is the first public ontology developed with the purpose of supporting REC implementation at European level. Moreover, it is the first ontology representing the concept of HESS to deploy flexibility services for grid stabilization purposes.
	PECO aims to be general enough to be reused and instantiated in different RECs and by different EMS with minimum effort and changes to its definitions.	EU-objective	
(2) Support deployment of flexibility services by representing the Hybrid Energy Storage Systems (HESS[1]) conceptualization	Among the assets covered within the domain of PECO, the electrical and thermal storage devices play a very important role, being defined as part of the Hybrid Energy Storage System	Project-objective	To the best of our knowledge, due to the novelty of the concept of HESS, PECO is the first public ontology

[1] At present, there is no common definition of HESS in Europe

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according to pilots-specific topologies	(HESS). These latter are connected to each other's according to pilots-specific topologies, with the aim to operate them in a coordinated way, as a result of EMS optimization algorithms. PECO represents each asset and localizes it within the system topology to facilitate optimization by the EMS.		facilitating storage abstraction on this level
(3) Alignment with major established ontologies in the energy domain	PECO aims to reuse and/or align with established ontologies dealing with the topic of energy, building devices and topology, as well as more general ones focusing on assets, persons, their activities and their relations to other people and objects.	Project-objective and EU-objective	Although PECO is not an extension of any existing ontology, it is intended to be an independent contribution to the field of REC, while remaining consistent with the current literature on ontology modelling.
(4) Supports project-specific tools	PECO supports the instantiation of the VLab, which will be used to emulate connections between the system components to proof their effectiveness.	Project-objective	PECO is the first public ontology supporting VLab in its operation.
(5) Enable ontology reusability in other countries to increase adoption and uptake of REC	PECO aims to be general enough to be easily reused at a European level, even in countries that are not part of the project pilot regions and therefore may be affected by different transpositions of the EU directives on energy communities. This way, PECO aims to promote the update of REC in Europe, by facilitating interoperability between relevant knowledge-sharing agents, among which, the energy management systems. Even considering the constantly	EU-objective	PECO is the first public ontology operating in the field of REC and contributing to their uptake in Europe.

	evolving legal context within the field of energy communities in Europe, PECO contains the basic definitions, concepts and relationships, which are needed by knowledge-sharing agents to operate in the field of REC.		

The domain covered by PECO is the one of Renewable Energy Communities (REC), according to the current guidelines available in the Renewable Energy Directive (RED) [8]. A special focus has been placed on its transposition into national regulations at European level and especially for the countries which host the PARMENIDES pilots (Austria and Sweden), as further specified in section 2.2.1.

Figure 3 shows a schematic representation of the 4 domains which are covered by PECO, which could be summarized as follows:

1. *Energy community and its members:* this includes energy community members (persons) and their organization at EC level (legal entities)
2. *Energy assets:* this includes both energy generation and storage assets, and for multiple energy vectors (electricity and heat). In particular, the energy storage assets fall within the Hybrid Energy Storage (HESS) category, which could be used an abstraction of specific storage technologies (see section 2.2.4). Moreover, being the energy assets monitored and modelled to either enhance flexibility or met prosumers targets (e.g., optimization strategies), their energy production or consumption forecasts and schedules are also represented within the ontology under this domain.
3. *Flexibility signals (grid perspective):* this includes incentives and grid tariffs issued by the DSO. Therefore, flexibility could be enhanced at REC level, by providing economic benefit to the prosumer/EC, whenever the consumption behavior supports grid stabilization, e.g., avoids grid congestions problem. PECO also supports the detection of the type of flexibility suggestions for the operation of the energy assets (e.g, ranges if operation or specific setpoints).
4. *Prosumer goals and engagement (user perspective):* this includes the preferences and optimization schemes available to EC and EC members (e.g., comfort maximization, environmental impact reduction and cost minimization), which are used by the EMS to parametrize optimization algorithms. Moreover, this domain also supports the communication interface between the EMS and the user, i.e., to display information on his consumption, preferences, as well as suggested modification of his behavior, based on results from EMS optimization.

Furthermore, PECO also supports the AIT Virtual Lab environment (VLab). In fact, the VLab is a support tool used in PARMENIDES project and not specifically designed for energy community support. Therefore, it is implemented as a separate model and will be separately instantiated in the context of the project's pilots.

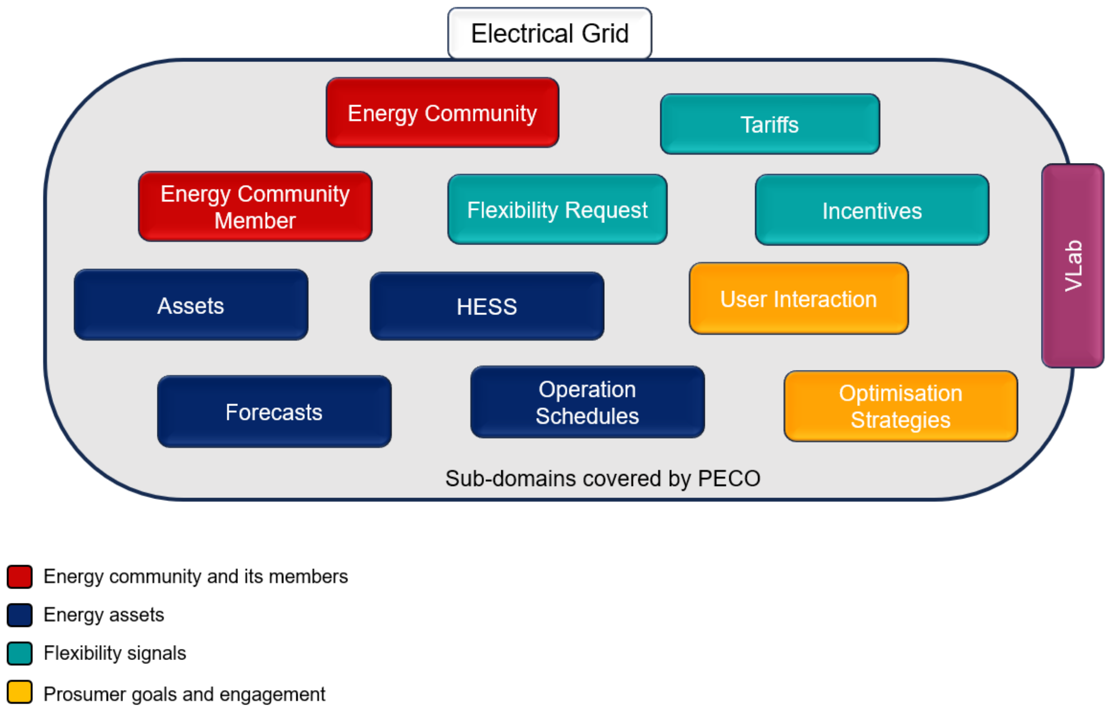

Figure 3: Schematic representation of domains covered by PECO

Examples of domains which are not covered by PECO are:

1. DSO infrastructure and communication system, including data exchange between the Grid Monitoring Device and the Grid Capacity management System (GCM).
2. Data exchange between Energy Supplier (ES) and the ECM. This is generally not considered within the boundaries of the system, if not for necessary information, e.g., electricity buy price, which is relevant to perform cost-driven optimizations from the EMS. However, being this a contractual information, it is usually established once and do not need further update, unless something changes within the legal agreement between ECM and ES. Therefore, information related to energy bills and internal allocation are also disregarded, since they take place ex-post and are therefore not relevant for the knowledge-sharing agents.
3. Interoperable message exchange. In fact, PECO does not aim to describe how messages are exchanged between different components, but only to provide the basis for smooth semantic interoperability between them.
4. Storage and timeseries within the knowledge base. While representation of timeseries related to datapoints is supported, current state of the art of knowledge bases does not allow collecting and processing of high volumes of time series information, e.g., storage and reasoning of full EMS time series database is out of scope of today's knowledge bases.

The modelling details of each of the domain covered in PARMENIDES are described insection 5.3, including examples of the assets modelled in the ontology.

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4.2.1 Transposition of European Renewable Energy Directive

Energy Communities as Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) have been legally implemented in the EU Clean Energy for all Europeans Package in 2019. However, the directives[2] needed to be transposed into national law of each member state for the concept to be enabled. Within PARMENIDES, the focus is on RECs – these are communities that enable renewable energy/electricity sharing with the usage of the public grid; however, the members of the REC need to be located within proximity of the renewable energy generation facility.

Annex 2 provides the thorough review of energy community transpositions in the European countries of all project partners, whereas the following paragraphs shall provide insides to the different legal possibilities concerning RECs in the demonstrator countries of Austria and Sweden.

Whereas Austria has transposed RECs and CECs entirely since 2021, Sweden currently only allows collective self-consumption within (a broader definition of) a building. However, Sweden has recently enabled pilot areas with concession exemption in order to test the concept. The legal definition in Austria allows for renewable electricity sharing with reduced grid tariffs and some waived taxes/levies within RECs, whereas all members of the REC need to be located within the same low-voltage or medium-voltage grid. Energy sharing is implemented as collective self-consumption in the case of Sweden and as an ex-post energy allocation done by network operators in the case of Austria. The energy price of the shared electricity can be determined freely by the REC in Austria.

4.2.2 Flexibility actors and incentivisation schemes

Flexibility could be defined as a service based on measurable and verifiable modification of energy production and/or consumption behaviour in reaction to external signals (request or activation) [9]. Flexibility is usually incentivized, usually by monetary compensation, in order to meet the goals of all the parties involved. According to the Bridge "Interoperability of flexibility assets" report, the stakeholders who take part into this process are the following [9]:

- *Flexibility provider (prosumer):* it is the actor that could take part in the flexibility provisioning by changing its consumption profile, according to the flexibility request received. It is an energy prosumer, e.g., in the case of PARMENIDES, an EC or EC member.
- *Flexibility consumer (system operator):* it is the party who initiate the flexibility request and who is willing to provide compensation to meet its specific targets, e.g., those related to grid stabilisation. It is noted that, in more general cases, the flexibility consumer does not necessarily correspond to the system operator. For instance, it may also correspond to an energy supply company. Nevertheless, in the case of PARMENIDES, this corresponds to the grid operator (DSO).
- *Flexibility service provider:* it is the party corresponding to the aggregator, who is not taking part to the flexibility by itself but facilitate its actuation by representing an intermediate actor between the flexibility provider and consumer, making flexibilities accessible to the market and by getting part of its compensation in turn. For the case of PARMENIDES, this stakeholder partially fits the role of the EMS, which is the party which collects the flexibility requests inputs from the DSO and

[2] The REC is defined in the Renewable Energy Directive, whereas the CEC is defined in the Energy Directive.

the available flexibility at the prosumer side, in order to suggest optimised consumption strategies to the EC. However, the EMS is not a player within the open market and does not have the role to negotiate flexibilities between the two parties.

- *Flexibility facilitator:* also named Balance Responsible Party (BRP), it is the party representing an aggregation of multiple flexibility consumers, to make them access to the market. In the case of PARMENIDES, this stakeholder is disregarded, and only one flexibility consumer (DSO) is considered.
- *Flexibility market operator:* it is the party which connects the flexibility providers and consumers, who is responsible for announcing the flexibility request and/or offers, thus contributing to the parties involved into flexibility to provide the service. For the case of PARMENIDES, this stakeholder is disregarded, but communication is directly instantiated between the flexibility consumer and provider.

According to Bridge [9], six different generic business processes (GBP) could be identified to describe the mechanisms behind the utilisation of flexibility through open market. Among them, GBP 2 (Figure 4) and GBP 4 (Figure 5) partially represent an abstraction of PARMENIDES high level use cases 3 and 4, even if with some substantial differences.

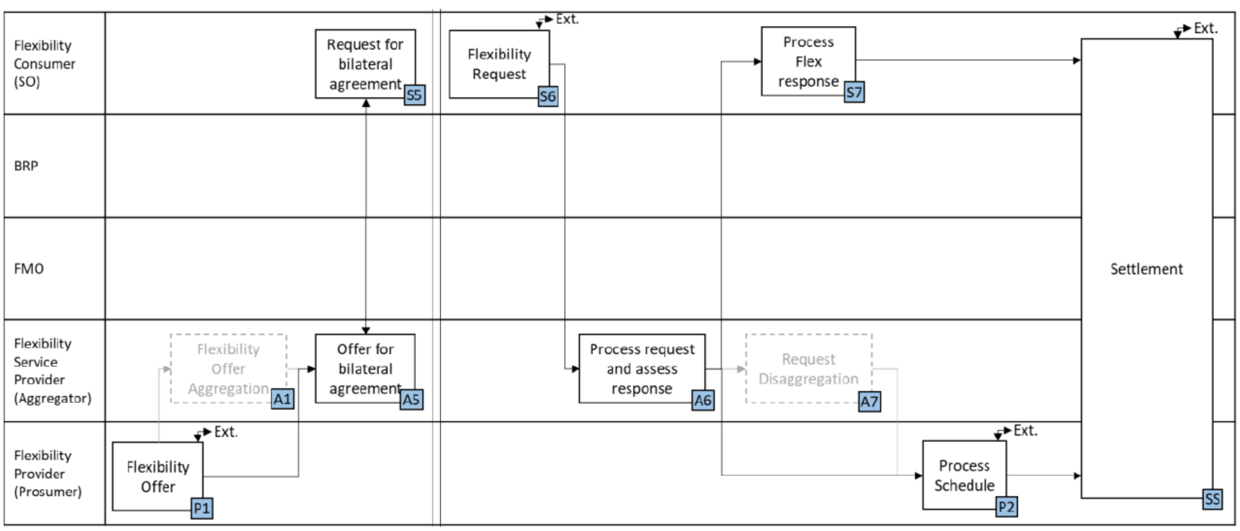

Figure 4: Business process diagram for GBP2 "SO flexibility via prior bilateral agreement" [9]

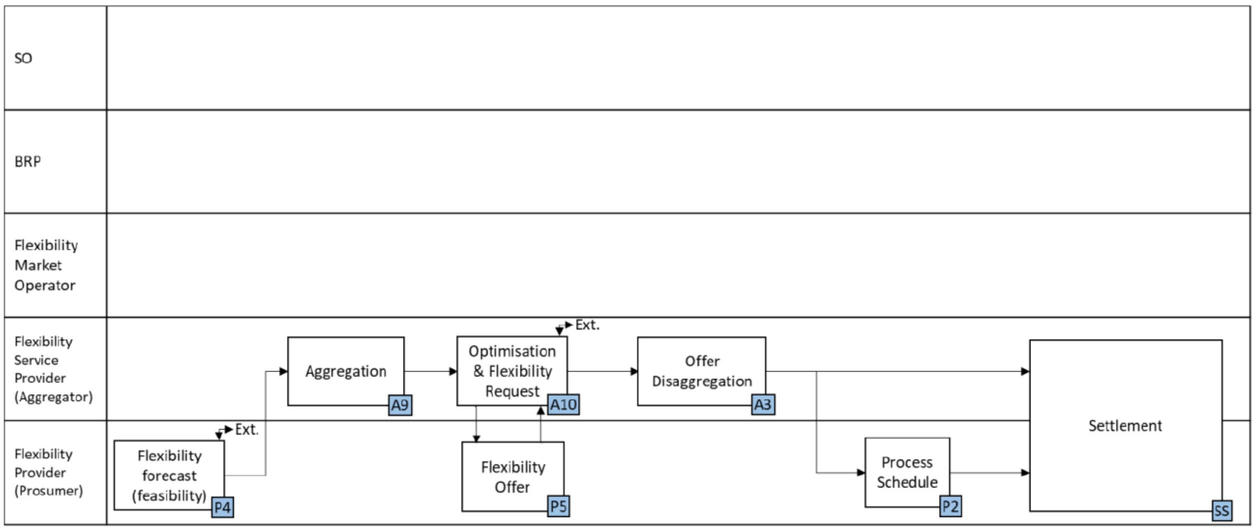

Figure 5: Business process diagram for GBP4 "Energy community optimisation" [9]

Generally, in PARMENIDES, the flexibility request is initiated from the DSO (i.e.., the system operator), which identifies and monetarily incentivizes consumption patterns to be followed within a specific timeframe, with the primary goal to ensure grid stability. These indications are sent and processed by the energy management system (EMS), which acts as a flexibility service provider, in the sense that it is able to aggregate the feasible flexibility of the prosumer (i.e., based on the utilisation status of the community shared energy assets), with the flexibility request coming from the grid. Therefore, the EMS has the role to suggest consumption strategies that best meet both grid requirements and the EC's optimisation objectives.

The main differences between PARMENIDES use cases 3 and 4 and the flexibility mechanisms illustrated in GBP 2 and 4 are the following:

1. Since the market role of the aggregator is missing in PARMENIDES, no offer for bilateral agreement could be instantiated between the two parties, but the flexibility request (including its incentivisation) is always starting from the DSO (system operator).
2. The prosumer in PARMENIDES does not instantiate any flexibility offer, but has a certain flexibility profile, based on his forecasted consumption pattern and based on the flexibility profiles of his energy assets.
3. The EMS has the role to aggregate relevant information from the two parties (flexibilities request and flexibility profiles) and further elaborate this information by use of optimisation algorithms. Thus, it is able to disaggregate the available flexibility, suggesting utilisation schedules for each energy asset and for the prosumer (EC and/or ECM).

Finally, it is noted that the consumption setpoints sent from the DSO in case of grid overload are not considered flexibility, as these must be respected to comply with the grid requirements. Nevertheless, the EMS may also elaborate an optimal operation of the energy assets in order to achieve the abovementioned requirements.

4.2.3 Tariffs

In PECO, two main categories are defined when referring to tariffs: grid tariffs (e.g., the price set from the DSO to utilize the grid infrastructure) and electricity tariffs (e.g., the price related to electricity negotiation, which could be further distinguished between buy and sell tariffs). Regardless their variability nature (e.g., fixed electricity price versus variable electricity price), electricity tariffs could be always defined as *unconditional* prices, since they are a result of a market agreement between the parties involved. Whenever subsidies are applied to tariffs, these are referred to as “incentives” (see section 2.2.2).

Moreover, as anticipated, different types of electricity prices for end costumers could apply at European level, for example: fixed electricity price (the energy price is kept constant at a fixed amount per kWh), daily variable electricity price (the energy price is varying interdaily), hourly electricity price (the energy price is varying between intradaily), zonal electricity price (the energy price is based on geographical constraints, e.g. nodal pricing). In the case of grid tariffs, these must be further broken down in accordance with the energy flow that is involved in the network infrastructure. In fact, as a result of the transposition of the Renewable Energy Directive in some EU countries, special grid tariff reductions (GTR) apply to energy communities which are exchanging surplus generation.

A practical example for the Austrian case is given in the “Systemnutzungsentgelte-Verordnung 2018 amendment of 2024” [10], where the following grid tariff reduction apply for renewable electricity that is shared within an REC:

- Local energy communities (grid levels 6 and 7, e.g., transformer stations and voltage up to 400/230 V) get grid tariff reduction of 57 %
- Regional energy communities (grid levels 6 and 7, e.g., transformer stations and voltage up to 400/230 V) get grid tariff reduction of 28 %
- Regional energy communities (grid levels 4 and 5, e.g., voltage up to 30-10 V) get grid tariff reduction of 64 %

Table 2 summarizes in which cases grid tariff reductions apply (GTR), rather than full grid tariffs (1), or no grid tariff (0).

Table 2: Applicability of grid tariff reductions

	Grid	**EC-Load**	**ECM-Load**	**ECM Self-Load**	**EC-Storage**	**ECM-Storage** (behind the meter)	**Grid-Storage** (operated by DSO[3])	**Grid-Storage** (operated by a 3rd party)
Grid	X	1	1	X	1	1	0	1
EC-PV	0	GTR	GTR	X	GTR	0	0	1
ECM-PV	0	GTR	GTR	0	GTR	0	0	1
EC-Storage	0	GTR	GTR	X	X	X	0	1
ECM-Storage	0	GTR	GTR	0	X	X	0	1

[3] There is currently no legal framework for this option, therefore this case is only supported by PARMENIDES for research purposes.

Finally, it must be considered that, in real operation, all the energy flows are utilizing the grid infrastructure and electricity could not be directly consumed using only the direct connections between EC members. In fact, the energy always flows from and into the grid, however, thanks to the real-time data registered by the smart meters, the amount of energy drawn from the grid at each point of time can be tracked and charged accordingly. Therefore, at the end of the month, the DSO is able to assign the energy flows and the correct costs to all its users (bills), considering the exact amounts of energy consumed and produced by the EC and ECM at each point of time (e.g., energy injected and drawn from the grid).

Finally, whenever the energy flows directly into the grid or grid storage operated by the DSO (infeed), no grid tariffs are applied, according to the current framework.

4.2.4 Assets classification and their properties

Assets classification

In PECO, assets could be divided into two main categories: energy assets and flow moving devices. The energy assets are primarily classified according to their function (generation or storage) and the type of energy vector which they deal with (electricity or heat). Moreover, the assets covering both electrical and thermal generation are assigned to the cogeneration class. An overview of the abovementioned classification is available in Table 3.

Table 3: Overview of energy assets

Electrical		Thermal		Electrical and Thermal
Generation	**Storage** [4]	**Generation**	**Storage** [2]	**Cogeneration**
Photovoltaic (PV)	Battery	Heat Pump	Water Tank	Photovoltaic-Thermal Collector (PVT)
	Hydrogen	Sorption Chiller	Building Thermal Mass	Combined Heat and Power Plant (CHP)
	Electric Vehicle Charger	Boiler		
		District Heating Grid		

Moreover, special attention is paid to the interoperable actuation of storage assets, coupling together the electrical and thermal vectors under the concept of Hybrid Energy Storage System (HESS). In PARMENDIES, this latter is defined as a combination of two or more energy storage mediums with one or more energy carriers as input(s) and/or outputs, coupled through energy coupling devices, transported through shared lines, buses, loops, nodes, and/or networks of those carriers, designed with a specific topology, and ideally controlled by an appropriate energy management system to inject and release desired energy quantities, rates, and/or quality of respective energy carriers at specific time intervals according to specific system objectives. It can be characterized as a collective unit in terms of power and energy injection requirements

[4] It is considered part of HESS.

and limitations, capacity and capacity constraints, system efficiency, and power and energy outputs, but can be further disaggregated into its respective carriers and components, including but not limited to the charge and discharge rates, storage losses and degradation factors, and efficiencies of coupling devices and transport systems. Energy demand by coupling devices is considered part of, and not isolated from, the system input energy requirements.

The goal of EMS4HESS is to intelligently control the storage devices in order to maximize their utilization and comply with the optimization strategies of the EC/ECM. In PECO, the modelling of assets already takes into account the topological network of devices, as well as their controllability, as explained in section 3.3.2. This way, the optimal actuation of EMS4HESS algorithms is ensured once the ontology is instantiated.

The flow moving devices are assets which are used to move heat transfer fluids (air or water) within the system. For instance, they could be part of an energy asset or be responsible for the motion of the energy carriers between two energy assets. In PECO, the flow moving devices are the pump and the fan. Additionally, flow controllers are defined as assets used to regulate the flow of the heat transfer fluids, such as: valve, duct splitter and joiner (Y).

Assets properties

Static and dynamic properties are assigned to both energy assets and flow moving devices. The first are assigned accordingly to the nameplate data available for each asset. These properties are useful to assign device-specific technical characteristics to the assets, which are related to the commercial device model which will be later instated in the ontology, such as: operation ranges, efficiency, expected performance under nominal conditions etc. Moreover, by definition, static properties are considered constant throughout the expected lifetime of the device and, therefore, do not have any timeseries attached to them. For each property, the data type and data unit are specified, as well as its definition.

Table 4 provides an example of static properties for the battery asset.

Table 4: Static properties of battery

Asset Class	Asset Name	Static Property	Data Type	Data Unit	Definition
Electrical Storage	Battery	ID	String	-	Asset ID.
Electrical Storage	Battery	Label	String	-	An optional label describing the asset.
Electrical Storage	Battery	Lifetime	Integer	y	Asset lifetime under nominal operating conditions.
Electrical Storage	Battery	Weight	Float	kg	Asset weight.
Electrical Storage	Battery	Volume	Float	m^3	Asset volume.
Electrical Storage	Battery	Nominal Voltage	Float	V	Nominal voltage.
Electrical Storage	Battery	Consumed Power	Float	kW	Electrical nominal power consumption during operation.

Electrical Storage	Battery	Maximum Charge Power	Float	kW	Maximum charge power.
Electrical Storage	Battery	Maximum Discharge Power	Float	kW	Maximum discharge power.
Electrical Storage	Battery	Nominal Storage Capacity	Float	kWh	Nominal storage capacity.
Electrical Storage	Battery	Maximum SoC	Float	%	Maximum state of charge of storage.
Electrical Storage	Battery	Minimum SoC	Float	%	Minimum state of charge of storage.
Electrical Storage	Battery	Charging Efficiency	Float	%	Average lifetime charging efficiency.
Electrical Storage	Battery	Discharging Efficiency	Float	%	Average lifetime discharging efficiency.

