EMB3Rs

Heat and Cold matching platform

Market Module

User and System manual

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DATE : 26.10.2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°847121

SPIRE PROJECT

Technical References

Project Acronym	EMB3Rs
Project Title	User-driven Energy-Matching & Business Prospection Tool for Industrial Excess Heat / Cold Reduction, Recovery and Redistribution
Project Coordinator	Mafalda Silva
Project Duration	September 2019 – May 2022 (45 months)

Deliverable No.	D3.5
Dissemination level [1]	PU
Work Package	WP3 – Platform Creation – Modules Development, Integration & Lab scale Validation
Task	T3.1 – Individual Module Development
Lead beneficiary	DTU Elektro
Contributing beneficiary(ies)	INESC TEC
Due date of deliverable	01/02/2023
Actual submission date	26/10/2022

[1]PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Document history

V	Date	Beneficiary	Author
1	22/04/2022	INESC TEC	A. S. Faria, T. Soares
1.1	13/07/2022	INESC TEC & DTUelektro	A. S. Faria, T. Soares, L. Frölke
3.1			
3.2			

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Summary

This deliverable reports the findings of work performed under WP3 on tasks 3.1 and 3.3 related to the development and implementation of the Market Module (MM) and its integration into the EMB3Rs platform. In this deliverable, there are two manuals (the User and System Manuals) that will assist the platform's users to explore the MM in the EMB3Rs platform.

Chapter 1 provides a brief introduction and the aim of the MM in the EMB3Rs platform, highlighting the main characteristics of the MM. The development of both short-term and long-term market analyses, including conventional and innovative market designs are addressed.

The System Manual (in chapter 2) provides all the theoretical background for the implementation and adaptation of the MM in the EMB3Rs platform. More precisely, the System Manual includes the complete description of the three different market designs implemented in the EMB3Rs platform, namely, (i) the Pool, (ii) Peer-to-Peer (P2P) and (iii) Community-based market. All the mathematical formulations used to model the market problem are provided. In addition, it includes a short description of the market analysis possibilities, namely, the short-term and long-term market analysis.

The User Manual (in chapter 3) provides a practical and succinct guide to the MM, allowing users to learn how to set up a market simulation case. This includes step-by-step details of inputs, simulation options and outputs for both short- and long-term market simulation analysis. In addition, and for both short- and long-term market simulation analysis, a test case is provided for the user to test the functionalities of the MM.

Chapter 4 describes the module report for both short-term and long-term analysis, as well as the simulation summary report for the EMB3Rs platform. The MM report comprises all the detailed outputs from the MM concerning the short- and long-term market analysis, while the summary simulation report considers a brief overview of the MM results. Note that the summary simulation report are the results addressed in the overall platform report for the user, and therefore, an overview of each module's results is considered.

Chapter 5 depicts the timeline of the developments of the MM, while Chapter 6 gathers the main conclusions.

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Acronyms

Notation		Description
ADG	–	Average Dispatched Generation
BM	–	Business Module
CF	–	Core Functionalities
CHP	–	Combined Heat and Power
DHC	–	District Heating and Cooling
GIS	–	Geographical Information System
HC	–	Heating and Cooling
MM	–	Market Module
P2P	–	Peer-to-Peer
QoE	–	Quality of Experience
SE	–	Settlement
SPM	–	Successful Participation in the Market
TEO	–	Techno-Economic Optimisation
USPM	–	Unsuccessful Participation in the Market

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Nomenclature

Notation	Description	Unit
Sets		
n	– Agent n	
t	– Time step index	
Ω_c	– Set of consumers/sinks	
Ω_n	– Set of agents n	
Ω_m	– Set of agents m	
Ω_p	– Set of producers/sources	
Ω_N	– Set of nodes N	
Ω_P	– Set of pipes P	
Parameters		
BIDSIZE	– Block offer number of time slots	
C_n	– Bid offer by agent n	€
C_{nt}^H	– CHP bid after electricity dependence	€
$\overline{P_n}, \underline{P_n}$	– Lower and upper bound of agent n	kWh
$C_{n,m}$	– Product differentiation cost applied to the trade between agents n and m	€/kWh
$c_{n,m}$	– Initial penalty between agents n and m	€/kWh
$d_{n,m}$	– Distance between agents n and m	m
E_n	– CO_2 signals coefficient by agent n	Kg.CO_2/kWh
l_n	– Thermal losses between agents n and m	W
$TotDist$	– Total pipeline distance in the network	m
$TotLoss$	– Total pipeline losses in the network	W
γ^{imp}	– Cost of importing heat from outside community	€/kWh
γ