On the contrary, dynamic properties are, by definition, variable with time: therefore, they are modelled as time-series. These properties could be either forecasted or monitored, thanks to the utilization of sensors. For each property, the data type, data unit and data interval are specified, as well as its definition.

Table 5 provides an example of dynamic properties for the battery asset.

Table 5: Dynamic properties of battery

Asset Class	Asset Name	Dynamic Property	Data Type	Data Unit	Data Resolution	Definition
Electrical Storage	Battery	Voltage	Float	V	15 min	Measured voltage during operation.
Electrical Storage	Battery	Active Power (Inlet)	Float	W	15 min	Measured power during charge.
Electrical Storage	Battery	Active Power (Outlet)	Float	W	15 min	Measured power during discharge.
Electrical Storage	Battery	Consumed Energy	Float	kWh	15 min	Energy consumed during operation.
Electrical Storage	Battery	Produced Energy	Float	kWh	15 min	Energy consumed during operation.
Electrical Storage	Battery	Available Storage Capacity	Float	kWh	15 min	Available storage capacity during operation.
Electrical Storage	Battery	Forecasted Storage Capacity	Float	kWh	15 min	Forecasted storage capacity.

Electrical Storage	Battery	SoC	Float	%	15 min	State of charge of storage during operation.
Electrical Storage	Battery	Forecasted SoC	Float	%	15 min	Forecasted state of charge of storage.
Electrical Storage	Battery	Charge Mode	Boolean	Yes – No	1 min	Storage charging mode.
Electrical Storage	Battery	Discharge Mode	Boolean	Yes – No	1 min	Storage discharging mode.

4.2.5 AIT Virtual Lab (AIT VLab)

Interoperability is a key enabler of smart grid potential and should be regarded as an intrinsic component of any smart grid application being developed from its inception. Because interoperability is a design consideration, it should be included from the early stages of development of the architecture model. This way, when the engaged partners and stakeholders have a better understanding, agreement and knowledge of the automation interfaces, dependencies, and expectations, it makes communication between them more effective and easier.

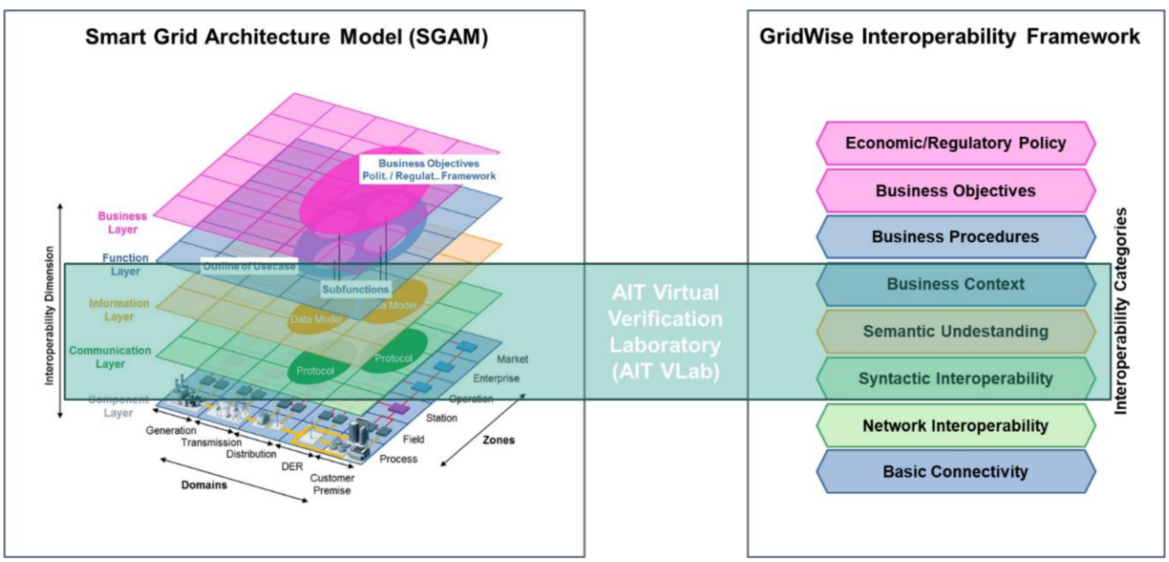

Figure 6: AIT Vlab interoperability coverage on SGAM and GridWise Interoperability Framework

In the PARMENIDES project, interoperability among various components and sub-systems of the developed solution is an important objective. Having an interoperable solution has many advantages for every stakeholder. To achieve this objective, the principle of *interoperability-by-design* is implemented. This principle advocates that interoperability must be considered from the very beginning of the solution design and should go all the way to the end. In the PARMENIDES project, this is achieved with the help of the AIT Virtual Lab (Vlab) and PECO. In particular, the utilization of PECO instances as input data for AIT Vlab (instead of filling out the input templates manually) is the main extension of AIT Vlab in PARMENIDES. AIT Vlab complies with standards in Smart Grid interoperability. Figure 6 shows the coverage of AIT Vlab's coverage of interoperability in reference to Smart Grid Architecture Model (SGAM) and GridWise Interoperability Framework.

One of the challenges to achieve a high interoperability maturity level is having an incompatible and ad-hoc workflow. The AIT Vlab addresses this challenge by providing a framework that includes a methodology and toolset for achieving a higher level (semantic and above) of interoperability. It advocates defining a common view of the system first, so that the functional objectives of the solution can be aligned with the implementation requirements. This way it also helps in bridging the knowledge and understanding the gaps between the requirement and implementation teams. The framework is equally beneficial for system architects, developers, and most other stakeholders. Vlab is an ecosystem of modules, interfaces, allowed operations, and data model along with both synchronous (REST APIs and client SDKs) and asynchronous (publisher/subscriber model) architectures with accompanying documentation packed in a portable environment to provide a mockup prototype of the proposed system for testing and integration. Supporting asynchronous architectures (e.g., MQTT-based communication as implemented in the Austrian pilots) is another extension of Vlab as part of PARMENIDES. Therefore, the input templates are adapted on the one hand and the generated code and mock-ups on the other. Figure 7 **Fehler! Verweisquelle konnte nicht gefunden werden.**presents a comparison between working of a project with and without AIT Vlab framework.

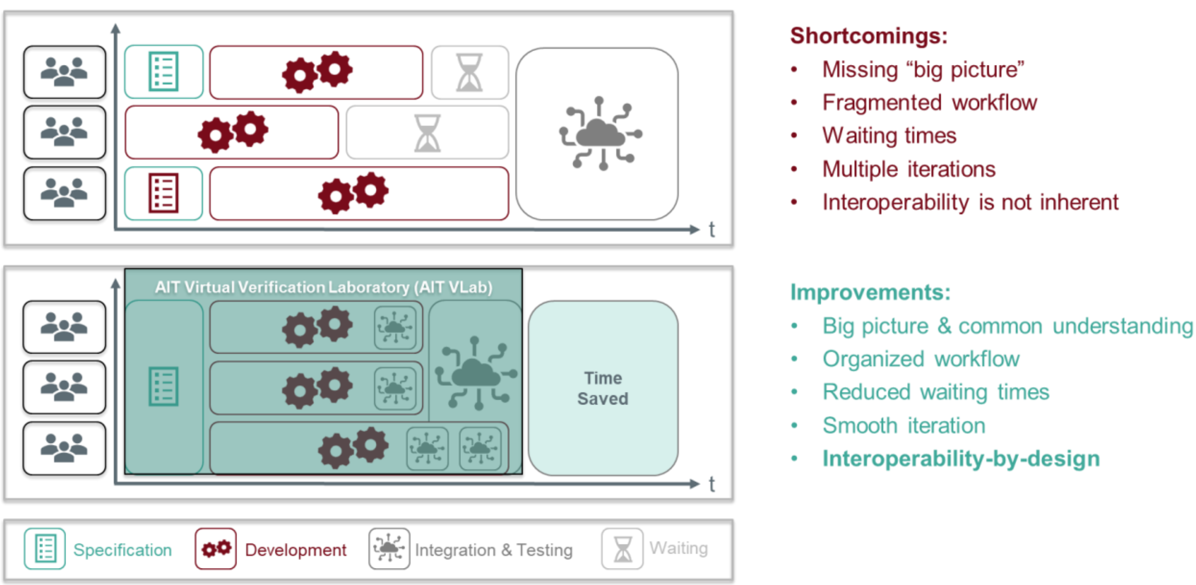

Figure 7: Summary of improvement by using AIT Vlab framework

Once the primary phenomena and their attributes have been agreed upon, Vlab can assist in designing an acceptable data model that can be used to represent these phenomena and their qualities in an information system. This data model may subsequently be utilized to establish public automation interfaces of the key subsystems for such communication. The only input required for AIT Vlab to operate is the definition of such a data model and the specification of the modules and interfaces using the Vlab Input Template. Once information is supplied, the toolkit may use it to produce a variety of artefacts. Finally, AIT

Vlab is also capable of performing post-pilot-implementation analysis for conducting scalability and replicability analysis that would help in identifying. The workflow is summarized in Figure 8 below.

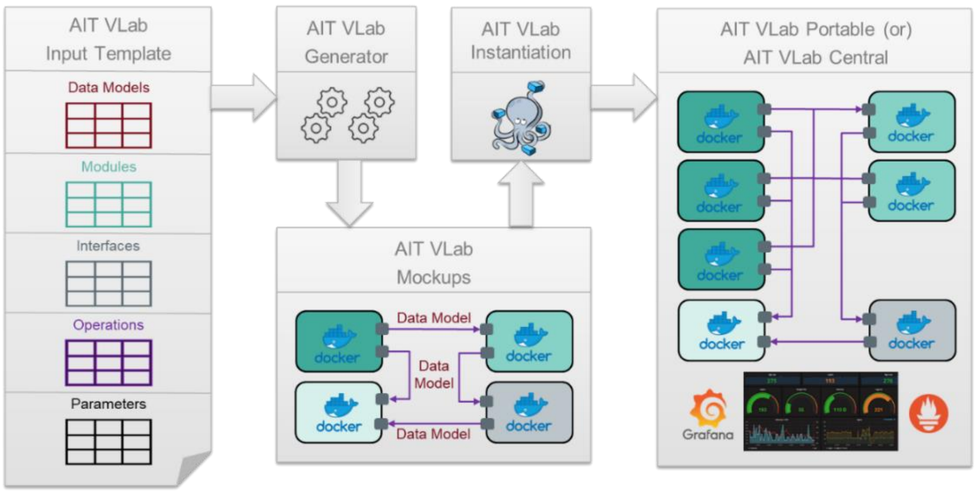

Figure 8: AIT Vlab workflow summarized

5. Methodology and implementation

The methodological approach used for the development of PECO follows the Linked Open Terms (LOT) methodology, which is a commonly used methodology for developing ontologies and vocabularies focusing on industrial projects [11]. This latter consists of four phases:

1. Ontology requirements specification
2. Ontology implementation,
3. Ontology publication and
4. Ontology maintenance

The LOT methodology defines an iterative workflow to be used by ontology developers in collaboration with domain experts and users, to successfully collect all the necessary information needed, resulting in an ontology requirement specification document(ORSD), and translate them into a structured vocabulary (ontology) to be iteratively published and maintained, according to the schema in Figure 9.

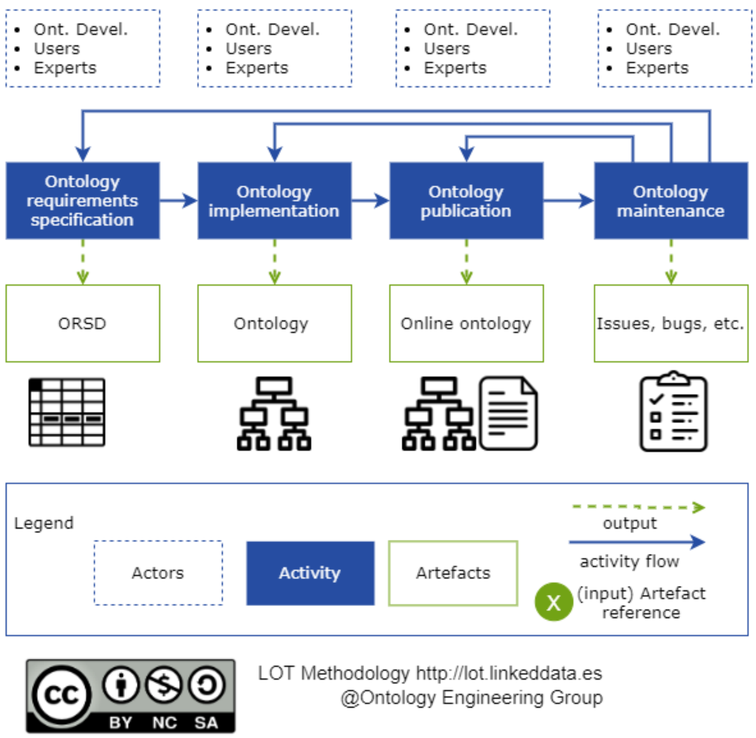

Figure 9: LOT Methodology general structure [11]

Moreover, the LOT methodology focuses on the alignment and reuse of terms and concepts which are already in use in other ontologies existing in literature and on the publication of the ontology according to Linked Data principles, and it is based on the ontology engineering activities defined in the NeOn methodology [12].

In this chapter a theoretical background on the LOT methodology is provided. Therefore, all the actions taken in the four phases of the development of PECO are illustrated, including examples and excepts from modelling approaches for the different domains described in 2.2.

5.1. Background on LOT methodology

The first phase of the LOT methodology is named “Ontology requirements specification”, and it aims at defining the purpose and scope of the ontology, as well as the functional requirements that the ontology needs to fulfil, which will be later used as inputs for later documentation and implementation.

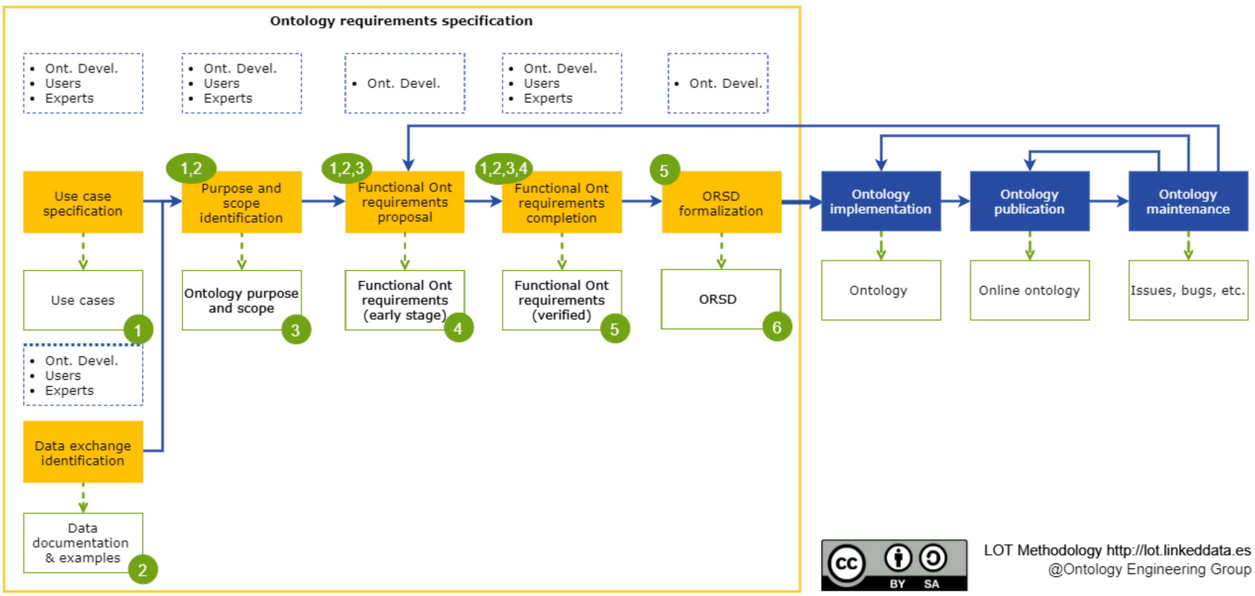

Figure 10: Schematic of Ontology Requirements Specification (ORSD) phase [11]

As visible in Figure 10, this phase begins with the definition of the use case specifications and of the data exchange identification, which help the ontology experts to define a clear purpose and scope of the ontology. While use cases define scenarios of usability of the ontology, examples of data exchange identification are: datasets, regulations, standards, data formats, application programming interface (APIs) specifications, database schemas, etc [11]. This practical approach targets specific knowledge related to the domain of the ontology and it is often conducted by the use of competency questions. The use of competency questions is well-known technique proposed by Grüninger and Fox [13], which suggests to elaborate a set of questions targeting each specific knowledge that the ontology must be able to represent and which constitute a requirement for the ontology. At this stage, the questions are elaborated in an informal language, and they can be accompanied by answers or expected results (early stage), which must be checked with relevant domain experts and users (verification), before entering the implementation phase of the ontology. Therefore, competency questions are an iterative process, with the scope of defining the ontology requirements with increasing levels of definition. The main outcome of this development phase is therefore the formalisation of the ontology requirements specification in a computational logic-based language (OWL language).

Once all the ontology requirements have been formalized, they are formally conceptualised, encoded and evaluated, as part of the ontology implementation phase (Figure 11).

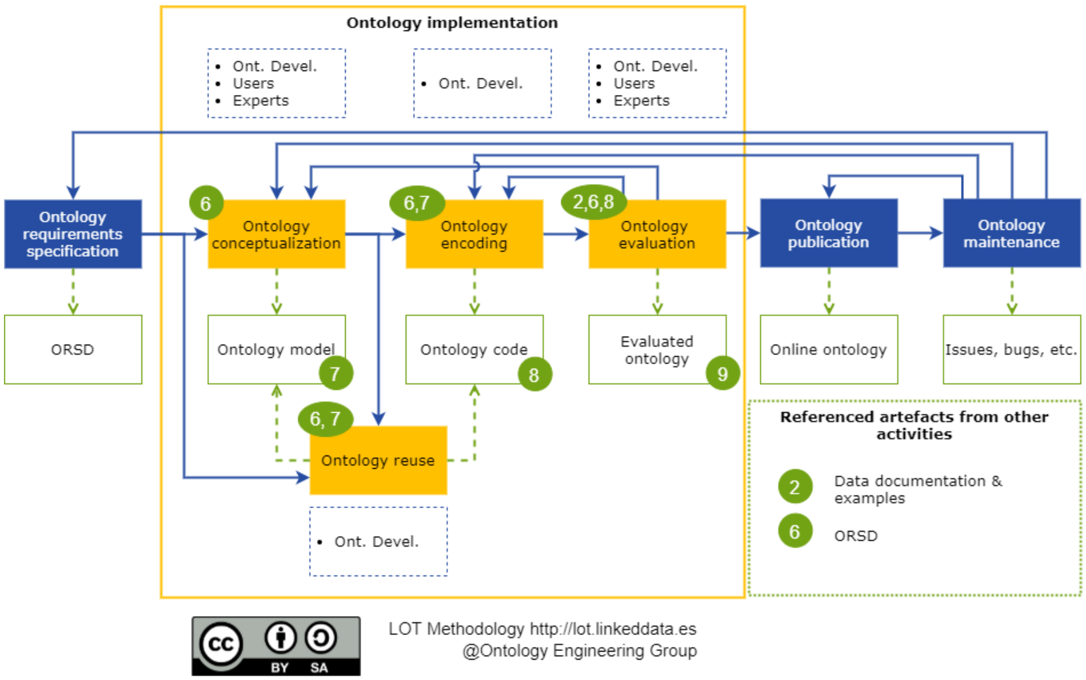

Figure 11: Schematic of ontology implementation phase [11]

The conceptualisation of the ontology entails ontology-specific modelling decisions from the developers, such as the level of abstraction to be used. Moreover, to develop the conceptualization, a common practice is to incrementally identify the following ontology elements, such as: classes (concepts), classes hierarchies, relationships (properties between classes), attributes (properties between classes and datatypes), property hierarchies and axioms. During the encoding, the models are further computed in OWL language. The code resultant from this activity includes metadata, such as creator, title, publisher, license, and version of the ontology. Both the conceptualisation and encoding phases make use of the ontology reuse, which is often not performed by means of importing the reused ontologies (hard reuse), but just by referencing the URIs of the reused ontology elements (soft reuse). Once the encoding phase is finished, the ontology can be evaluated by its users and by the relevant domain experts, with the possibility to apply changes through an iterative process.

Afterwards, a first ontology candidate is proposed and selected for release, the ontology can enter the phase of documentation and publication (Figure 12). The documentation includes [11]: a human-readable description of the ontology (usually as HTML document), diagrams which store the graphical representation of the ontology, examples of use that illustrate how to use ontologies in practice, the license URI and title being used. Once the documentation is complete, the ontology can proceed for publication.

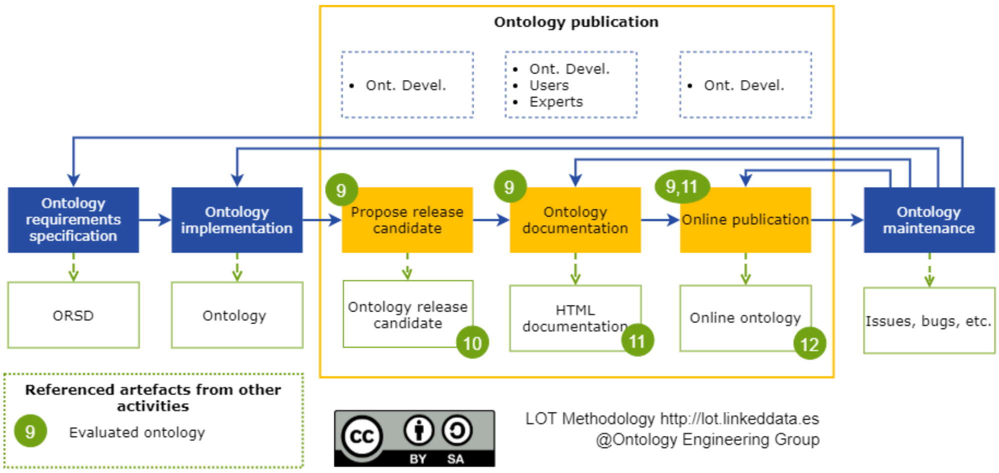

Figure 12: Schematic of ontology publication phase [11]

Finally, the ontology can enter the phase of maintenance (Figure 13), with the goal to update and add new requirements to the ontology that are not identified in the ORSD, to identify and correct errors (bug detection) or to schedule a new iteration for ontology development. During the ontology development process, the domain experts can propose new requirements or improvements over the ontology, as well as identify errors both in the requirements and in the implementation.

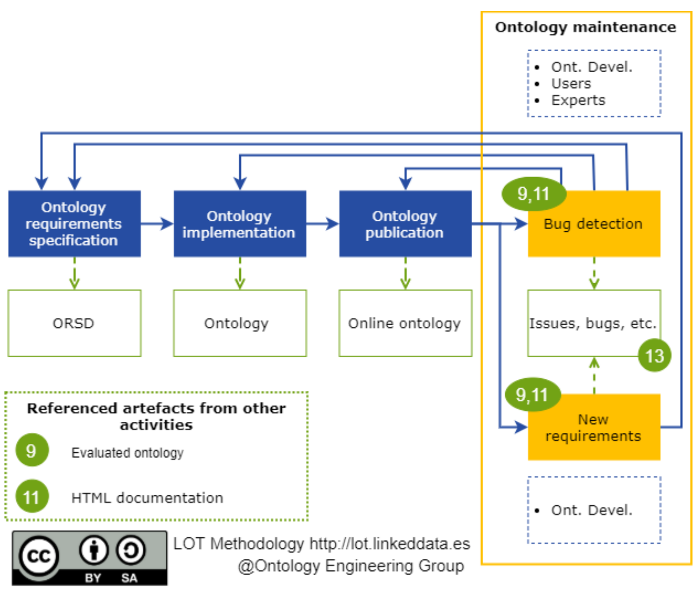

Figure 13: Schematic of ontology maintenance phase [11]

5.2. Requirements specifications

The collection of inputs for the ORSD has been based on the project-pilots' specifications, in relation to the 4 domains identified in section 2.2. Particular emphasis has been given to the pilots´ topologies, in relation to the different use cases defined in PARMENIDES Deliverable 2.2. Moreover, a similar approach has been used for the development of the ontology related to the virtual environment Vlab.

5.2.1 Use case specifications and system topology of project pilots

Swedish Pilot

PARMENIDES Swedish pilot is composed by 3 different sub-pilots:

- *Testbed Einar Mattsson (EM):* this sub-pilot belongs to the Live-in Lab and it is the site where the experiments on users' behaviour take place. The objective is to perform behavioural surveys to determine occupant preferences and tendencies related to energy consumption, as well as flexibility potential and corresponding trade-offs. Moreover, users' data will be collected (prior agreement) to obtain real energy-related occupant data to serve as input in scenarios for technology tests of hybrid energy storage system.
- *Testbed KTH:* this sub-pilot belongs to the Live-in Lab and it is the site for software interoperability testing. The objective is to perform interoperability tests to evaluate the capabilities of the ontology-based EMS4HESS in the context of a multi-apartment building as an energy community.
- *EGI ETT Lab:* this is the site where the experiments with the hybrid energy storage system technologies take place. The objective is to perform tests based on the results obtained at the Live-in Lab, as well as to obtain data to serve as input in scenarios for behavioural experiments at the Live-in Lab. Moreover, here it is possible to perform interoperability tests to evaluate capabilities of ontology-based EMS4HESS in managing different storage technologies (HESS) and to develop and improve operation algorithm based on results of technology tests and behavioural experiments.

The major goal of PECO is to correctly represent each sub-pilot, specifically in terms of controllable assets, collected measurements (i.e., monitored dynamic properties of assets), topology, and, eventually, user interaction messages, in order to support both the EMS4HESS and the user behavioural experiments happening at the pilot regions.

However, in the case of the Live-in Lab sub-pilots, the sites are constituted by student apartments, where the energy assets are not controllable from the EMS4HESS, but the building automation and control is done by Schneider Electric BMS. Therefore, the detailed assets topology representation for these sub-pilots is not represented in PECO, but only the type of measurements collected at each apartment and at the building level. Moreover, the user interaction infrastructure is also represented, with a first general classification of the user engagement messages (considering the current limitations highlighted in 3.2.2).

On the contrary, a detailed representation of the assets available at the EGI ETT Lab and their topology is essential to support the EMS4HESS in the generation of optimisation algorithms to make the best use of the available hybrid storage technologies.

Table 6 summarizes the information represented by PECO for the Testbed EM.

Table 6: Measurements collected at Testbed EM

Measurements at apartment level	Measurements at building level
Electricity consumption (kWh)	Outdoor temperature (°C)
CO2 concentration (ppm)	Bought electricity (kWh)
Indoor temperature (°C)	Electricity use (MWh)
Hot water consumption (m^3)	PV electricity production (kWh)
	Heat pumps: – Compressor power (kW) – Compressor frequency (Hz) – Operation mode (SH, DHW) – Operation time (h) – Discharge temperature (°C) – Evaporator in/out temperatures (°C) – Condenser in/out temperatures (°C)
	Ground-source heat pump system: – Condenser power for space heating (kW, aggregated for 3 buildings) – Condenser power for domestic hot water (kW, aggregated for 3 buildings) – Condenser energy for space heating (kWh, aggregated for 3 buildings) – Total electricity use (kWh, aggregated for 3 buildings)

Table 7 summarizes the information represented by PECO for the Testbed KTH.

Table 7: Measurements collected at Testbed KTH

Measurements at apartment level
Metered electricity consumption (kWh)
Real-time power consumption (kW)
Air pressure (Pa)
Occupancy (True, False)
Luminance (lux)
Temperature (°C)
Relative humidity (%)
CO2 concentration (ppm)
VOC concentration (ppm)
Secondary heater set-point temperature (°C)
Secondary heater air temperature (°C)
Lamp dimming status (%)
Water consumption (m^3)

Table 8 summarizes the information represented by PECO for the EGI ETT Lab.

Table 8: Monitored assets properties at EGI ETT Lab

Assets	Monitored assets properties
Photovoltaic-Thermal Collector (PVT)	Heat power meters: – PVT thermal power (kW) – PVT loop volumetric flow rate (m^3/h) – Inlet temperature to PVT (°C) – Outlet temperature from PVT (°C)
	Microinverter system: – PV panel real-time electricity generation (W) – PV array real-time electricity generation (kW) – PV array aggregated electricity generation (kWh)
Heat Pump	– Compressor speed (rpm) – Compressor power (W) – Brine temperature in (°C) – Brine temperature out (°C) – Condenser temperature (°C) – Condenser temperature out (°C)
Water Tank	– Hot water tank temperature – upper (°C) – Hot water tank temperature – lower (°C)
Building Thermal Mass	None (Modelled storage)
Battery	– Active power inlet (W) – Active power outlet (W) – Energy consumed (kWh) – Energy produced (kWh) – Voltage (V) – Available storage capacity (Wh) – State of charge (%)

The topology of the assets at the EGI ETT Lab is schematically shown in Figure 14. Here the system is represented from the perspective of the HESS model, where the storage assets are aggregated together to form a compact interoperable module.

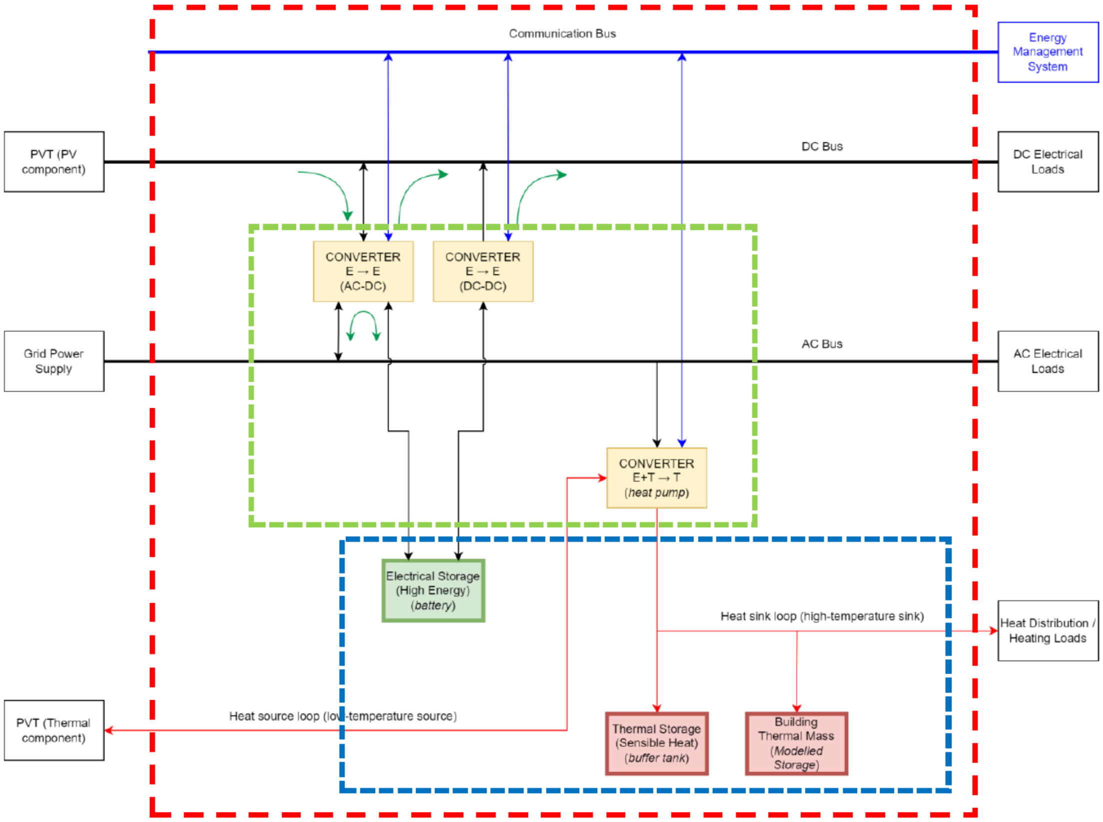

Figure 14: EGI ETT Lab topology of HESS model

The energy generation devices (PVT and electrical grid, outside of the red HESS box) are able to inject energy in the thermal (red) and electrical (green) storage systems thanks to the energy conversion devices (yellow). Moreover, the role of the converter is also to exchange data with the communication bus connected to the EMS4HESS (blue). Therefore, the electrical and thermal load could be either directly satisfied from the energy generation devices or by the storages, thanks to the DC and AC buses (electrical loads) or heat sink loops (thermal loads).

A more detailed representation of the EGI ETT Lab system architecture for the thermal connections, in relation to their connection to the EMS4HESS, is provided in Figure 15.A more detailed representation of the EGI ETT Lab system architecture for the thermal connections, in relation to their connection to the EMS4HESS, is provided in Figure 15.

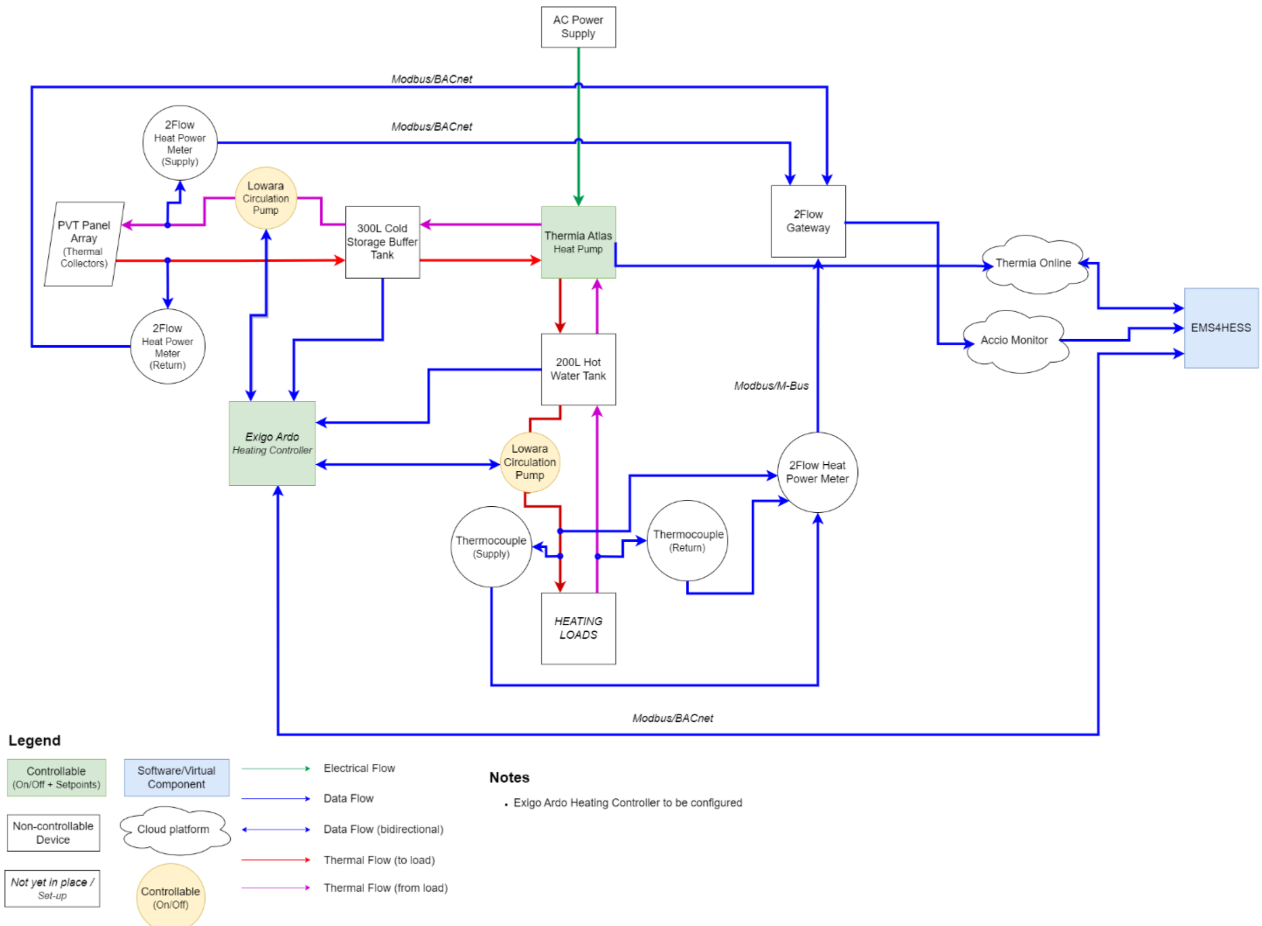

Figure 15: System architecture of EGI ETT Lab (thermal)

The sketch above provides a detailed representation of the topology of the system, distinguishing the data flows (blue), from the thermal flows (red to load, pink from load) and from the electrical flows (green). Moreover, the flow moving devices, such as the circulation pumps, are also depicted, since they allow the physical connection between the different energy assets, by moving the heat transfer fluids in the different circulation loops. The measurement devices, such as the thermocouples (temperature) and heat power meters (power) are shown in relation to each asset whose properties could be monitored. The data collected could be therefore transferred to the EMS4HESS thanks to the interlude of the 2Flow Gateway (Accio Monitor) and the Thermia Online API.

Similarly, a detailed representation of the EGI ETT Lab system architecture for the electrical connections is provided in Figure 16. Similarly, a detailed representation of the EGI ETT Lab system architecture for the electrical connections is provided in Figure 16.

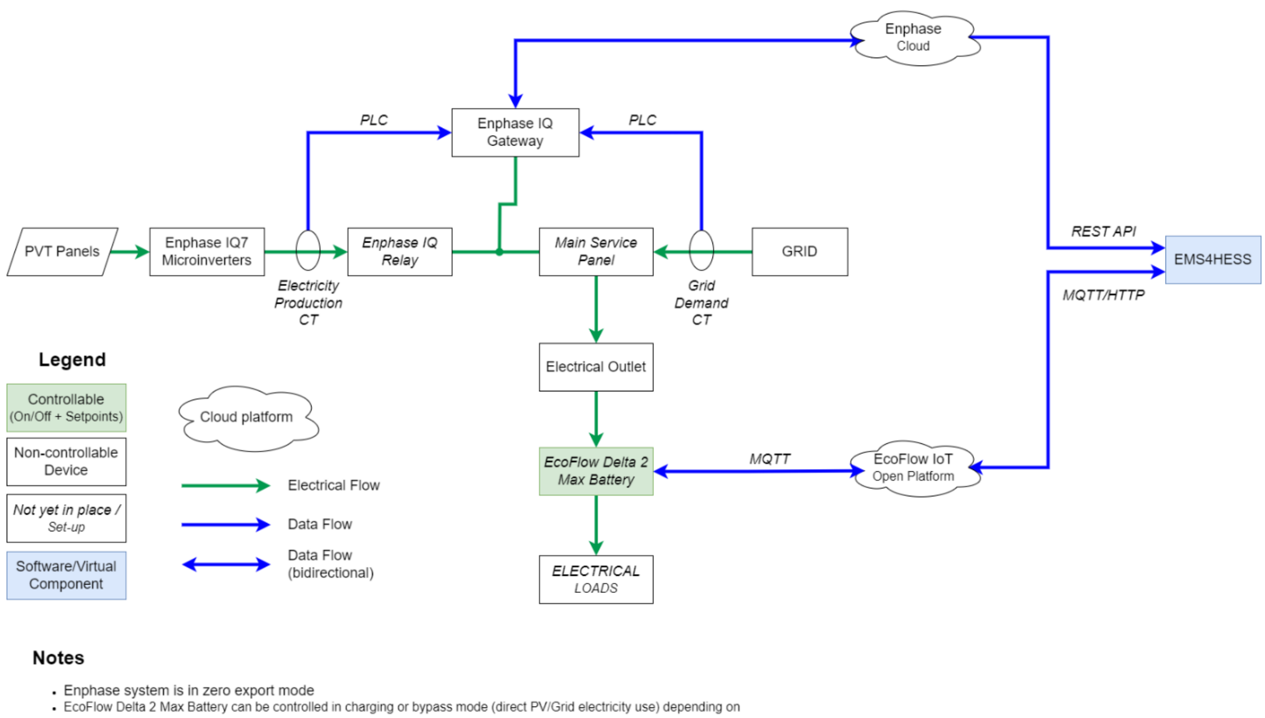

Figure 16: System architecture of EGI ETT Lab (electrical)

In this case, the microinverters are responsible for the conversion of the direct current (DC) power harvested from the PVT system into the alternating current (AC) which feeds the electrical storage (battery, green). Moreover, the battery could also be fed from the electrical grid. The power injected into the system from the PVT system and from the grid is monitored and saved in the Enphase Cloud, thanks to the interlude of the Enphase IQ Gateway, which is communicating with the EMS4HESS. The energy management system is also capable of communicating with the battery system thanks to the EcoFlow IoT Open Platform, thanks to the intermediary entity of the MQTT broker.

Austrian Pilot

PARMENIDES Austrian pilots are located in the regions of Gasen and Heimschuh. Despite, at the time this deliverable is written, the ECM recruiting process for the participation to the project demonstration is not completed yet, a preliminary list of assets could already be drawn for both sites.

Table 9 summarizes the assets present at the two pilot regions.

Moreover, the properties of the controllable assets are monitored with the use of Siemens PAC devices, which are mainly used for monitoring the voltage (V), the current (A), and the power (W).

Table 9: Assets availability and controllability at the Austrian pilot regions of Gasen and Heimschuh

Gasen			Heimschuh		
EC-Level	**ECM**	**External to EC**	**EC-Level**	**ECM**	**External to EC**
One battery storage system (80 kW/160 kWh)	Private PV systems	District heating grid at municipality level *Note: this asset does not take part to the project*	One battery storage system (100 kW/100 kWh)	Private PV systems	Private DH grid *Note: this asset does not take part to the project*
Two public EV charging stations (22 kW)				One private EV charging station	
One biomass-fired CHP system (55 kW) *Note: this asset is not controllable for the purpose of the project*					One private biomass-fired CHP system

5.2.2 Competency questions for definition of ORSD

Competency questions have been addressed in relation to the domains described in section 2.2, developing each concept further using a top-down approach, by breaking down each topic with increasing level of detail. Therefore, a set of questions has been elaborated for each sub-domain, and natural language sentences (facts) have been assigned to them, identifying specific questions that PECO should be able to answer, with the help of the domain experts for each field.

A summary of the topics addressed in the competency questions is provided in Table 10.

Table 10: Summary of domains and topics of Competency Questions

Domain	Sub-domain	Topics from Competency Questions
Physical members and their aggregation	Energy Community (EC)	Identification, ownership of assets, consumption timeseries, consumption forecast, internal energy allocation models
	Energy Community Member (ECM)	
Energy assets	Electricity generation assets	

	Thermal generation assets	Static and dynamic properties, generation profile, generation forecast, operation schedule, controllability, topology, measurements and sensors
	Cogeneration assets	
	Electrical storage assets	
	Thermal storage assets	
	Hybrid Energy Storage System (HESS)	Aggregation, topology, static and dynamic properties, generation profile, generation forecast, operation schedule
Flexibility signals (grid perspective)	Flexibility request	Recommendations on consumption pattern at a specific time interval (band), event detection for flexibility activation, feasible flexibility (related to consumption forecast)
	Tariffs	Classification of tariffs (grid vs. electricity), nature of grid tariffs and possible modifications depending on the direction of the energy flows
	Incentives	Types of incentivization schemes and their applicability
Prosumer targets (user perspective)	Optimisation strategies	Self-consumption maximization, cost minimization, comfort maximization, environmental impact reduction
	User engagement	Categorisation of messages for interaction with user

Moreover, it is noted that each sub-domain may include further sub-classifications. For instance, in the case of the energy assets, each generation or storage asset class entails further device classifications (see section 2.2.4), which may differ from each other for the answers to the competency questions.

At the current state of the project, a minor number of topics addressed with the competency questions are not yet known with the level of precision needed for their inclusion in PECO. For instance, despite a general classification of the user interaction messages has been identified, their applicability in relation to the different use case scenarios and optimisation strategies needs further clarification. Therefore, this will be included in PECO once the necessary information is available from the respective domain´s experts.

5.3. Implementation

In this chapter we focus on specific aspects of the implementation. For more in-depth view the source of the developed ontology is included in the Annex 1 – Ontology source. Rather than reading the ontology source, ontology can be directly accessed online. Details about URLs are described in Section 5.5 (Publication). How certain parts of the ontology were designed, as well as reasons for certain decisions. In the source, ontology entities have been commented according to ontology development best practices. Specifically, authors used rdfs:comment and rdfs:label for describing entities and skos:example for further describing how certain elements are meant to be used.

5.3.1 Modelling of energy community and energy community members

Energy community members are one of the core concepts of PARMENIDES project. Important relationships are shown in Figure 17. Points-of-Delivery (**PODs)** are also a type of **asset** and each **energy community member** should have at least one as this is the main entry point for any energy flow. Furthermore, each **Energy community member** defines one or more **optimization strategies**. Ultimately, **energy community member** occupies a **Space.** Currently, the number of **energy communities** that **energy community member** can be part of is limited to one. In further iterations of the ontology this can be amended if specific pilot requirements or national transpositions of Renewable Energy Directive require or allow it.

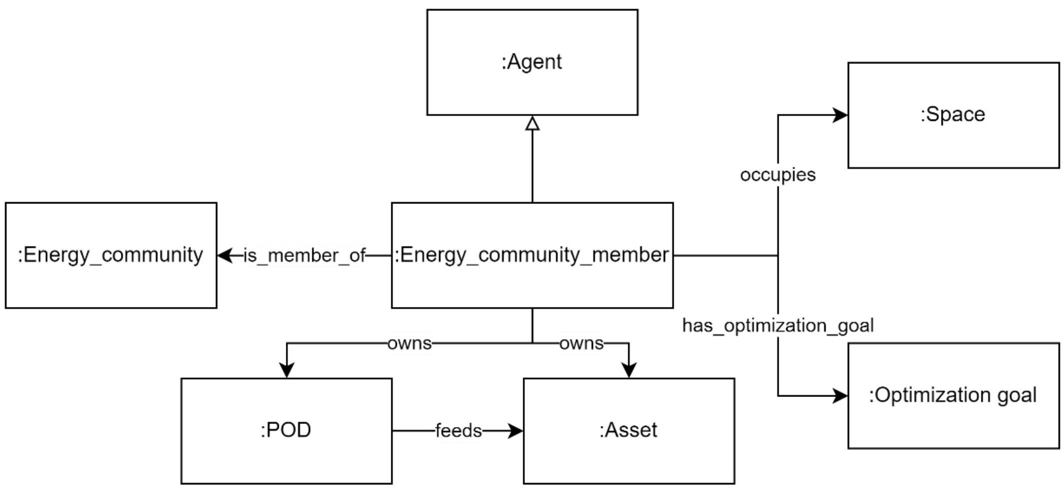

Figure 17: Energy community member and related classes

Similarly to energy community members, the following applies to energy community:

- has point of delivery (grid connection)
- has optimization strategy (but compared to ECM, it can have only one)
- has assets

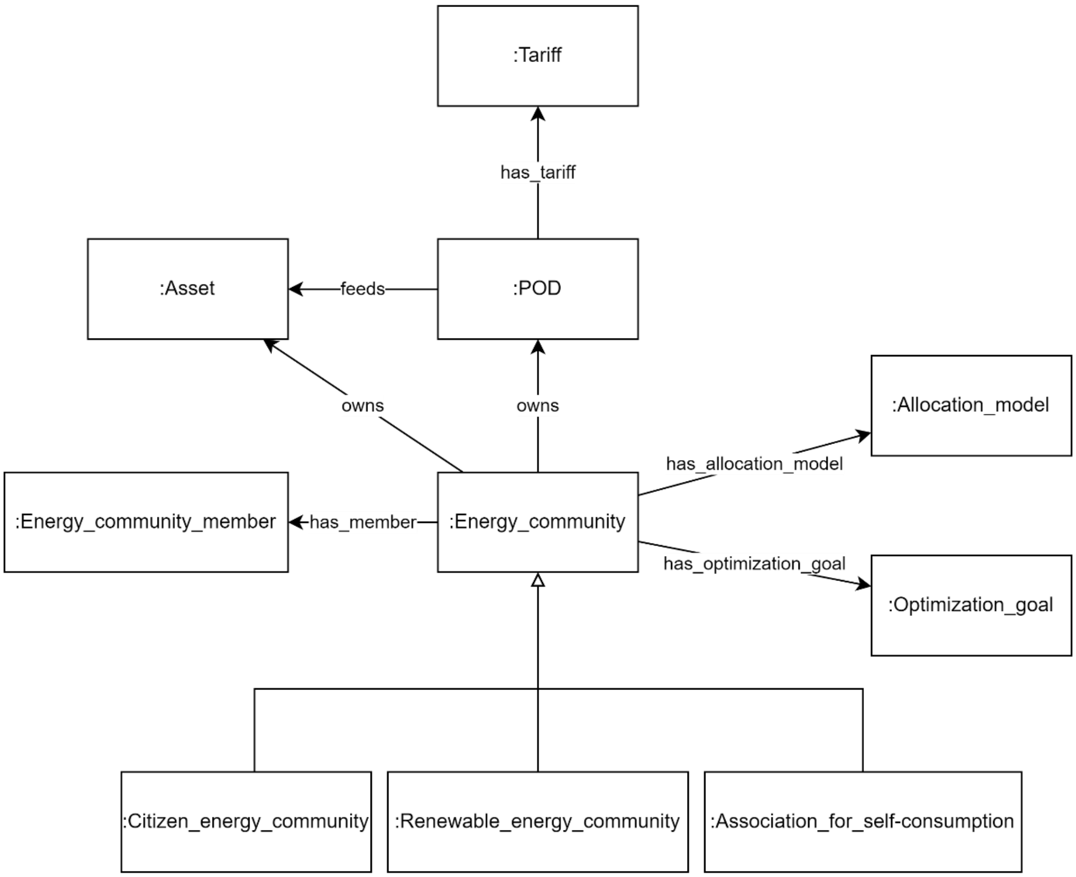

Figure 18: Energy community and related classes

In addition to that, energy community (Figure 18):

- has energy community members
- has an Allocation model that specifies how produced energy is allocated to its members. Instances of the allocation model foreseen in PARMENIDES are shown in Figure 19
- has internal energy price that is represented by a Tariff associated to the point of delivery

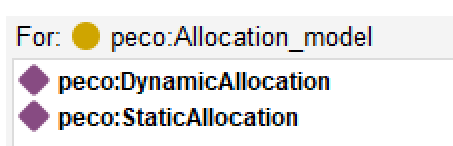

Figure 19: Currently supported allocation models in PECO

Static allocation prescribes specific static share of surplus locally produced energy to each of the energy community members. In dynamic allocation instead, for each allocation interval, the surplus energy share is dynamically allocated in proportion to the Energy Community member's consumption share of the total

EC consumption (i.e. every 15 minute different allocation ratio is calculated based on ratio of member's consumption to energy community's total consumption).

5.3.2 Modelling of assets

a. Assets

Assets include physical devices having properties that can be observed and actuated. Examples of assets include a range from simple devices such as sensors measuring only one property, up to complex devices having potentially tens or hundreds of internal sensors and actuators. Assets are arranged in hierarchies depending on their primary usage (Figure 20). The asset list with its static and dynamic properties is defined in a table and then converted into the ontology format using Protégé plugin Cellfie [5].

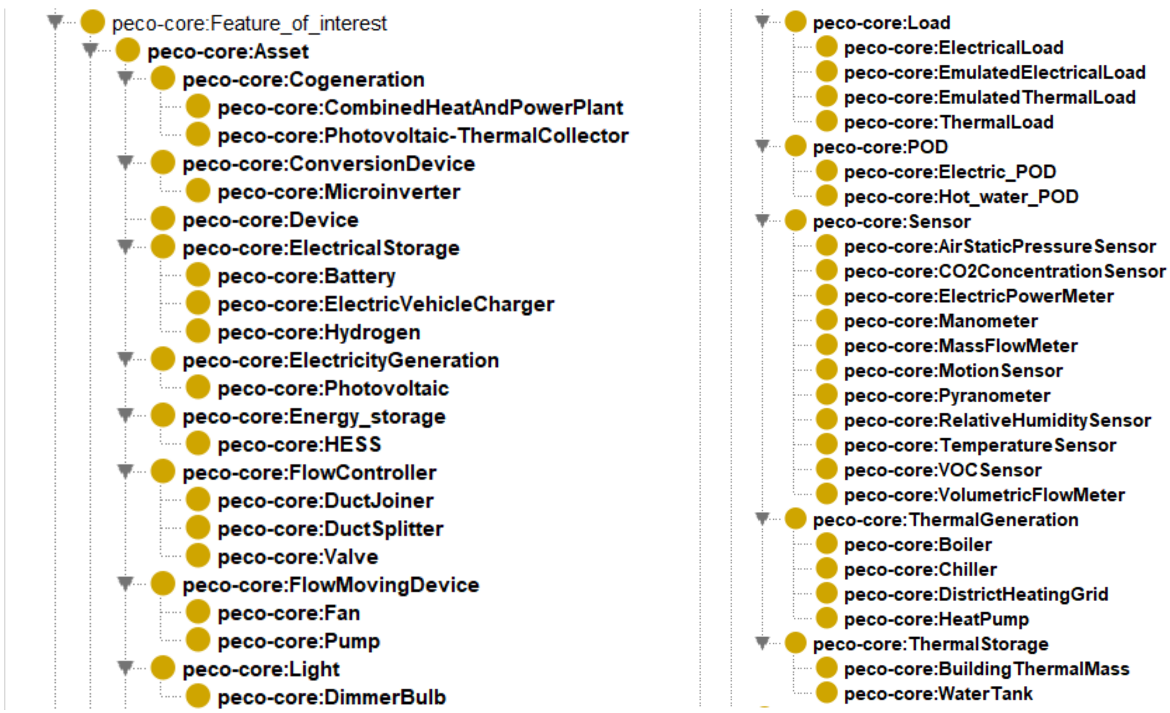

Figure 20: Asset hierarchy in PECO

b. Static and dynamic properties

Different objects (assets, spaces, ports and tariffs) can have static and dynamic properties (Figure 21). Assets have static properties describing their non-changing characteristics. Examples of such properties include the capacity of a hot water storage tank, the operating range of a sensor or a factory-assigned ID of the device. Furthermore, assets have dynamic properties (Datapoints) such as measurements, setpoints, alarms, and commands. Those properties change and it is beneficial to keep track of those changes. Some of dynamic properties can be directly acted upon (actuated), such as setpoints. While in pilot sites

[5] https://github.com/protegeproject/cellfie-plugin

in the PARMENIDES project only actuated setpoints are considered, many more different classes of actuators (such as on/off switches, light level and colour control, etc) could be used.

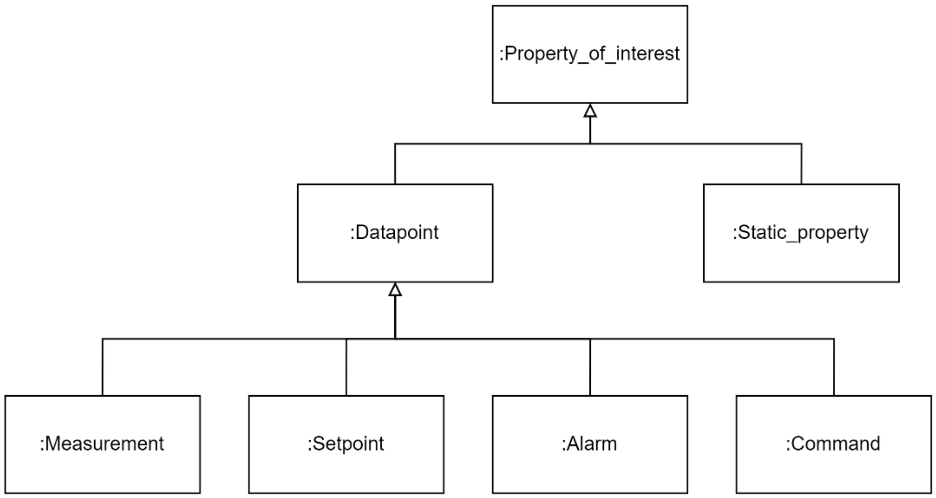

Figure 21: Static and dynamic properties in PECO

Figure 22 depicts how datapoints (subclass of Property of interest) are linked to timeseries. Each datapoint can be part of a timeseries. Timeseries is then stored in some datastore, which can represent a reference to a database table, REST URI, CSV file or something else.

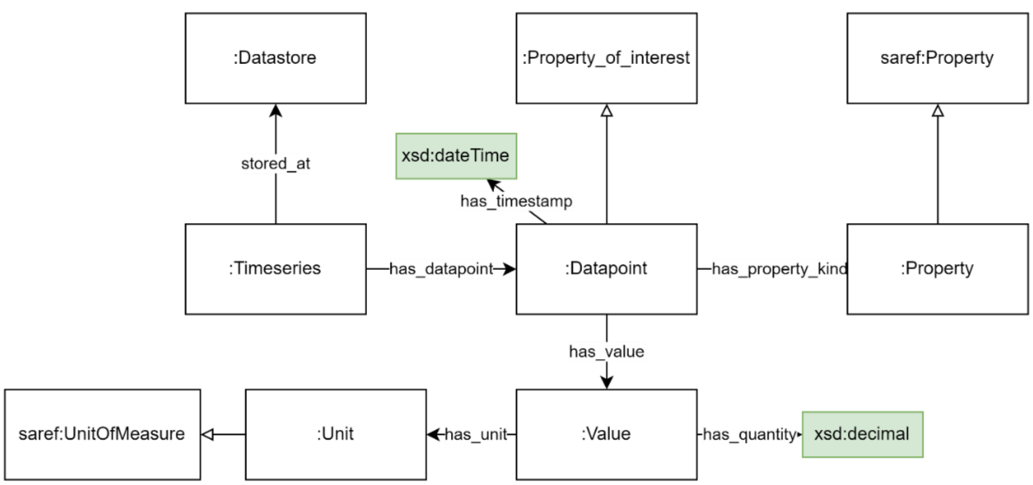

Figure 22: Implementation of dynamic properties in PECO

Specific example of instantiation of one room with a number of properties that illustrates approach from Figure 22 can be seen in Figure 23. Each room property is a type of Measurement class, which is itself subclass of Property_of_instance class. Each property is further qualified by assigning it a property type through has_property_kind relation. Yellow boxes indicate instances while white boxes indicate classes.

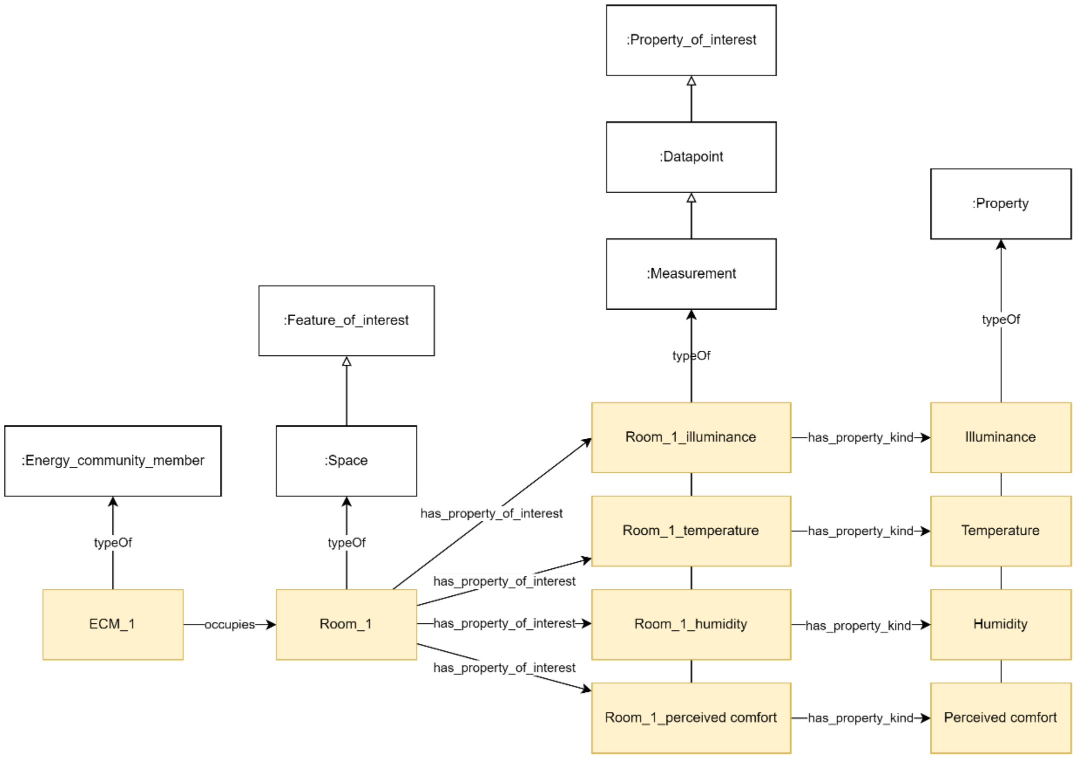

Figure 23: Example of instantiation of a room with some dynamic properties

Similar example in Figure 24 shows how an asset with one controllable property (setpoint) and one static property could be instantiated.

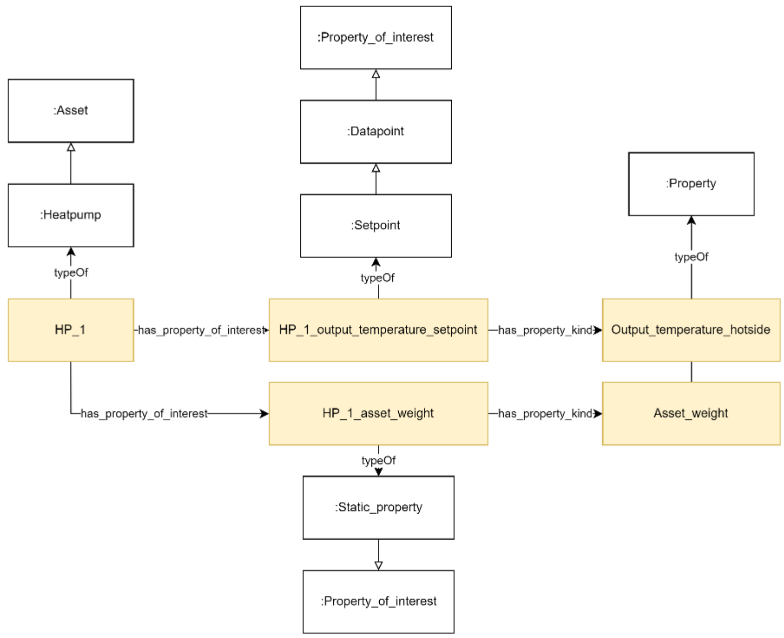

Figure 24: Instantiation of an asset with a setpoint

Asset connections

Assets are connected among each other via ports (Figure 25). Each asset can have a number of ports used for flow of different mediums. By default, data, electrical and hot water ports are supported. Additionally, ports can have properties of interest associated with them, allowing precise positioning of observable and actionable dynamic properties. Finally, ports can be input or output and inference can be used to validate proper connectivity between them. Specifically, input ports can be connected only to output ports and only ports of the same medium type can be connected together.

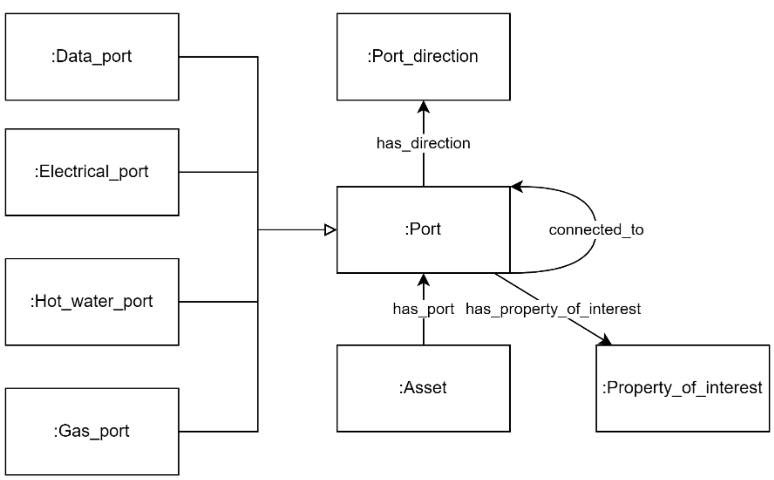

Figure 25: Port class implementation in PECO

To clarify usage of ports, Figure 26 shows how ports can be used to represent connections of relevant assets in the system. Each port allows precisely locating properties of interest.

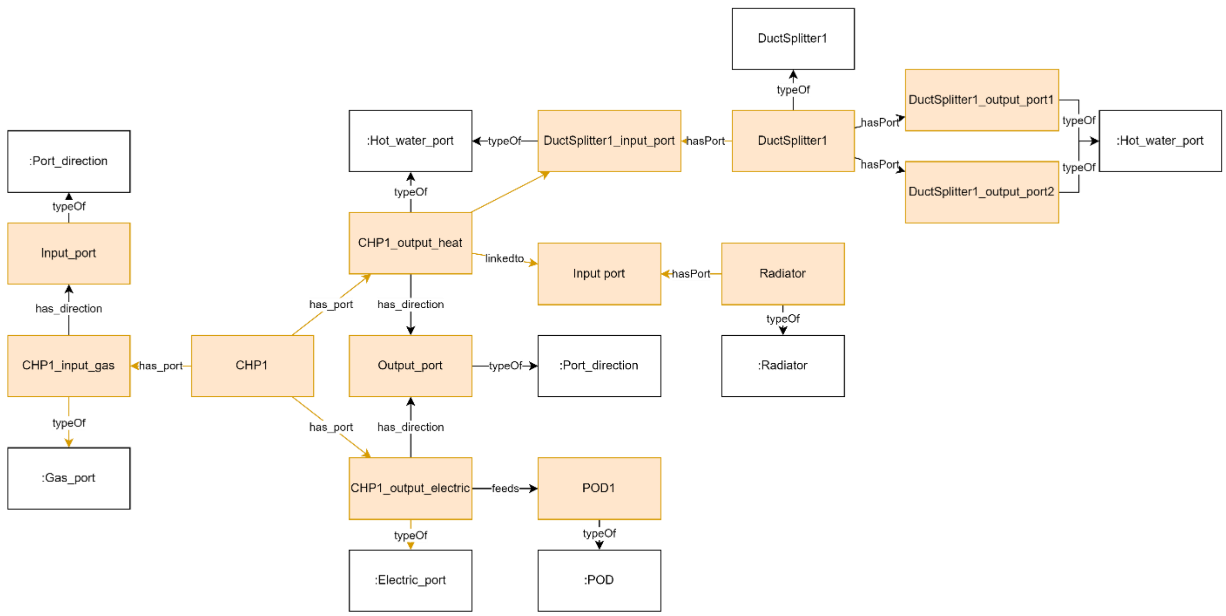

Figure 26: Using ports to connect assets together. Some port direction properties have been deliberately omitted

5.3.3 Modelling of optimization plan

Optimization is a process of modifying a system operation in order to maximize or minimize optimization objectives. It entails setting a number of schedules for controllable properties of different assets. Energy community can set one optimization goal, and energy community members can further specify several weighed goals. Optimization plan (Figure 27) is related to a series of forecasts and is guided by the above-mentioned goals. Finally, optimization plan may be influenced by a specific flexibility request. Forecasts are series of predicted future values, and can be made for any observable property (related_to_property_of_interest). Forecasts can be internally (e.g., forecast of tomorrow's energy consumption, forecast of dwelling occupancy) or externally generated (e.g., weather forecast from external services, such as temperature or humidity forecast). Schedules are also generated series of future values, but they refer to desired values of controllable properties. Schedules are the results of the optimization process of the system.

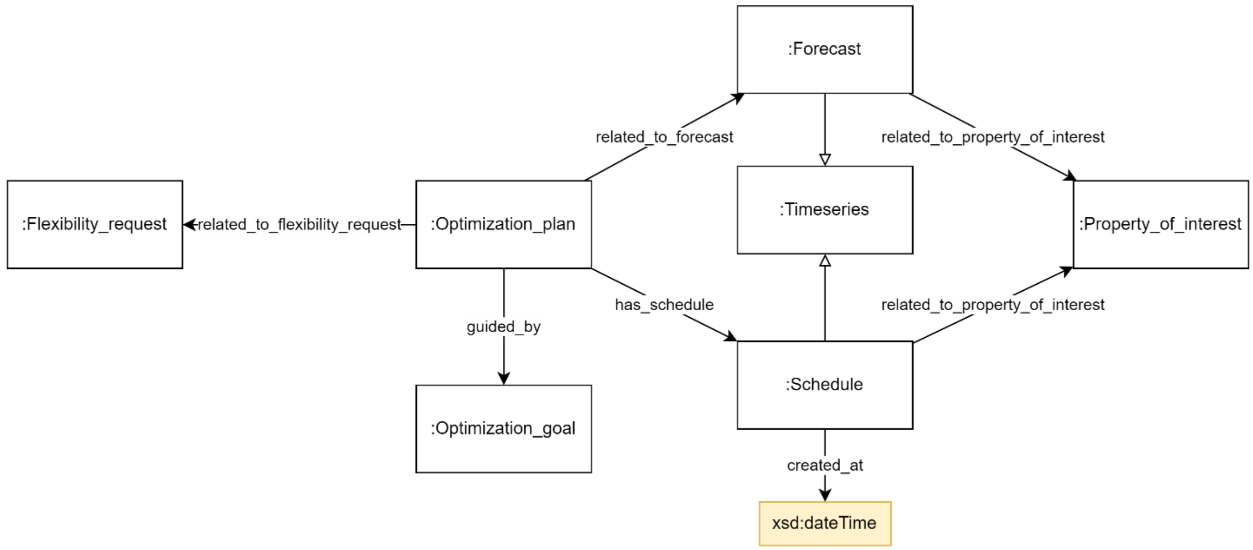

Figure 27: Implementation of an optimization plan in PECO

If forecasts indicate that the total consumption of the energy community will be above a certain threshold prescribed by the system operator, this needs to be taken into account during optimization.

5.3.4 Modelling of user engagement activities

User engagement activities involve sending messages and notifications (Figure 28) to energy community members in order to accomplish a desirable change of behaviour.

Messaging refers to textual messages that are classified according to whether some reaction is needed and the urgency of expected reaction.

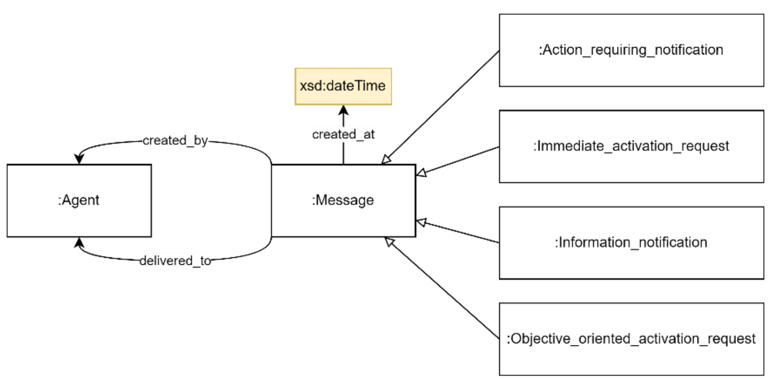

Figure 28: Implementation of Message in PECO

5.3.5 Modelling of tariffs

Tariff domain proved to be much more complex than expected. As there are many factors that influence how different tariffs are specified, we decided to subclass tariffs into electricity tariffs, grid tariffs and energy community tariffs (Figure 29). Practical implementation of energy community tariff depends on the country and its implementation of energy community legislation.

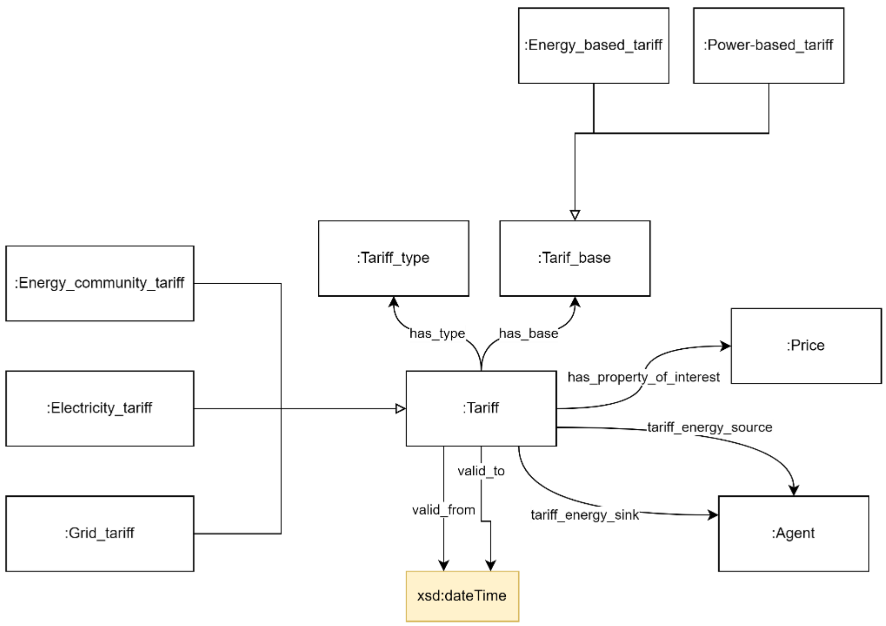

Figure 29: Tariff implementation in PECO

Representing energy community energy price as tariff consolidates it as just another cost factor that can be processed by downstream applications (e.g., energy management systems or accounting systems) in a unified way. Example of this is given in Figure 30. Energy community has a tariff of 0.02 EUR/kWh, which is active since 01.01.2024 and applies to energy produced by the energy community and sold to all energy community members.

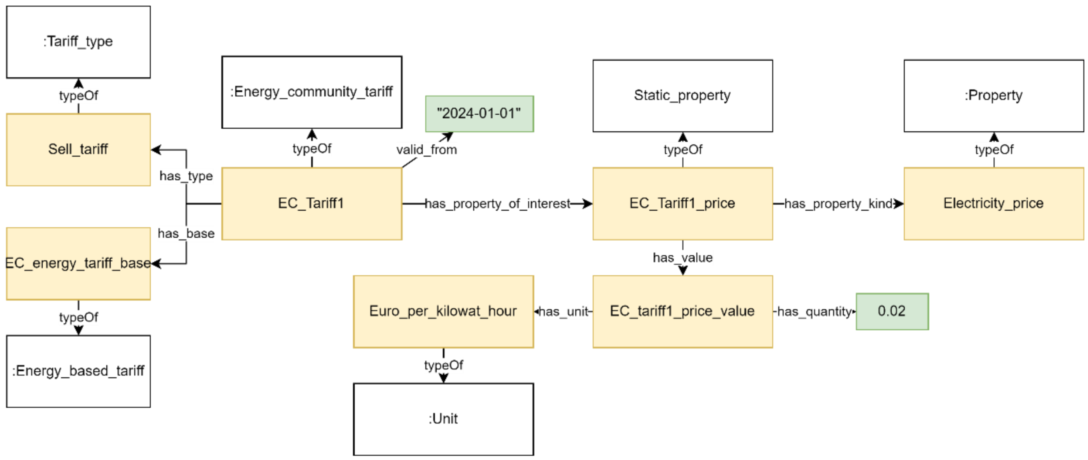

Figure 30: Instantiation of energy community's internal sell tariff. Everybody gets the same price.

Tariff type represents whether tariff is for buying or selling the energy. Tariff base indicates whether the basis of cost is power or energy. This specifically covers cases where variable costs on a monthly, daily, or hourly basis are applied to a customer based on the daily peak, which is present in some grid tariffs. Example of such a case is given in Figure 31. Each customer is charged by the grid an additional surcharge per kilowatt of peak-power for each 15-minute time period. This tariff has been active for one month, between 01.01.2024 and 01.02.2024. Different aggregation functions, application period and observation interval allow coverage of wide array of cases that may be encountered.

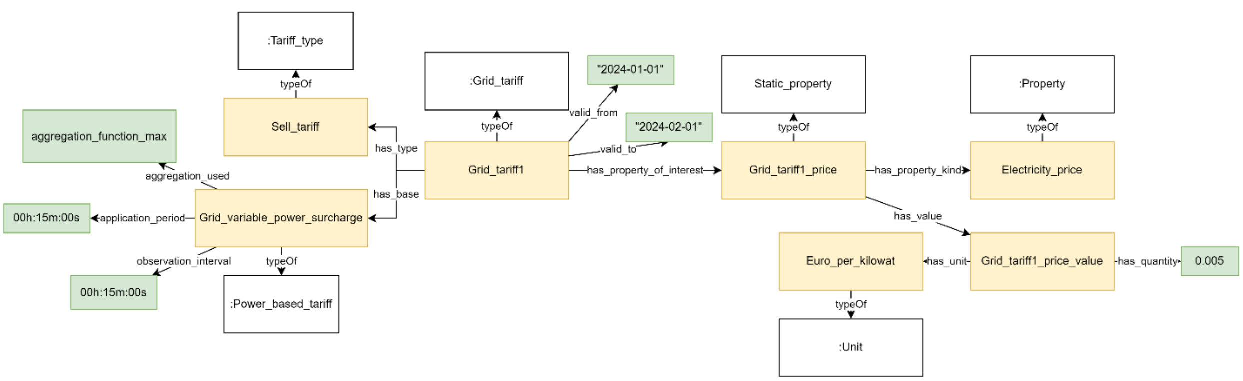

Figure 31: Instantiation of a power peak-based surcharge

Tariffs are linked with PODs. This allows assigning different electricity buy tariffs for different energy community members, as in most countries, energy markets are open and customers have a choice of energy suppliers with different tariffs. Grid tariffs are usually the same for everyone within the same grid segment.

Tariffs can further have materialization in a form of a Price that is modelled as a dynamic property.

Finally, as presented in Table 2, it is possible for prices to vary depending on where the energy comes from or goes to. For that purpose, it is possible to specify energy source and sink for a tariff. Figure 32 depicts an example of a reduced grid tariff that applies for energy flows between energy community as an energy source and energy community members as energy sinks. Furthermore, previously discussed case of dynamic price modelling is shown in this figure (i.e. tariff price is a dynamic rather than static property).

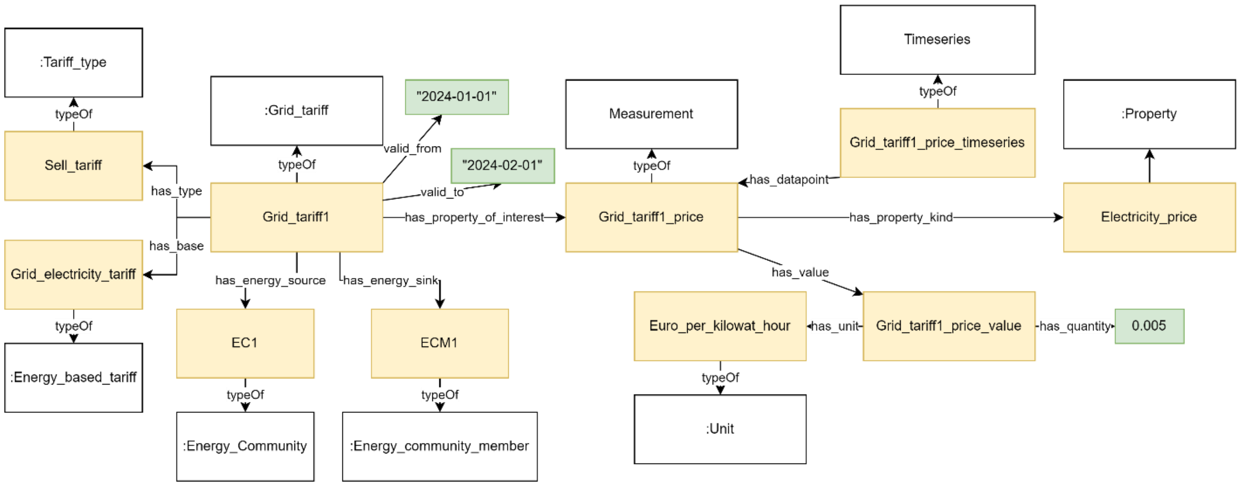

Figure 32: Instantiation of reduced grid tariff applicable to energy flows with specific energy source and sink. This tariff is also modelled as dynamic.

Real-world example of instantiation of tariff entities for a pilot site would entail separately describing electricity buy and sell tariffs from electricity supplier for energy community and each energy community member, one or more grid tariffs depending on whether there is only one grid tariff or there are multiple reduced grid tariffs for certain energy flows (e.g., from energy community to energy community members), or from energy community member to itself, in case of prosumers. Finally, energy community specifies its own internal electricity tariff, for excess energy sold internally to energy community members.

5.3.6 Modelling of flexibility and incentives

In PARMENIDES, there are two major types of Flexibility requests: Requests for grid support – with the highest priority - that define conditions that the customer must satisfy (mandatory request), and incentivized flexibility requests that have conditions that customer have the option to satisfy in which case he is rewarded with the positive incentive (Figure 33). Flexibility requests relate to a POD.

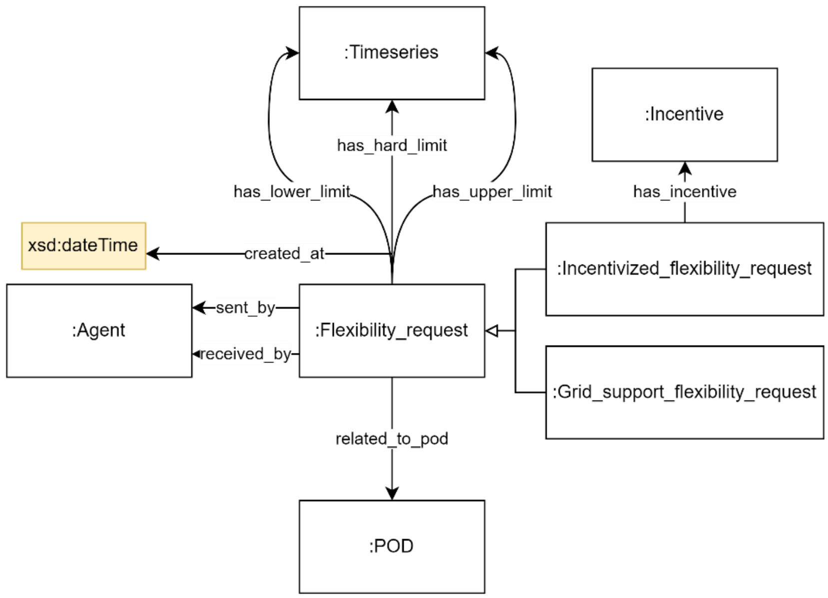

Figure 33: implementation of flexibility requests in PECO

Details of Incentive relationships are shown in Figure 34. Worth noting is that Incentives are related to tariff, i.e. they can modify tariff's price, or they can override it (which depends on the incentive type)

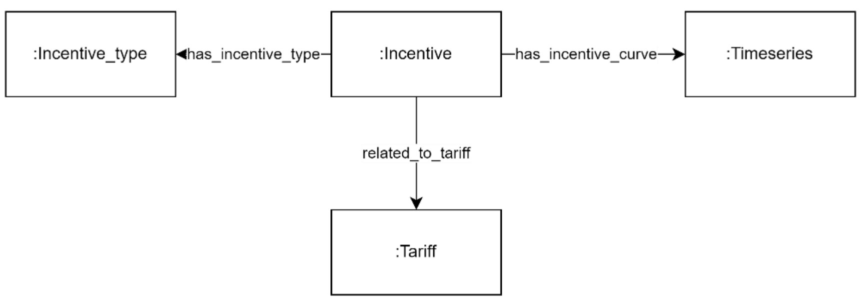

Figure 34: Incentive implementation in PECO

5.3.7 Modelling of AIT VLab

VLAB module is intended for simple instantiation of VLAB experiments. Original VLab instantiation is done by filling a number of tables that describe modules, interfaces, operations, parameters and data models. Specification of these tables was used to design an ontology module. Additionally, we suggest a linkage with the external world via vlab:Operation class (to saref:Command) and between vlab:Module and foaf:Agent.

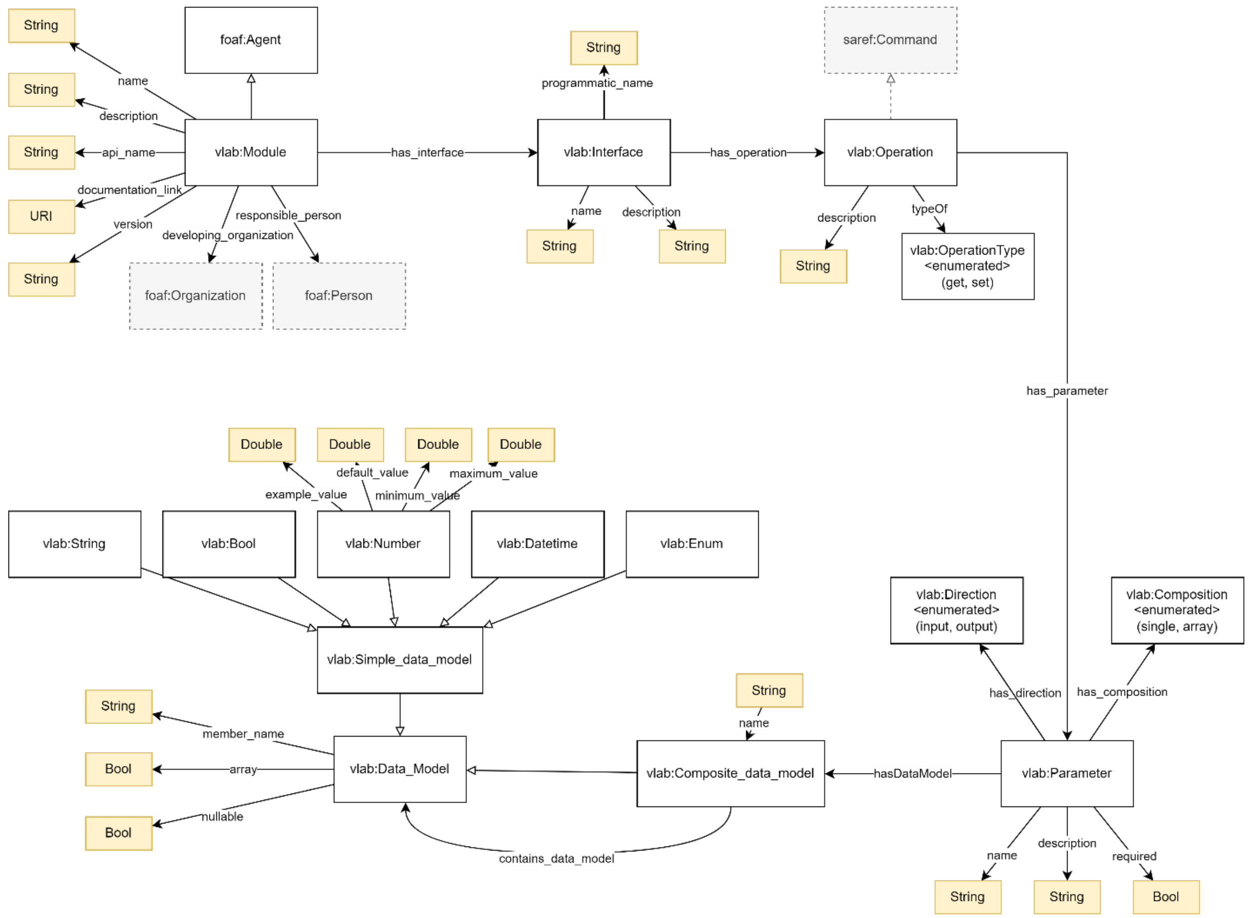

Figure 35: Model of the ontology module for VLab support

5.3.8 Alignment with existing ontologies

Work in on the ontology development is heavily inspired by SAREF family of ontologies. We adopt several patterns used in SAREF to model relationships between observable and actionable properties. For example, we adopt “Property of interest” and “Feature of interest” patterns (Figure 36) to represent instantiations of specific properties linked to a Feature of interest (specific entity in the real world with relevant dynamic properties). Features of interest in PECO (Figure 37) include assets (like equipment and sensors), building elements (like spaces), tariffs and ports used for modelling flows between devices. Each of these entities can contain a number of static and dynamic properties, that are modelled as its properties of interest, which are then linked with a specific property (that is aligned to saref:Property).

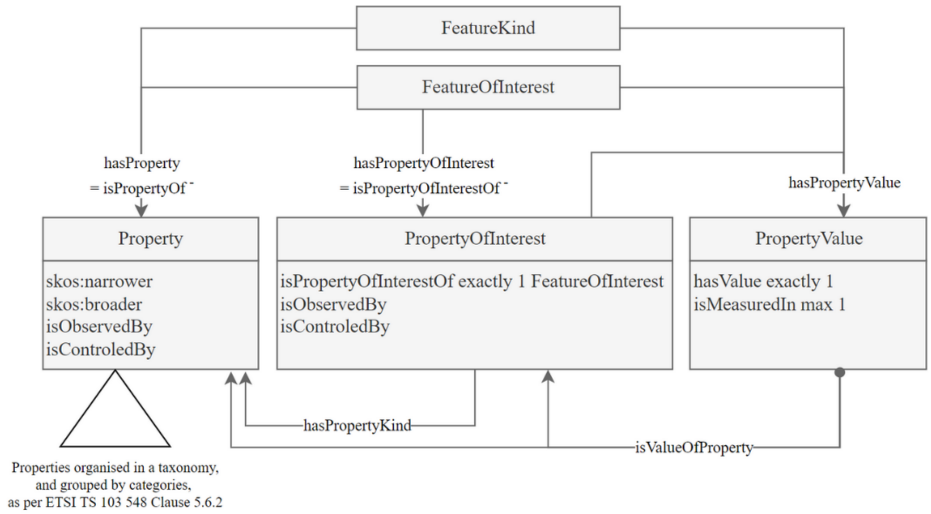

Figure 36: Properties, properties of interest, and property values in SAREF[6]

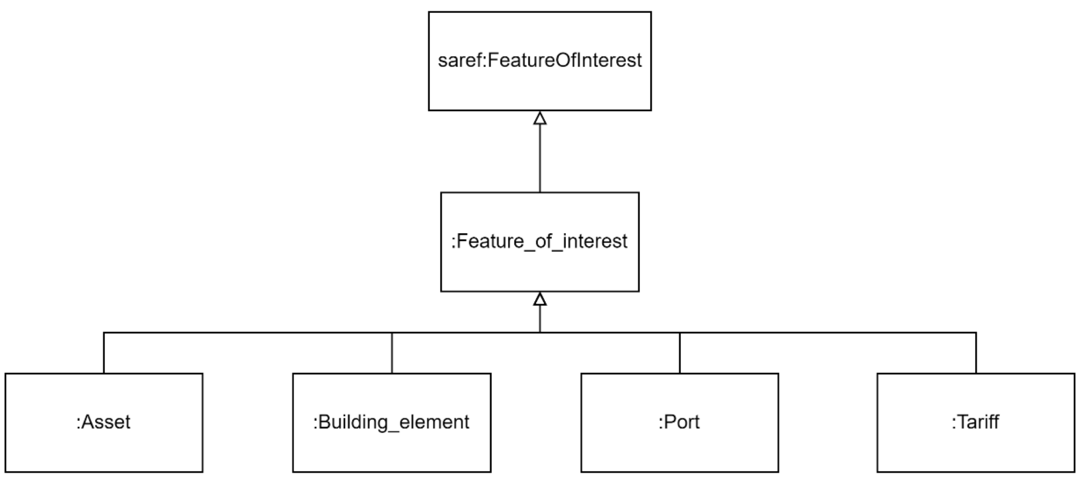

Figure 37: Features of interest in PECO

Friend-of-a-friend (FOAF)

We reuse FOAF for representation of Agents for energy community, energy community member, energy management system and grid condition monitor.

Units of measurements

Units of measurement are localized in peco:Value class, and external ontologies can be chosen to align to it based on needs. Common choices include QUDT (Quantities, Units, Dimensions and Types) and OM

[6] https://saref.etsi.org/core/v3.2.1/

(Ontology of units of measure). As PECO aims to enable real-time inference, both of these ontologies turned out to be too resource intensive to support this use case.

As only rudimentary space topology is needed in PARMENIDES, for the sake of simplicity we are not importing the BOT ontology. Aligning with it would be straightforward in the case of need.

5.4. Validation

There are many ways to evaluate the ontology. Some of those approaches include consistency validation (i.e. if ontology is internally consistent) and functional validation (i.e. if it satisfies functional requirements).

Consistency validation was continuously performed throughout the ontology development process using the Pellet reasoner within the Protégé environment. Reasoners are expanding axioms and inferring facts test examples were instantiated to validate that no inconsistencies occur. By manually validating that inferred facts are indeed as expected, and that there are no inconsistencies with existing axioms we conclude that PECO is consistent.

Additionally, functional validation was performed against the design documents. As of writing this report (06.2024) all the requirements collected in requirement documents are covered. This should come as no surprise, as indeed the implementation was progressing by using the requirements documents as a checklist.

5.5. Publication and documentation

PECO online documentation was generated using the OntosPy[7] documentation and review package.

Following table describes the published PECO modules including their URIs and accompanying documentation.

Table 11: PECO modules

Module name	Module description	Module URI	Module documentation
peco-core	Core PECO ontology	https://purl.org/peco/peco-core	https://purl.org/peco/docs/peco-core
peco-aap	Module describing assets and properties	https://purl.org/peco/peco-aap	https://purl.org/peco/docs/peco-aap
peco-vlab	Module for AIT VLab support	https://purl.org/peco/peco-vlab	https://purl.org/peco/docs/peco-vlab

[7] https://github.com/lambdamusic/Ontospy

5.6. Maintenance

PECO will enter the maintenance phase (as part of Work Package 5) after the initial publication date. Throughout the project, the ontology will be updated according to corresponding need of the pilots and use cases. Specifically, assets and properties will be extended. Additionally, in case of deficiencies or late requirement discovery, provisions will be made to amend and support additional use cases as needed. The ontology development team will also offer support with the instantiation of knowledge base for project pilots.

As pilots are not fully defined yet, especially with regards to community members' engagement, and as especially HESS concept was not fully evolved for inclusion, some changes and modifications to requirements will be necessary later on. Ontology team intends to implement necessary changes and additions as requirements develop.

Also, while performing large scale instantiations we expect some deficiencies will be discovered that were not visible or noticeable while doing small scale tests. If any are discovered an analysis will be performed how to mitigate or resolve them. This includes functional (requirements not satisfied under certain requirements) and non-functional deficiencies (i.e. reasoner performance degrades with size of the knowledge base).

6. Semantic interoperability approach with PECO

6.1. Architectural view

In PARMENIDES, the architecture was developed based on standardized frameworks and methodologies, such as the Smart Grid Architecture Model (SGAM), the Data Exchange Reference Architecture (DERA) developed by Bridge, the Smart Home and Building IoT Reference Architecture (SHBIRA), and the Semantic Interoperability Framework (SIF) developed by Interconnect, as described in Deliverable 3.1.

One of the main objectives of PECO is to enable interoperability at the level of the information layer, by generating an abstraction of the domains described in section 2.2. The information layer entails the information that is being exchanged between functions, services and components of the system. Moreover, it allows the establishment of semantic interoperability, by providing all the necessary mechanisms and components to facilitate interworking between IoT devices, digital platforms, the energy infrastructure and energy/non-energy applications.

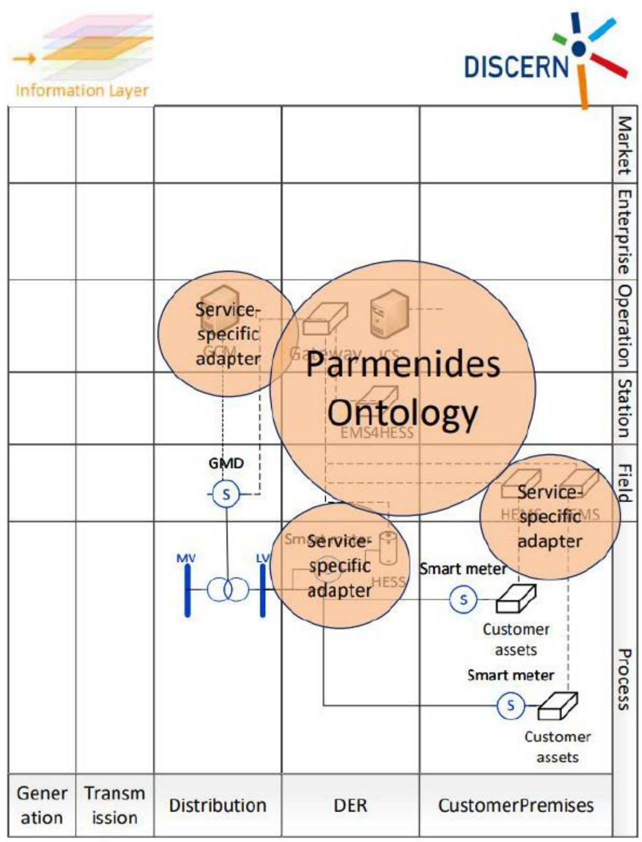

Figure 38: SGAM information layer of the generic architecture (ontology) [Deliverable 3.1]

A representation of the SGAM information layer in relation with the components in PARMENIDES is presented in Figure 38. A special focus is given to the allocation and role of PECO within the system. As visible, the components where PECO will be instantiated are primarily the energy management system

(EMS4HESS), the Information and Configuration System (ICS) and the Gateway. Moreover, thanks to the use of service-specific adapters, data and information exchange is possible between these components and the grid monitoring device (GCM), as well as the smart meters available at the customer side (EC).

The SHBIRA architecture has been implemented in PARMENIDES as a complement of the SGAM, providing more in-depth structure in the customer premises area (Figure 39). This additional representation emphasizes that the information exchange between the pilot regions and the EMS4HESS and ICS passes through the use of PECO as a common vocabulary (with the interlude of the gateway).

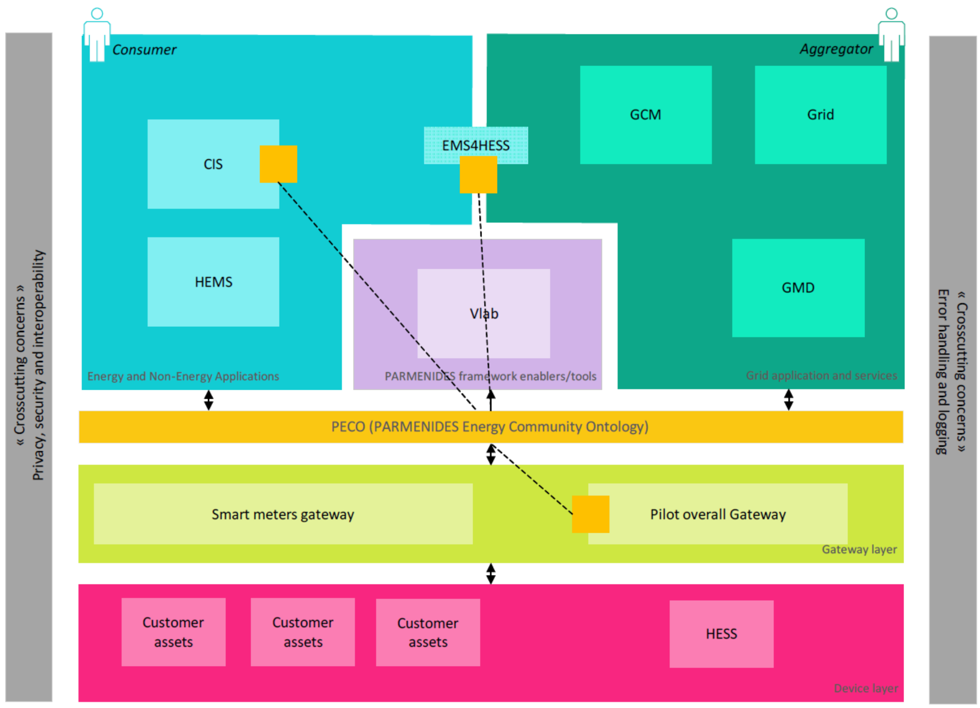

Figure 39: SHBIRA architecture of PARMENIDES, including the ontology implementation by the components (interfaces in yellow) [Source: Deliverable 3.1]

From the point of view of the energy management system, the compliance with the PARMENIDES Ontology (PECO) is ensured by the integration of components which ensure interoperability boundaries within the ROSE EMS standard software architecture (Figure 40).

PARMENIDES

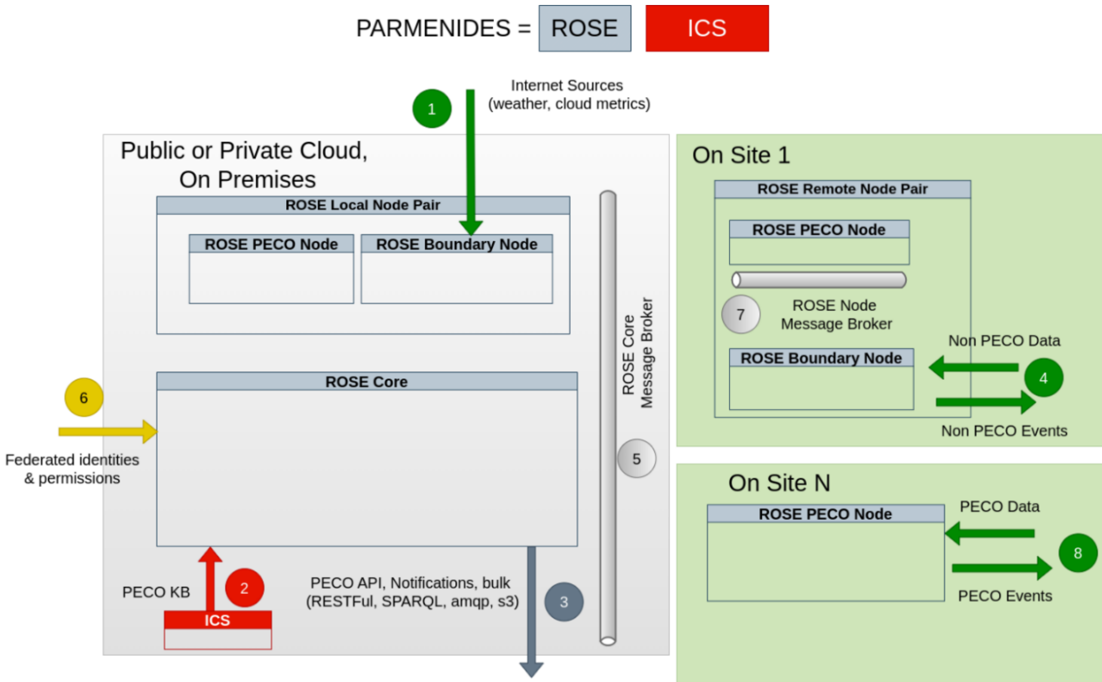

Figure 40: Architectural integration points in ROSE EMS [Source: Deliverable 4.1]

PARMENIDES Deliverable 4.1 describes the type of information exchange and connections within ROSE and ICS, both of which make use of PECO for this purpose. On a Remote Node Pair ("On Site 1" case) the two Nodes communicates through a lightweight Node Broker to enable offline runtime support (7). The Node Broker exchanges PECO messages across the Pair; the Boundary Node transforms the machine dialect data received into PECO objects and PECO events into messages consumable by external sources (4). The PECO Node collects PECO data, transforming it into ROSE KB compliant objects and vice versa; ROSE data are exchanged through the Core Broker (5).

If the Node Pair is hosted in the same infrastructure of the ROSE Core (Local Node Pair), the Pair interoperates through the Core Broker using dedicated subscriptions (5); the Local Boundary Node receives non-PECO messages, transforming them into PECO messages to be forwarded to the PECO Node (1)

If the external source language is PECO-compliant, the distribution requires only the PECO Node, as shown in "On Site N" case (8).

ICS handles the primary Knowledge Base, the PECO KB. ICS exchanges PECO KB updates with the ROSE Core to maintain ROSE KB alignment (2). The ROSE Interoperability Layer for external client is a gateway providing pluggable semantic adapters properly configured for the PARMENIDES EMS4HESS to offer API and other integrations in compliance with the PECO Ontology (3).

6.2. Ontology as a semantic interoperability layer

This chapter focuses on the usage of PECO as a common vocabulary for semantic interoperability, to support knowledge sharing activities between the energy management system (EMS4HESS) and the other digital platforms, among which, primarily, the Information and Configuration System (ICS). The following descriptions regarding the plug and play interoperability supported by the EMS4HESS architecture is referenced from PARMENIDES Deliverable 4.1.

EMS supports the ingestion of domain data from ontologies or data catalogues through a layer of pluggable adapters and connectors, using the same design and components of a ROSE Node, which is responsible for collecting data from the fields and sending events (such as actuation requests) to the external sources (e.g. devices, gateways). A Connector is simply a data sender and receiver with no data processing capability. It is responsible for the adequate management of integration with the source. It implements its own connection lifecycle strategy, ensuring transparent rebinding, scaling, and availability support. Connectors persist data in a Staging Area that is dedicated to maintaining the original, unmodified raw data. A Semantic Adapter is responsible for a processing pipeline involving both technical (syntax validation, data format transformation) and semantic (validation and correlation with the existing KB, enrichment, data model adaptation) aspects.

In PARMENIDES, ROSE main components are reorganized to support PECO as the preferred communication language.

Non-PECO compliant external sources integration is managed by a pair of nodes:

- A Boundary Node to integrate the external source and generate or receive PECO messages.
- A PECO Node to translate ROSE objects into PECO objects and vice versa.

The ROSE KB is fully generated as secondary domain model from a PECO compliant Knowledge Base built and maintained by the ICS system. The interoperability gateway exposes PECO compliant interfaces only (API, events, SPARQL endpoints, import/export).

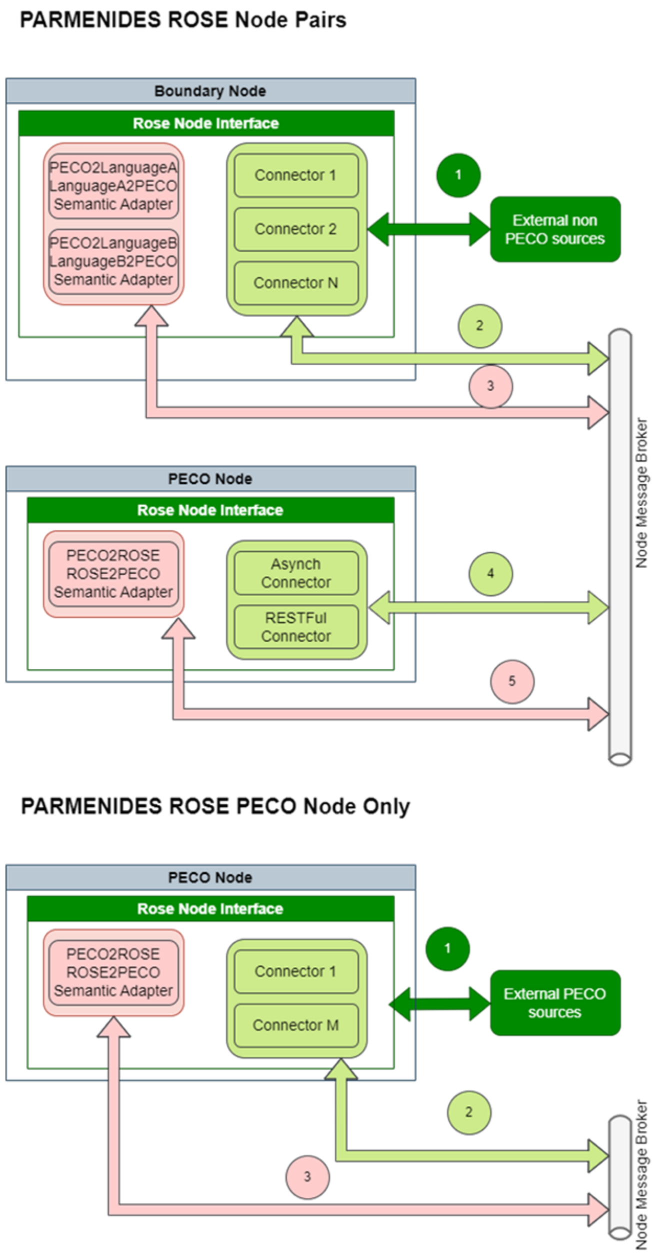

Figure 41: ROSE EMS Node architecture for PECO compliancy [Source: Deliverable 4.1]

PARMENIDES EMS4HESS promotes “PECO” data normalization at source. The ROSE EMS Node architecture design enforces PECO compliancy by defining:

- A Node Pair collaboration (Boundary and PECO) to generate both PECO and ROSE objects for “non-PECO” data sources.
- A PECO Node to interoperate with PECO data sources.

The diagram in Figure 41 describes the two cases.

In the first scenario (PARMENIDES ROSE Node Pairs), the Boundary Node connectors receive data from external sources (1), triggering the Adapter (2) to translate the data into PECO messages and publish them in the local broker (3). The PECO Node subscribes to these events (4), and the asynchronous or RESTful Connector is activated depending on the nature of the message (near real-time events versus huge-sized content or chunked/paginated data). Once the data is received, the Adapter translates them into ROSE messages and sends them to the other Node components and the Core (5).

Similarly, all the events to be sent to the external sources are sent as ROSE messages, translated to PECO by the PECO Node then transmitted to the source by the Boundary node using the source standards.

In the second scenario (PARMENIDES ROSE Node PECO only), the Boundary Node, acting as the "PECO broker", is not required since the source is already PECO compliant. Information is acquired directly by the PECO Node connectors (1), which trigger the Semantic Adapter (2). The Adapter translates them to be compliant with the ROSE KB, forwarding them through the Broker (3). Similarly, all events to be sent to the data sources are processed by the PECO Node and translated into PECO events.

Knowledge base composition

ICS maintains the primary Knowledge Base in compliance with the PARMENIDES Ontology. ROSE Knowledge Base is maintained as a secondary store to serve ROSE internal elaboration.

The Figure 42 shows the ICS - ROSE Knowledge Base alignment process:

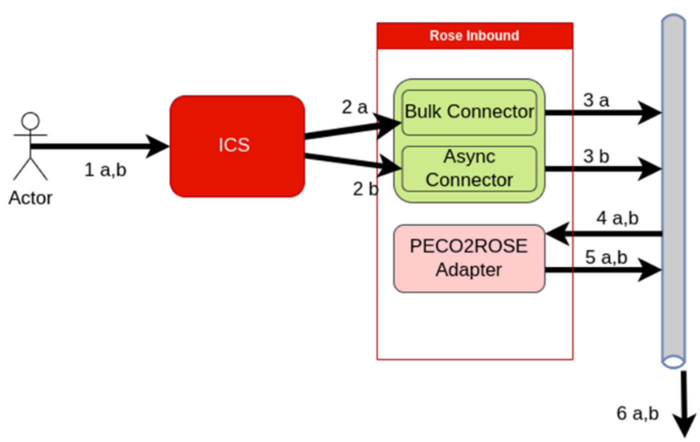

Figure 42: KB alignment process [Source: Deliverable 4.1]

ICS offers two alignment hooks:

- Event driven: each PECO Knowledge Base change triggers a change event.
- Full restore: a full PECO KB export with configurable historical depth.

When a full ROSE KB creation is required (e.g., for first installation or misalignment), ICS initiates a bulk flow (1a), triggering the Bulk Connector (2a) to retrieve data for the PECO2ROSE Adapter (3a). The Adapter receives the event (4a), transforms the KB, and notifies the full restore through the Broker (5a) for the overall alignment process (6a).

When the end user promotes changes on the PECO KB through the ICS configuration wizard (1b), ICS generates an event that is collected by a ROSE Async Connector (2b), which forwards it through the Core Broker (3b) to the PECO2ROSE Adapter (4b), reusing the same components (Connectors and Adapters) and flows defined for Node interoperability. The Adapter sends the transformed ROSE object(s) (5b) to the Core Broker. This event triggers the KB alignment flows and the Intelligence platform (6b).

Transformation for client interfaces

PARMENIDES EMS4HESS Outbound is designed as a "machine-actionable", Open Data interface using PECO as the semantic enabler for automatic discovery and understanding.

The ROSE Outbound design for PARMENIDES is built on top of the technical support of the Gateway transmitting and receiving PECO messages through the ROSE2PECO/PECO2ROSE Adapter translations. Figure 43 offers an overview of the stack:

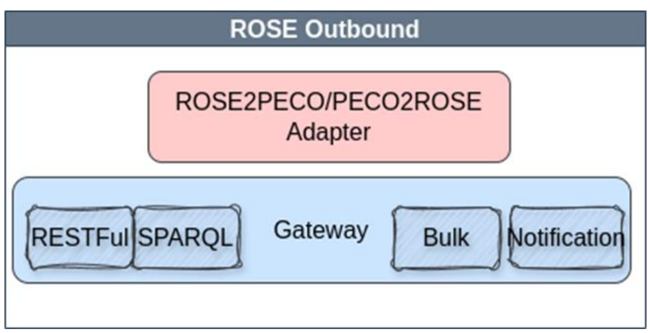

Figure 43: ROSE2PECO Adapter [Source: Deliverable 4.1]

Interoperability architectural overview in Swedish pilot

The Sweden EMS4HESS platform is deployed on a hybrid infrastructure distributed across public cloud and ETT Lab premises.

The public cloud hosts a EMS4HESS ROSE Core distribution with a Local Node Pair comprising:

- A Boundary Node able to read data and send actuations to the Cloud Services (secured RESTful API or asynchronous MQTT).
- A PECO Node sharing data with the Boundary Node using dedicated routes in the ROSE Core Broker (local to the Pair since they share the same Core Infrastructure).

The ROSE Remote Node Pair deployed on the ETT Lab infrastructure is made of:

- A Boundary Node reading data and sending commands from/to the Thermia Heat Pumps Controller and the Regin Exigo Ardo heating controller via Modbus.
- A PECO Node that shares data with the Boundary Node using dedicated routes in the ROSE Node Message Broker.

Interoperability architectural overview in Austrian pilot

In the Austria use case the EMS4HESS acquires data from the assets and measurement devices (SM and GCM) via Siemens Gateway infrastructure having as backbone a MQTT Broker publishing and consuming messages through a two-way SSL Internet communication. Messages are published and received using devices-oriented languages (GCM and Siemens Gateway) – see Figure 44.

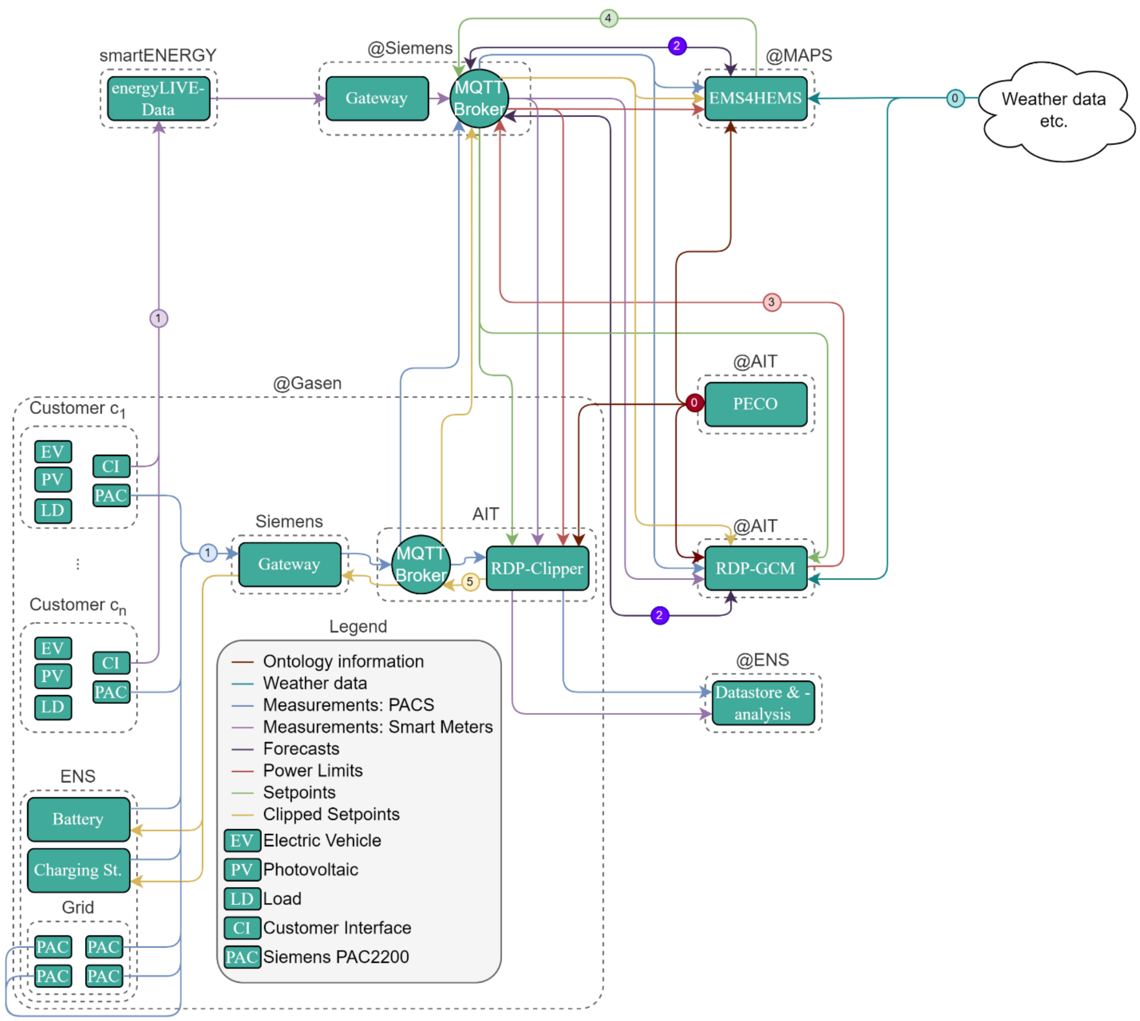

Figure 44: Austrian pilot architecture

The use case requires a PARMENIDES EMS4HESS standard distribution with a Local Node Pair deployed on the same environment of the Core having:

- A Boundary Node able to read messages published and received using devices-oriented languages (GCM and Siemens Gateway) and a MQTT connector.
- A PECO Node sharing data with the Boundary Node using dedicated routes in the ROSE Core Broker (local to the Pair since they share the same Core Infrastructure).

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Annex 1 – Ontology source (peco-core)

```
@prefix : <https://purl.org/peco/peco-core#> .
@prefix om: <http://www.ontology-of-units-of-measure.org/resource/om-2/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix time: <http://www.w3.org/2006/time> .
@prefix saref: <https://saref.etsi.org/core/> .
@prefix s4bldg: <https://saref.etsi.org/saref4bldg/> .
@prefix peco-core: <https://purl.org/peco/peco-core#> .
@base <https://purl.org/peco/peco-core#> .

<https://purl.org/peco/peco-core> rdf:type owl:Ontology ;
                        owl:versionIRI <https://purl.org/peco/peco-core> ;
                        owl:imports <http://www.w3.org/2006/time#2016> ,
                                <http://xmlns.com/foaf/0.1/> ,
                                <https://saref.etsi.org/core/v3.2.1/> ;
                        <http://purl.org/dc/elements/1.1/date> "2024-07-01"^^xsd:date ;
                        <http://purl.org/dc/elements/1.1/description> "PARMENIDES Energy Community Ontology (PECO) aims at establishing a com-
mon vocabulary focused on heating and electricity domain for buildings, customers and renewable energy communities (REC) in Europe. PECO is
developed within the Parmenides project (https://parmenides-project.eu) funded by the European Union." ;
                        <http://purl.org/dc/elements/1.1/title> "Parmenides energy community ontology (PECO)" ;
                        <http://purl.org/dc/terms/contributor> "Bernadette Fina (Bernadette.Fina@ait.ac.at)" ,
                                        "Carolin Monsberger (Carolin.Monsberger@ait.ac.at)" ,
                                        "Dune Sebilleau (dune.sebilleau@trialog.com)" ,
                                        "Kazmi Jawad (Jawad.Kazmi@ait.ac.at)" ,
                                        "Lorenz Ray Ballares Payonga (payonga@kth.se)" ,
                                        "Lorenzo Niccolai (Lorenzo.Niccolai@mapsgroup.it)" ,
                                        "Léo Cornec (leo.cornec@trialog.com)" ,
                                        "Malek Anouti (malek.anouti@experientia.com)" ,
                                        "Maria Aigner (maria.aigner@e-netze.at)" ,
                                        "Mark Stefan (mark.stefan@ait.ac.at)" ,
                                        "Vieri Emiliani (Vieri.Emiliani@mapsgroup.it)" ;
                        <http://purl.org/dc/terms/creator> "Fabrizia Giordano (fabrizia.giordano@ait.ac.at)" ,
                                       "Miloš Šipetić (milos.sipetic@ait.ac.at)" .

#################################################################
#    Object Properties
#################################################################

###  https://purl.org/peco/peco-core#aggregation_used
peco-core:aggregation_used rdf:type owl:ObjectProperty .


###  https://purl.org/peco/peco-core#application_period
peco-core:application_period rdf:type owl:ObjectProperty .


###  https://purl.org/peco/peco-core#connected_to
peco-core:connected_to rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf owl:topObjectProperty ;
                rdf:type owl:SymmetricProperty ;
                rdfs:domain peco-core:Port ;
                rdfs:range peco-core:Port .
```

```
### https://purl.org/peco/peco-core#created_by
peco-core:created_by rdf:type owl:ObjectProperty ;
              rdfs:subPropertyOf owl:topObjectProperty ;
              rdfs:range peco-core:Agent .


### https://purl.org/peco/peco-core#delivered_to
peco-core:delivered_to rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#energy_allocation_period
peco-core:energy_allocation_period rdf:type owl:ObjectProperty ;
                       rdfs:domain peco-core:Allocation_model ;
                       rdfs:range <http://www.w3.org/2006/time#Duration> ;
                       rdfs:comment "Period across which the energy consumption and production is summed up and matched for allocation" .


### https://purl.org/peco/peco-core#guided_by
peco-core:guided_by rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#has_datapoint
peco-core:has_datapoint rdf:type owl:ObjectProperty ;
               owl:inverseOf peco-core:is_datapoint_of .


### https://purl.org/peco/peco-core#has_direction
peco-core:has_direction rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#has_hard_limit
peco-core:has_hard_limit rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf peco-core:has_limit .


### https://purl.org/peco/peco-core#has_incentive
peco-core:has_incentive rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#has_incentive_curve
peco-core:has_incentive_curve rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#has_incentive_type
peco-core:has_incentive_type rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#has_limit
peco-core:has_limit rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#has_lower_limit
peco-core:has_lower_limit rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf peco-core:has_limit .


### https://purl.org/peco/peco-core#has_member
```

```
peco-core:has_member rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf owl:topObjectProperty ;
             owl:inverseOf peco-core:is_member_of .


###  https://purl.org/peco/peco-core#has_negative_incentive
peco-core:has_negative_incentive rdf:type owl:ObjectProperty ;
                     rdfs:subPropertyOf peco-core:has_incentive .


###  https://purl.org/peco/peco-core#has_occupant
peco-core:has_occupant rdf:type owl:ObjectProperty ;
              owl:inverseOf peco-core:occupies ;
              rdfs:domain peco-core:Space ;
              rdfs:range peco-core:Agent .


###  https://purl.org/peco/peco-core#has_optimization_goal
peco-core:has_optimization_goal rdf:type owl:ObjectProperty ;
                    rdfs:subPropertyOf owl:topObjectProperty .


###  https://purl.org/peco/peco-core#has_port
peco-core:has_port rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf owl:topObjectProperty ;
            owl:inverseOf peco-core:is_port_of ;
            rdfs:domain peco-core:Device ;
            rdfs:range peco-core:Port .


###  https://purl.org/peco/peco-core#has_positive_incentive
peco-core:has_positive_incentive rdf:type owl:ObjectProperty ;
                     rdfs:subPropertyOf peco-core:has_incentive .


###  https://purl.org/peco/peco-core#has_preference
peco-core:has_preference rdf:type owl:ObjectProperty .


###  https://purl.org/peco/peco-core#has_property_kind
peco-core:has_property_kind rdf:type owl:ObjectProperty ;
                  rdfs:subPropertyOf owl:topObjectProperty .


###  https://purl.org/peco/peco-core#has_property_of_interest
peco-core:has_property_of_interest rdf:type owl:ObjectProperty ;
                      rdfs:subPropertyOf owl:topObjectProperty ;
                      owl:inverseOf peco-core:is_property_of_interest_of .


###  https://purl.org/peco/peco-core#has_schedule
peco-core:has_schedule rdf:type owl:ObjectProperty ;
              owl:inverseOf peco-core:is_part_of_plan .


###  https://purl.org/peco/peco-core#has_tariff
peco-core:has_tariff rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf owl:topObjectProperty ;
             rdfs:domain peco-core:POD ;
             rdfs:range peco-core:Tariff .
```

```
### https://purl.org/peco/peco-core#has_unit
peco-core:has_unit rdf:type owl:ObjectProperty ;
          rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#has_upper_limit
peco-core:has_upper_limit rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf peco-core:has_limit .


### https://purl.org/peco/peco-core#has_value
peco-core:has_value rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#is_datapoint_of
peco-core:is_datapoint_of rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#is_member_of
peco-core:is_member_of rdf:type owl:ObjectProperty ;
             rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#is_owned_by
peco-core:is_owned_by rdf:type owl:ObjectProperty ;
            rdfs:subPropertyOf owl:topObjectProperty ;
            owl:inverseOf peco-core:owns .


### https://purl.org/peco/peco-core#is_part_of_plan
peco-core:is_part_of_plan rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#is_port_of
peco-core:is_port_of rdf:type owl:ObjectProperty ;
           rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#is_property_of
peco-core:is_property_of rdf:type owl:ObjectProperty ;
               rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#is_property_of_interest_of
peco-core:is_property_of_interest_of rdf:type owl:ObjectProperty ;
                     rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#observation_interval
peco-core:observation_interval rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#occupies
peco-core:occupies rdf:type owl:ObjectProperty .


### https://purl.org/peco/peco-core#owns
peco-core:owns rdf:type owl:ObjectProperty ;
        rdfs:subPropertyOf owl:topObjectProperty ;
        rdfs:domain peco-core:Agent ;
```

```
            rdfs:range peco-core:Asset .


###  https://purl.org/peco/peco-core#received_by
peco-core:received_by rdf:type owl:ObjectProperty ;
                      rdfs:subPropertyOf owl:topObjectProperty ;
                      rdfs:range [ rdf:type owl:Restriction ;
                                   owl:onProperty peco-core:received_by ;
                                   owl:someValuesFrom peco-core:Agent
                                 ] .


###  https://purl.org/peco/peco-core#related_to
peco-core:related_to rdf:type owl:ObjectProperty ;
                     rdfs:subPropertyOf owl:topObjectProperty .


###  https://purl.org/peco/peco-core#related_to_datapoint
peco-core:related_to_datapoint rdf:type owl:ObjectProperty ;
                               rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_flexibility_request
peco-core:related_to_flexibility_request rdf:type owl:ObjectProperty ;
                                         rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_forecast
peco-core:related_to_forecast rdf:type owl:ObjectProperty ;
                              rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_pod
peco-core:related_to_pod rdf:type owl:ObjectProperty ;
                         rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_property
peco-core:related_to_property rdf:type owl:ObjectProperty ;
                              rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_property_of_interest
peco-core:related_to_property_of_interest rdf:type owl:ObjectProperty ;
                                          rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#related_to_tariff
peco-core:related_to_tariff rdf:type owl:ObjectProperty ;
                            rdfs:subPropertyOf peco-core:related_to .


###  https://purl.org/peco/peco-core#stored_at
peco-core:stored_at rdf:type owl:ObjectProperty .


###  https://purl.org/peco/peco-core#tariff_energy_sink
peco-core:tariff_energy_sink rdf:type owl:ObjectProperty ;
                             rdfs:subPropertyOf owl:topObjectProperty ;
                             rdfs:domain peco-core:Tariff ;
                             rdfs:range peco-core:Agent .
```

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```
### https://purl.org/peco/peco-core#tariff_energy_source
peco-core:tariff_energy_source rdf:type owl:ObjectProperty ;
                       rdfs:subPropertyOf owl:topObjectProperty .


### https://purl.org/peco/peco-core#tariff_type
peco-core:tariff_type rdf:type owl:ObjectProperty ;
                rdfs:subPropertyOf owl:topObjectProperty ;
                rdfs:domain peco-core:Tariff ;
                rdfs:range peco-core:Tariff_type .


#################################################################
#    Data properties
#################################################################

### https://purl.org/peco/peco-core#created_at
peco-core:created_at rdf:type owl:DatatypeProperty .


### https://purl.org/peco/peco-core#has_quantity
peco-core:has_quantity rdf:type owl:DatatypeProperty ;
                 rdfs:subPropertyOf owl:topDataProperty .


### https://purl.org/peco/peco-core#has_timestamp
peco-core:has_timestamp rdf:type owl:DatatypeProperty ;
                  rdfs:subPropertyOf owl:topDataProperty .


### https://purl.org/peco/peco-core#has_weight
peco-core:has_weight rdf:type owl:DatatypeProperty ;
               rdfs:subPropertyOf owl:topDataProperty .


### https://purl.org/peco/peco-core#valid_from
peco-core:valid_from rdf:type owl:DatatypeProperty ;
               rdfs:subPropertyOf owl:topDataProperty .


### https://purl.org/peco/peco-core#valid_to
peco-core:valid_to rdf:type owl:DatatypeProperty ;
             rdfs:subPropertyOf owl:topDataProperty .


#################################################################
#    Classes
#################################################################

### http://www.w3.org/2006/time#Duration
<http://www.w3.org/2006/time#Duration> rdf:type owl:Class .


### https://purl.org/peco/peco-core#Action_requiring_notification
peco-core:Action_requiring_notification rdf:type owl:Class ;
                           rdfs:subClassOf peco-core:Message ;
                           rdfs:comment "Direct alert about immediate opportunities or needs for energy conservation and sustainable practices.
Designed to prompt users to take swift, environmentally responsible actions." .


### https://purl.org/peco/peco-core#Agent
```

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```
peco-core:Agent rdf:type owl:Class .


###  https://purl.org/peco/peco-core#Aggregation_function
peco-core:Aggregation_function rdf:type owl:Class .


###  https://purl.org/peco/peco-core#Alarm
peco-core:Alarm rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Datapoint .


###  https://purl.org/peco/peco-core#Allocation_model
peco-core:Allocation_model rdf:type owl:Class ;
                rdfs:subClassOf [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:energy_allocation_period ;
                                owl:someValuesFrom <http://www.w3.org/2006/time#Duration>
                              ] ;
                rdfs:comment "Energy community allocation model. This influences how the locally produced energy is allocated to energy com-
munity members" .


###  https://purl.org/peco/peco-core#Apartment
peco-core:Apartment rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Space .


###  https://purl.org/peco/peco-core#Asset
peco-core:Asset rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Feature_of_interest .


###  https://purl.org/peco/peco-core#Association_for_self_consumption
peco-core:Association_for_self_consumption rdf:type owl:Class ;
                              rdfs:subClassOf peco-core:Energy_community .


###  https://purl.org/peco/peco-core#Building
peco-core:Building rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Location .


###  https://purl.org/peco/peco-core#Building_element
peco-core:Building_element rdf:type owl:Class ;
                rdfs:subClassOf peco-core:Feature_of_interest .


###  https://purl.org/peco/peco-core#Citizen_energy_community
peco-core:Citizen_energy_community rdf:type owl:Class ;
                     rdfs:subClassOf peco-core:Energy_community .


###  https://purl.org/peco/peco-core#Comfort_goal
peco-core:Comfort_goal rdf:type owl:Class ;
             rdfs:subClassOf peco-core:Optimization_goal ;
             rdfs:comment "Comfort goal guides optimization towards optimal user comfort" .


###  https://purl.org/peco/peco-core#Command
peco-core:Command rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Datapoint .
```

```
###  https://purl.org/peco/peco-core#Commercial_building
peco-core:Commercial_building rdf:type owl:Class ;
                    rdfs:subClassOf peco-core:Building .


###  https://purl.org/peco/peco-core#Data_port
peco-core:Data_port rdf:type owl:Class ;
             rdfs:subClassOf peco-core:Port ,
                         [ rdf:type owl:Restriction ;
                           owl:onProperty peco-core:connected_to ;
                           owl:allValuesFrom peco-core:Data_port
                         ] .


###  https://purl.org/peco/peco-core#Datapoint
peco-core:Datapoint rdf:type owl:Class ;
             rdfs:subClassOf peco-core:Property_of_interest ,
                         [ rdf:type owl:Restriction ;
                           owl:onProperty peco-core:has_timestamp ;
                           owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                           owl:onDataRange xsd:dateTime
                         ] .


###  https://purl.org/peco/peco-core#Datastore
peco-core:Datastore rdf:type owl:Class .


###  https://purl.org/peco/peco-core#Device
peco-core:Device rdf:type owl:Class ;
           rdfs:subClassOf peco-core:Asset .


###  https://purl.org/peco/peco-core#EMS
peco-core:EMS rdf:type owl:Class ;
         rdfs:subClassOf peco-core:Agent .


###  https://purl.org/peco/peco-core#Economy_goal
peco-core:Economy_goal rdf:type owl:Class ;
               rdfs:subClassOf peco-core:Optimization_goal ;
               rdfs:comment "Economy goal guides optimization towards best monetary outcome" .


###  https://purl.org/peco/peco-core#Electric_POD
peco-core:Electric_POD rdf:type owl:Class ;
               rdfs:subClassOf peco-core:POD .


###  https://purl.org/peco/peco-core#Electrical_port
peco-core:Electrical_port rdf:type owl:Class ;
                 rdfs:subClassOf peco-core:Port ,
                             [ rdf:type owl:Restriction ;
                               owl:onProperty peco-core:connected_to ;
                               owl:allValuesFrom peco-core:Electrical_port
                             ] .


###  https://purl.org/peco/peco-core#Electricity_grid
peco-core:Electricity_grid rdf:type owl:Class ;
                 rdfs:subClassOf peco-core:Agent .
```

```
### https://purl.org/peco/peco-core#Electricity_tariff
peco-core:Electricity_tariff rdf:type owl:Class ;
                      rdfs:subClassOf peco-core:Tariff ;
                      rdfs:comment "Tariff used for valorization of electricity flows by the TSO" .


### https://purl.org/peco/peco-core#Energy
peco-core:Energy rdf:type owl:Class ;
            rdfs:subClassOf peco-core:Unit .


### https://purl.org/peco/peco-core#Energy_based_tariff
peco-core:Energy_based_tariff rdf:type owl:Class ;
                      rdfs:subClassOf peco-core:Tariff_base .


### https://purl.org/peco/peco-core#Energy_community
peco-core:Energy_community rdf:type owl:Class ;
                  rdfs:subClassOf peco-core:Agent ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:has_member ;
                                owl:someValuesFrom peco-core:Energy_community_member
                              ] ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:has_tariff ;
                                owl:someValuesFrom peco-core:Tariff
                              ] ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:owns ;
                                owl:someValuesFrom peco-core:Asset
                              ] ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:owns ;
                                owl:someValuesFrom peco-core:POD
                              ] ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:has_optimization_goal ;
                                owl:maxQualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                                owl:onClass peco-core:Optimization_goal
                              ] ;
                  rdfs:comment "" .


### https://purl.org/peco/peco-core#Energy_community_member
peco-core:Energy_community_member rdf:type owl:Class ;
                        rdfs:subClassOf peco-core:Agent ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty peco-core:has_optimization_goal ;
                                      owl:someValuesFrom peco-core:Optimization_goal
                                    ] ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty peco-core:occupies ;
                                      owl:someValuesFrom peco-core:Space
                                    ] ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty peco-core:owns ;
                                      owl:someValuesFrom peco-core:Asset
                                    ] ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty peco-core:owns ;
```

```
                    owl:someValuesFrom peco-core:POD
                   ] ;
        rdfs:comment "Energy community member is a person (or an organization) that joined a certain energy community" .


### https://purl.org/peco/peco-core#Energy_community_tariff
peco-core:Energy_community_tariff rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Tariff ;
        rdfs:comment "Tariff used for valorization of  EC-generated electricity flows" .


### https://purl.org/peco/peco-core#Energy_storage
peco-core:Energy_storage rdf:type owl:Class ;
      rdfs:subClassOf peco-core:Asset .


### https://purl.org/peco/peco-core#Environment_goal
peco-core:Environment_goal rdf:type owl:Class ;
      rdfs:subClassOf peco-core:Optimization_goal ;
      rdfs:comment "Environment goal guides optimization towards minimal possible environmental effect in terms of greenhouse gases
and other emissions" .


### https://purl.org/peco/peco-core#Feature_of_interest
peco-core:Feature_of_interest rdf:type owl:Class .


### https://purl.org/peco/peco-core#Flexibility_request
peco-core:Flexibility_request rdf:type owl:Class ;
       rdfs:subClassOf [ rdf:type owl:Class ;
           owl:unionOf ( [ owl:intersectionOf ( [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_lower_limit ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onClass peco-core:Timeseries
                       ]
                       [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_upper_limit ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onClass peco-core:Timeseries
                       ]
                      ) ;
               rdf:type owl:Class
              ]
              [ rdf:type owl:Restriction ;
               owl:onProperty peco-core:has_hard_limit ;
               owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
               owl:onClass peco-core:Timeseries
              ]
             )
          ] ,
          [ rdf:type owl:Restriction ;
           owl:onProperty peco-core:created_by ;
           owl:someValuesFrom peco-core:Agent
          ] ,
          [ rdf:type owl:Restriction ;
           owl:onProperty peco-core:received_by ;
           owl:someValuesFrom peco-core:Agent
          ] ,
          [ rdf:type owl:Restriction ;
           owl:onProperty peco-core:related_to_pod ;
           owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
           owl:onClass peco-core:POD
```

```
                        ] ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty peco-core:created_at ;
                          owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                          owl:onDataRange xsd:dateTime
                        ] ;
                rdfs:comment """An incentive describes a certain effect (benefit or penalty) offered in exchange for certain consumption or production behavior.

Desired behavior can be described by

- upper and/or lower limit or
- a hard limit (setpoint) for a property.

Positive effect describes effect of compliance, and negative effect to the non-compliance to the requested behavior.""" .


###  https://purl.org/peco/peco-core#Forecast
peco-core:Forecast rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Timeseries ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:created_by ;
                  owl:someValuesFrom peco-core:Agent
                ] ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:related_to_property_of_interest ;
                  owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                  owl:onClass peco-core:Property_of_interest
                ] ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:created_at ;
                  owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                  owl:onDataRange xsd:dateTime
                ] .


###  https://purl.org/peco/peco-core#GCM
peco-core:GCM rdf:type owl:Class ;
      rdfs:subClassOf peco-core:Agent .


###  https://purl.org/peco/peco-core#Gas_port
peco-core:Gas_port rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Port .


###  https://purl.org/peco/peco-core#Grid_support_flexibility_request
peco-core:Grid_support_flexibility_request rdf:type owl:Class ;
                rdfs:subClassOf peco-core:Flexibility_request .


###  https://purl.org/peco/peco-core#Grid_tariff
peco-core:Grid_tariff rdf:type owl:Class ;
         rdfs:subClassOf peco-core:Tariff ;
         rdfs:comment "Tariff for valorization of electricity flows by the electrical grid" .


###  https://purl.org/peco/peco-core#HEMS
peco-core:HEMS rdf:type owl:Class ;
      rdfs:subClassOf peco-core:Agent .
```

```
### https://purl.org/peco/peco-core#HESS
peco-core:HESS rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Energy_storage .


### https://purl.org/peco/peco-core#Hallway
peco-core:Hallway rdf:type owl:Class ;
            rdfs:subClassOf peco-core:Space .


### https://purl.org/peco/peco-core#Hot_water_POD
peco-core:Hot_water_POD rdf:type owl:Class ;
                rdfs:subClassOf peco-core:POD .


### https://purl.org/peco/peco-core#Hot_water_port
peco-core:Hot_water_port rdf:type owl:Class ;
                 rdfs:subClassOf peco-core:Port ,
                         [ rdf:type owl:Restriction ;
                           owl:onProperty peco-core:connected_to ;
                           owl:allValuesFrom peco-core:Hot_water_port
                         ] .


### https://purl.org/peco/peco-core#Immediate_activation_request
peco-core:Immediate_activation_request rdf:type owl:Class ;
                          rdfs:subClassOf peco-core:Message ;
                          rdfs:comment "Request requiring swift action in response to opportunities for immediate energy conservation or sustaina-
ble practices, emphasizing quick decision-making in favour of environmental sustainability and demand for flexibility." .


### https://purl.org/peco/peco-core#Incentive
peco-core:Incentive rdf:type owl:Class ;
             rdfs:subClassOf [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_incentive_curve ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onClass peco-core:Timeseries
                       ] ,
                       [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_incentive_type ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onClass peco-core:Incentive_type
                       ] ,
                       [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:related_to_tariff ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onClass peco-core:Tariff
                       ] .


### https://purl.org/peco/peco-core#Incentive_type
peco-core:Incentive_type rdf:type owl:Class ;
                 rdfs:comment "Defines the type of incentive. Specifies how effect's values should be interpreted" .


### https://purl.org/peco/peco-core#Incentivized_flexibility_request
peco-core:Incentivized_flexibility_request rdf:type owl:Class ;
                            rdfs:subClassOf peco-core:Flexibility_request ,
                                    [ rdf:type owl:Restriction ;
                                      owl:onProperty peco-core:has_incentive ;
                                      owl:someValuesFrom peco-core:Incentive
                                    ] .
```

```
### https://purl.org/peco/peco-core#Informative_notification
peco-core:Informative_notification rdf:type owl:Class ;
                        rdfs:subClassOf peco-core:Message ;
                        rdfs:comment "Notification providing insights into sustainable energy practices and the impact of community actions on environmental conservation. Its role is to keep users informed and motivated about ongoing sustainability efforts." .


### https://purl.org/peco/peco-core#Location
peco-core:Location rdf:type owl:Class .


### https://purl.org/peco/peco-core#Measurement
peco-core:Measurement rdf:type owl:Class ;
               rdfs:subClassOf peco-core:Datapoint .


### https://purl.org/peco/peco-core#Meeting_room
peco-core:Meeting_room rdf:type owl:Class ;
                rdfs:subClassOf peco-core:Space .


### https://purl.org/peco/peco-core#Message
peco-core:Message rdf:type owl:Class ;
            rdfs:subClassOf [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:created_by ;
                        owl:someValuesFrom peco-core:Agent
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:delivered_to ;
                        owl:someValuesFrom peco-core:Agent
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:created_at ;
                        owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onDataRange xsd:dateTime
                      ] ;
            rdfs:comment "Message aimed at end user" .


### https://purl.org/peco/peco-core#Module
peco-core:Module rdf:type owl:Class ;
            rdfs:subClassOf peco-core:Agent .


### https://purl.org/peco/peco-core#Multi_family_house
peco-core:Multi_family_house rdf:type owl:Class ;
                    rdfs:subClassOf peco-core:Building .


### https://purl.org/peco/peco-core#Objective_oriented_activation_request
peco-core:Objective_oriented_activation_request rdf:type owl:Class ;
                                rdfs:subClassOf peco-core:Message ;
                                rdfs:comment "Message for guiding users towards long-term sustainability goals. This involves strategic planning for energy conservation and integrating renewable energy sources into daily routines, distinguishing them from short-term reactive measures. This is important to take into account flexibility demand on a daily, weekly and other periodic basis." .


### https://purl.org/peco/peco-core#Optimization_goal
peco-core:Optimization_goal rdf:type owl:Class ;
                    rdfs:subClassOf [ rdf:type owl:Restriction ;
```

```
                        owl:onProperty peco-core:has_weight ;
                        owl:maxQualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                        owl:onDataRange xsd:decimal
                      ] .


### https://purl.org/peco/peco-core#Optimization_plan
peco-core:Optimization_plan rdf:type owl:Class ;
                rdfs:subClassOf [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:guided_by ;
                        owl:someValuesFrom peco-core:Optimization_goal
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_schedule ;
                        owl:someValuesFrom peco-core:Schedule
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:related_to_flexibility_request ;
                        owl:someValuesFrom peco-core:Flexibility_request
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:related_to_forecast ;
                        owl:someValuesFrom peco-core:Forecast
                      ] .


### https://purl.org/peco/peco-core#POD
peco-core:POD rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Asset ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:has_tariff ;
                  owl:someValuesFrom peco-core:Tariff
                ] .


### https://purl.org/peco/peco-core#Parameter
peco-core:Parameter rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Datapoint .


### https://purl.org/peco/peco-core#Port
peco-core:Port rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Feature_of_interest ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:has_property_of_interest ;
                  owl:someValuesFrom peco-core:Property_of_interest
                ] ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:has_direction ;
                  owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                  owl:onClass peco-core:Port_direction
                ] ,
                [ rdf:type owl:Restriction ;
                  owl:onProperty peco-core:connected_to ;
                  owl:maxQualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                  owl:onClass peco-core:Port
                ] .


### https://purl.org/peco/peco-core#Port_direction
peco-core:Port_direction rdf:type owl:Class .
```

```
### https://purl.org/peco/peco-core#Power
peco-core:Power rdf:type owl:Class ;
        rdfs:subClassOf peco-core:Unit .


### https://purl.org/peco/peco-core#Power_based_tariff
peco-core:Power_based_tariff rdf:type owl:Class ;
              rdfs:subClassOf peco-core:Tariff_base ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:aggregation_used ;
                        owl:someValuesFrom peco-core:Aggregation_function
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:application_period ;
                        owl:someValuesFrom <http://www.w3.org/2006/time#Duration>
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:observation_interval ;
                        owl:someValuesFrom <http://www.w3.org/2006/time#Duration>
                      ] ;
              rdfs:comment "Allows specifying power-based tariffs depending on aggregating power over a variable interval and applying a certain cost to a certain period." .


### https://purl.org/peco/peco-core#Preference
peco-core:Preference rdf:type owl:Class .


### https://purl.org/peco/peco-core#Preference_range
peco-core:Preference_range rdf:type owl:Class ;
             rdfs:subClassOf peco-core:Preference ,
                     [ rdf:type owl:Restriction ;
                       owl:onProperty peco-core:has_lower_limit ;
                       owl:someValuesFrom peco-core:Value
                     ] ,
                     [ rdf:type owl:Restriction ;
                       owl:onProperty peco-core:has_upper_limit ;
                       owl:someValuesFrom peco-core:Value
                     ] .


### https://purl.org/peco/peco-core#Preference_timed_range
peco-core:Preference_timed_range rdf:type owl:Class ;
                rdfs:subClassOf peco-core:Preference ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty peco-core:has_lower_limit ;
                          owl:someValuesFrom peco-core:Timeseries
                        ] ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty peco-core:has_upper_limit ;
                          owl:someValuesFrom peco-core:Timeseries
                        ] .


### https://purl.org/peco/peco-core#Property
peco-core:Property rdf:type owl:Class .


### https://purl.org/peco/peco-core#Property_of_interest
peco-core:Property_of_interest rdf:type owl:Class ;
               rdfs:subClassOf [ rdf:type owl:Restriction ;
```

```
                                owl:onProperty peco-core:has_property_kind ;
                                owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                                owl:onClass peco-core:Property
                              ] ,
                              [ rdf:type owl:Restriction ;
                                owl:onProperty peco-core:has_value ;
                                owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                                owl:onClass peco-core:Value
                              ] .


###  https://purl.org/peco/peco-core#Renewable_energy_community
peco-core:Renewable_energy_community rdf:type owl:Class ;
                          rdfs:subClassOf peco-core:Energy_community .


###  https://purl.org/peco/peco-core#Room
peco-core:Room rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Space .


###  https://purl.org/peco/peco-core#Schedule
peco-core:Schedule rdf:type owl:Class ;
              rdfs:subClassOf peco-core:Timeseries ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty peco-core:created_by ;
                            owl:someValuesFrom peco-core:Agent
                          ] ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty peco-core:related_to_property_of_interest ;
                            owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                            owl:onClass peco-core:Property_of_interest
                          ] ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty peco-core:created_at ;
                            owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                            owl:onDataRange xsd:dateTime
                          ] .


###  https://purl.org/peco/peco-core#Setpoint
peco-core:Setpoint rdf:type owl:Class ;
              rdfs:subClassOf peco-core:Datapoint ,
                          [ rdf:type owl:Restriction ;
                            owl:onProperty peco-core:has_preference ;
                            owl:someValuesFrom peco-core:Preference
                          ] .


###  https://purl.org/peco/peco-core#Single_family_house
peco-core:Single_family_house rdf:type owl:Class ;
                     rdfs:subClassOf peco-core:Building .


###  https://purl.org/peco/peco-core#Site
peco-core:Site rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Location .


###  https://purl.org/peco/peco-core#Space
peco-core:Space rdf:type owl:Class ;
           rdfs:subClassOf peco-core:Building_element ,
```

```
                    peco-core:Location ,
                    [ rdf:type owl:Restriction ;
                      owl:onProperty peco-core:has_occupant ;
                      owl:someValuesFrom peco-core:Agent
                    ] .


###  https://purl.org/peco/peco-core#Static_property
peco-core:Static_property rdf:type owl:Class ;
                  rdfs:subClassOf peco-core:Property_of_interest .


###  https://purl.org/peco/peco-core#Storey
peco-core:Storey rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Space .


###  https://purl.org/peco/peco-core#Tariff
peco-core:Tariff rdf:type owl:Class ;
          rdfs:subClassOf peco-core:Feature_of_interest ,
                    [ rdf:type owl:Restriction ;
                      owl:onProperty peco-core:tariff_energy_sink ;
                      owl:someValuesFrom peco-core:Agent
                    ] ,
                    [ rdf:type owl:Restriction ;
                      owl:onProperty peco-core:tariff_energy_source ;
                      owl:someValuesFrom peco-core:Agent
                    ] ,
                    [ rdf:type owl:Restriction ;
                      owl:onProperty peco-core:valid_from ;
                      owl:someValuesFrom xsd:dateTime
                    ] ,
                    [ rdf:type owl:Restriction ;
                      owl:onProperty peco-core:valid_to ;
                      owl:someValuesFrom xsd:dateTime
                    ] .


###  https://purl.org/peco/peco-core#Tariff_base
peco-core:Tariff_base rdf:type owl:Class .


###  https://purl.org/peco/peco-core#Tariff_type
peco-core:Tariff_type rdf:type owl:Class .


###  https://purl.org/peco/peco-core#Temperature
peco-core:Temperature rdf:type owl:Class ;
               rdfs:subClassOf peco-core:Unit .


###  https://purl.org/peco/peco-core#Timeseries
peco-core:Timeseries rdf:type owl:Class ;
               rdfs:subClassOf [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:has_datapoint ;
                        owl:someValuesFrom peco-core:Datapoint
                      ] ,
                      [ rdf:type owl:Restriction ;
                        owl:onProperty peco-core:stored_at ;
                        owl:someValuesFrom peco-core:Datastore
                      ] .
```

```
### https://purl.org/peco/peco-core#Unit
peco-core:Unit rdf:type owl:Class .


### https://purl.org/peco/peco-core#Value
peco-core:Value rdf:type owl:Class ;
        rdfs:subClassOf [ rdf:type owl:Restriction ;
                          owl:onProperty peco-core:has_unit ;
                          owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                          owl:onClass peco-core:Unit
                        ] ,
                        [ rdf:type owl:Restriction ;
                          owl:onProperty peco-core:has_quantity ;
                          owl:qualifiedCardinality "1"^^xsd:nonNegativeInteger ;
                          owl:onDataRange xsd:decimal
                        ] .


#################################################################
#    Individuals
#################################################################

### https://purl.org/peco/peco-core#Buy_tariff
peco-core:Buy_tariff rdf:type owl:NamedIndividual ,
                    peco-core:Tariff_type .


### https://purl.org/peco/peco-core#DynamicAllocation
peco-core:DynamicAllocation rdf:type owl:NamedIndividual ,
                           peco-core:Allocation_model .


### https://purl.org/peco/peco-core#Input_port
peco-core:Input_port rdf:type owl:NamedIndividual ,
                    peco-core:Port_direction .


### https://purl.org/peco/peco-core#Output_port
peco-core:Output_port rdf:type owl:NamedIndividual ,
                     peco-core:Port_direction .


### https://purl.org/peco/peco-core#Sell_tariff
peco-core:Sell_tariff rdf:type owl:NamedIndividual ,
                     peco-core:Tariff_type .


### https://purl.org/peco/peco-core#StaticAllocation
peco-core:StaticAllocation rdf:type owl:NamedIndividual ,
                          peco-core:Allocation_model .


### https://purl.org/peco/peco-core#absolute_cost
peco-core:absolute_cost rdf:type owl:NamedIndividual ,
                       peco-core:Incentive_type .


### https://purl.org/peco/peco-core#aggregation_function_max
peco-core:aggregation_function_max rdf:type owl:NamedIndividual ,
                                  peco-core:Aggregation_function .
```

```
###  https://purl.org/peco/peco-core#aggregation_function_mean
peco-core:aggregation_function_mean rdf:type owl:NamedIndividual ,
                                    peco-core:Aggregation_function .


###  https://purl.org/peco/peco-core#aggregation_function_min
peco-core:aggregation_function_min rdf:type owl:NamedIndividual ,
                                   peco-core:Aggregation_function .


###  https://purl.org/peco/peco-core#cost_change
peco-core:cost_change rdf:type owl:NamedIndividual ,
                      peco-core:Incentive_type .


#################################################################
#    General axioms
#################################################################

[ rdf:type owl:AllDisjointClasses ;
  owl:members ( peco-core:Action_requiring_notification
                peco-core:Immediate_activation_request
                peco-core:Informative_notification
                peco-core:Objective_oriented_activation_request
              )
] .


[ rdf:type owl:AllDisjointClasses ;
  owl:members ( peco-core:Association_for_self_consumption
                peco-core:Citizen_energy_community
                peco-core:Renewable_energy_community
              )
] .


[ rdf:type owl:AllDisjointClasses ;
  owl:members ( peco-core:Data_port
                peco-core:Electrical_port
                peco-core:Hot_water_port
              )
] .


###  Generated by the OWL API (version 4.5.29.2024-05-13T12:11:03Z) https://github.com/owlcs/owlapi
```

Annex 2 – Review of energy community transpositions in the European countries

Table 12: Comparison of energy community transpositions in the European countries (part 1)

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
Austria	Yes, both REC and CEC	Renewable Expansion Act (EAG), Electricity Act (ElWOG) (foreseen update end of 2023, ElWG) and its System Tariff Ordninance (SNE-VO)	Low-voltage distribution network and the low-voltage part of the transformer station (local area) or the medium-voltage network and the medium-voltage busbar in the transformer station (regional area) in the concession area of a network operator.	At least two members. REC: citizens, municipalities, legal entities under public law, small and medium businesses. In the case of private companies, participation must not be their main commercial or professional activity. CEC: natural persons as well as legal entities and local authorities. Control over a CEC (e.g., a majority vote to amend the statutes) may be exercised only by natural persons, local governments, and small businesses, provided they do not perform the function of an electric utility.	Affected DSOs must be informed about the establishment of the EC and its mode of operation and participants. The operating and controlling power over the generation plants lies with the EC. The DSO must measure the consumption of all participants with a smart meter (must be retrofitted within 2 months). In addition, the DSO must make the measurement data available to the suppliers as well as to the EC, in the case of a CEC to all other network operators (to the energy community free of charge via a web portal). The grid operator must allocate the static (fixed percentage of generation goes to one participant) or dynamic share (distribution of energy according to consumption of the participants) of the generated energy agreed between the participants to the respective plants and must be shown on the invoice.	No

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
					P2P shall be implemented in the update of the Electricity Act end of 2023.	
Sweden	Only collective self-consumption is possible. Legislative proposal (proposed by Energy Market Inspectorate EI), however, bill 2021/22:153 concluded that ECs are already possible in Sweden, no obstacles exist and no new legislation is needed[14],[15]. There exist first pilot areas with concession exemption (e.g., Tamarinden, ElectriCITY – Hammerby Sjöstad 2.0 and SIMRIS[16], [17])	Legislative proposal by EI (not adopted) and bill 2021/22:153 "Implementation of the Electricity Market Directive", Ordinance 2007:215 (Section 22c)[14].	Legislative proposal by EI: Living in geographical proximity (to be defined by RECs), but not adopted by bill 2021/22:153.	Legislative proposal by EI: Three or more natural or legal persons differentiating between investing and non-investing members [18], but not adopted by bill 2021/22:153.	Current legislation: collective self-consumption in an apartment building with the same grid connection is allowed (general approach: same electricity supplier for entire building and individual electricity consumption measurement that affects monthly rent)[18]. Ordinance 2007:215 (Section 22c) makes exemption from requirement for a network concession under Electricity Act (1997:857) for underground cables between a production facility or storage facility between neighboring buildings [15].	Undecided in EI proposal, not possible now (Ordinance 2007:215 (Section 22c) makes exemption from requirement for a network concession for underground cables between a production facility or storage facility between neighboring buildings [15].
Italy	RECs And CECs	There are always three different acts that are	Originally, national regulations limited the capacity of RES installations to 200	RECs are not-for-profit organisations. RECs' members that can rule over control and	Energy sharing in an EC is implemented such that electricity is fed into the grid, and then generation	Not Allowed (only one exception for actual

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
		needed to have the setting fully operational. A Legislative Act taken by the parliament (Decreto Legge 199/2021) later converted into a law and partially amended. With this law the Italian parliament brought into the Italian legislation the requirements of the the RED-II EU Directive. A Government Act that establishes the incentives (D.m. 414/2023 – Decreto CACER comunità energetiche rinnovabili). A Regulatory act (Delibera Arera TIAD[8]) considers RECs and more generally rules for the Internal Electricity Market as required by another EU Directive. [19],[20] ,[21],[22],[23] , [24],[25].	kW and required participants to be connected via the same low voltage grid[20]. This limitation has been overcome by Legislative Decree no. 199 of 8 November 2021. The capacity limit of REC generation units is raised to 1 MW and allows members and plants of a REC to be connected to the medium voltage grid (under HV-MV voltage substation) [20]. There also exist the so-calleds "Self-consumption group" - gruppi di autoconsumo collettivo - (have to be in the same building with a slighlty extensive definition of building).	configuration of the REC must be physical persons, SME, local authorities, and territorial bodies such as municipalities, research centres, schools and universities, religious bodies, not-for-profit organisations and organisations that protect the environment. Large Enterprises and any company working in the energy market cannot be members of RECs. It is possible for owners of production plants to contribute to the REC – without being members - with their plant and be rewarded with a private contract between the REC and themselves.	and consumption amounts of the participating parties are matched. Based on this data, the participants receive a certain refund. The "self-consumption" of ECs is calculated on an hourly basis: Article 8 of reference Italian law [22], has legally defined the concept of "shared energy", which is energy produced with renewables and consumed in the same hour by users within a REC. More in detail, Article 2, letter q) of 199/2021, defines that shared energy "is equal to the minimum, in each hourly period, between the electricity produced and fed into the grid by renewable source plants and the electricity withdrawn by all the associated end-customers located in the same market area"[25]. The shared energy is valued according to a formula that puts it in the range of 70 to 120 € per MWh based on the nominal power of the plants and on the current market price of electricity.	self-consumption of energy produced by the subject that has production and consumption distanced but within 10kms)

[8] Arera I the Italian Regulatory Authority and TIAD is the Italian acronym for "Integrated Regulation for Diffuse Self-Consumption".

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
		Since 8 April 2024 all the regulatory and operational settings are completed.			If one has received subsidies for the instalment of the plant, the subsidies for the shared energy are reduced accordingly. There are limits: up to 5 GW of new power from renewable sources installed before end of 2027; subsidies for energy shared last for 20 years from inception of the REC.	
Germany	RECs	**Old:** Amendments of the Renewable Energy Sources Act (RESA) of December 2020 and June 2021 failed to fully and timely transpose the provisions for RECs defined in RED [20]. Some EC initiatives in Germany do already fulfil requirements for RECs as per the RED II, but there is still no implementation of RECs in German legislation. The government also plans to make full use of the "de minimis" rules under the revised Guidelines on State Aid for Climate, Environmental Protection and Energy	At least 75% of the voting rights must be held by natural persons living in a zip code area that is wholly or partially within 50 kilometers of the proposed facility[27].	At least 50 natural persons as voting members or voting shareholders (at least 75% of the voting rights must be held by natural persons living in a zip code area that is wholly or partially within 50 kilometers of the proposed facility). The remainder of the voting rights must be held by microenterprises, small or medium-sized enterprises, or local governmental entities. No member or shareholder of the corporation may hold more than 10% of the voting rights in the corporation (§3 Nr. 15 EEG 2023)[27].	So far, there are no mechanisms in place to ensure cooperation of DSOs with RECs to facilitate energy transfers within RECs [20]. Energy sharing possible within tenant sharing models ("Mieterstrommodelle") – behind the meter.	possible

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
		(2022/C 80/01) and exempt RECs below certain thresholds from the auctions as a contribution to reducing bureaucracy[20]. **New:** The new Citizen Energy Company (Bürgerenergie-gesellschaft) definition of Renewable Energy Resources Act 2023 (§3, para. 15, EEG 2023) transposes the elements of the REC definition from the REDII[26],[27].				
France	Yes, both RECs and CECs	Ordonnance n° 2021-236 of March 2021 (Art. L. 291-294) which is amending the Code of Energy and its following Application Decree [26], [28].	For natural persons and SMEs, close proximity is residence or location in the department or a bordering department where the project is being implemented (there are exceptions for departments that do not have more than two neighboring departments). There are also standards made for local authorities and for enterprises with majority ownership (direct and indirect) by local authorities[26]. For associations, there	REC: shareholders or members are natural persons, small and medium-sized enterprises, local authorities or their groupings. When a private company participates in a renewable energy community, this participation cannot constitute its principal commercial or professional activity. RECs are effectively controlled by shareholders or members located close to the renewable energy projects to which they have subscribed and which they have developed.	For collective self-consumption, a contract needs to be established between the DSO and the legal entity which identifies the different participants and determines the sharing scheme between the involved consumers. Net metering is not allowed for either scheme[30]. We do not have information if energy communities are treated equally concerning energy sharing as the "collective self-consumption" scheme.	No.

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
			must be at least 20 natural persons as members fulfilling the geographical proximity mentioned above. For regions and municipalities, each of the renewable energy projects to which the community has subscribed and which it has developed concerns an installation located on its territory (also applicable to a department as member, although also installations in the neighboring department are possible)[29].	CEC: Any natural and legal persons, but it must be effectively controlled only by members/shareholders who are natural persons, local authorities or their groupings, or small businesses[28]. According to Décret n° 2023-1287, to meet the autonomy condition of RECs, individual members cannot have more		
Switzerland[9]	Not part of the European Union, therefore no obligation to transpose European Directives	Energiegesetz (EnG) (engl: Energy Law) and Stromversorgungsgesetz (StromVG) (engl: Electricity Supply Law)	Basically, there is no proximity constraint. ZEVs can also be implemented across properties; the prerequisite is that the public grid is not used. If the ZEV spans across properties that do not participate, electricity transmission rights need to be ensured. [31].. However, due to the restriction that the public	Open to all entities (?); could not find any restrictions. However, the focus is certainly on households.	Energy sharing is possible 'behind the meter' through concepts called "Zusammenschluss zum Eigenverbrauch" (ZEV), in engl. "association for self-consumption". The participants of such association are considered as a single customer within the electricity supply legislation. The obligation to provide basic electricity supply and other obligations of the DSO are towards the ZEV as a whole (art. 18 par. 1	No.

[9] A ZEV is only possible if the generation of the installations amounts to at least 10% of the ZEV's load (Art.15 Para.1 EnV). In case the load changes at a later point in time, the ZEV can only proceed with the operation, if the changes can be justified by increased load of individual existing participants (e.g. heat pump installation, EV, etc.). In case a new participant is accountable for the load changes, the generation capacities would need to be topped up to fulfil the 10% threshold[28].

Country	ECs possible? REC/CEC?	Legislative acts	Proximity constraint for REC	Participating entities	Implementation of energy sharing, P2P	Operation of electricity grid
			grid must not be used, the ZEV is implicitly constrained due to significant financial burdens of establishing direct lines between buildings of different properties.		EnG), and not anymore towards the individual end-customers which are part of the ZEV. Instead, the landlords at the place of production are obliged to supply electricity in the manner of a basic supplier (art. 17 par. 2 EnG). The relation between ZEV and DSO is regulated in the StromVG.[31]. The ZEV is also responsible for electricity allocation and metering.	

Table 13: Comparison of energy community transpositions in the European countries (part 2)

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
Austria	Energy prices within ECs can be determined freely, just a consent within the EC is necessary (aligned to the chosen legal personality of the EC). The pricing logic would be such that entities generating electricity benefit by selling energy to the EC at higher prices compared to selling to the conventional supplier. And, entities consuming energy should pay less for inner-community energy than if they would purchase from the conventional supplier. Nevertheless, the EC is free in choosing any pricing logic	RECs profit from reduced grid tariffs; thereby it is distinguished between local RECs (all participants connected via the same low-voltage grid feeder) and regional RECs (all participants connected via the same medium-volage grid feeder). For local RECs, the grid-usage charges are reduced by 57% for	-) Investment subsidies for renewable generation plants according to Renewable Expansion Act -) Electricity fed into the public electricity grid can receive a market premium (max. 50% of the generated electricity within the community) according to Renewable Expansion Act. → Investment subsidies and market premium are mutually exclusive.	Any legal entity eligible if it can exercise rights and be subject to obligations in its own name ("Association, cooperative, partnership or corporation or similar association with legal	Smart meters are the only necessary technical equipment. To ensure efficient energy usage, e.g., EMS would be useful, but this is not a requirement.	Despite the legislative enforcement mid-2021, the practical implementation of certain features of RECs/CECs happened stepwise. While RECs were able to be established a few months after the laws were enforced, CECs	

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
	according to their wishes. Energy can also be gifted.	grid levels 6 & 7; for regional RECs, the grid-usage charges are reduced by 28% for grid levels 6 & 7, and by 64% for grid levels 4 & 5. (SNE-VO 2023) For CECs, no reduced grid tariffs apply. For ECs that fall under the "small business regulation" (Kleinunternehmer-regelung), no taxes need to be paid for energy transfers within the EC. Furthermore, consumption from electricity within an EC is exempt from the electricity levy (Elektrizitätsabgabe) and the renewable energy charge (Erneuerbaren-Förderbeitrag).	-) Special funding for innovative RECs from the climate and energy fund.	personality" § 79 EAG). Excluded are a "civil law company" (GsbR) and a 1-person-company (2 participating parties necessary to found an EC). Often used are associations or cooperatives, since these are comparably easy to establish. Also, already existing legal personalities can be used.		could only be established from April 2022. Moreover, still it is not possible to implement CECs across concession areas of different DSOs. This is expected to be possible from autumn 2023. Within the first quarter of 2024, multiple participation will be possible in Austria, meaning that individual participants or generation units can simultaneously be part of more than one EC.	
Sweden	Currently only collective self-consumption allowed, and pricing often included in monthly rent of housing association [18].	Unchanged	No special subsidies (apart from existing for renewable generation plants).	Economic Association (Swedish version of cooperative) – one	/	No special policies or measures to promote energy communities or include them in	

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
				person one vote principle		renewables support schemes [32].	
Italy	The Energy Authority (ARERA) Resolution of 4 August 2020, 318/2020/R/eel established criteria for regulating specific economic items (i.e., energy costs, energy prices, taxes and duties) related to self-consumption or energy sharing within RECs [20]. ECs receive a refund for the amounts of energy "shared", which is 110€/MWh for RECs and 100€/MWh for collective self-consumption[33]. RECs participation has no impact on electricity pricing, both bought or sold.	The Energy Authority (ARERA) Resolution of 4 August 2020, 318/2020/R/eel established criteria for regulating specific economic items (i.e., energy costs, energy prices, taxes and duties) related to self-consumption or energy sharing within RECs [20]. RECs receive a refund for network operating tariffs.	For RECs, Italian authorities have defined incentive tariffs dedicated to shared energy among the members [23]. – However, with this, the way of EC implementation is meant (by receiving a refund) – please see category "Implementation of energy sharing". Under the Italian Recovery and Resilience Plan (PNRR, Italian implementation of the Next Generation EU plan), a fund of 2.2 billion Euro provides financial resources for the establishment of RECs in small towns with fewer than 5000 inhabitants. The 2.2 billions euros are devoted to subsidies the installment of new renewable production plants (up to 40% of the cost) connected to RECs. There also exist initiatives at federal state level: Regional Law no. 2 of 23 February 2022 of Lombardia allocated 21.5 million Euros for the establishment of RECs between 2022 and 2024 [20].	A legal entity needs to be established and rules need to be defined to govern the relationships among its members. The most common forms are co-operatives and associations [23].	Smart meters have been rolled-out in Italy even before the adoption of EC concepts[34], so there are no further technical requirements. Since it is a virtual sharing of energy, no technical equipment is required. The data are provided to the GSE (official body that manages electrical services at national level) by the local DSO. IT is the GSE that calculates the subsidies.		

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
			Beside Lombardia several other regions have allocated money always in the range of millions of euros (Emilia Romagna, Puglia, Veneto, Liguria, ...).		Equipment can be used by the community to improve the performances, i.e. the quantity of energy shared.		
Germany	No specific regulations/reductions for citizen energy companies.	No specific regulations/reductions for citizen energy companies.	On January 1, 2023, a new funding guideline was launched to support the costs of the planning and approval phase (70% of the costs, up to a maximum of 200,000 euros per project) of onshore wind turbines of citizen energy companies up to a total size of 25 megawatts per applicant. The amendment to the EEG, which has also been in force since January 1, has largely exempted the wind and solar projects of civic energy from the tendering process for the most part excluded [35].	Citizen Energy Companies can be associations or any other company form (§22 EEG 2023) [27].	/	No transposition or support for CEC [26].	

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
			Energy generation plants in citizen energy companies (for wind power plants up to 18 MW, for PV up to 6 MW) can get funding without the need to bid into auctions [36], [37].				
France	No specific regulations/reductions.	No specific regulations/reductions.	Public tenders to receive subsidies for energy communities [38].	A draft application decree elaborates which legal entities are allowed to become energy communities, including joint-stock companies, and co-operative societies [26].	The DSOs (in France primarily Enedis) are required to equip each participant with a smart meter and implement necessary contractual and technical arrangements to facilitate self-consumption [24].		CEC are financially responsible for imbalance costs (balance responsible parties) [28].
Switzerland	Costs for the participants in a ZEV consists of costs for electricity from the conventional supplier (energy-, grid-, measurement-costs and levies) and costs for electricity generated and used inside the ZEV. The ZEV is only allowed to charge the participants with 80% of the electricity costs that would occur if they would not participate in the ZEV. Alternatively to the flat rate of 80%, a landlord may charge the tenant	Not relevant for the ZEV, due to operation behind the meter only.	-	Law and regulations leave the legal form open; The foundation of a legal entity is not required. The legal relationship between the participants is	A ZEV is only possible if the generation of the installations amount to at least 10% of the ZEV's load (Art.15 Para.1 EnV) [31]. The participants need to be		

Country	Electricity pricing	Network pricing and taxes	Subsidies	Legal form	Necessary equipment	Missing	Comments
	with effective costs for the ZEV-internal electricity. Thereby, the revenues of the amount of electricity fed into the grid are subtracted. Moreover, the maximum costs for the tenant is the amount that would have to be paid in case of no ZEV installed. In case the ZEV-internal costs are cheaper compared to the default setting, at maximum half of the obtained revenues may be charged to the tenants [31].			established by contracts or by regulation (in the case of condominium ownership)[31].	connected 'behind the meter' – infrastructure is necessary accordingly.		


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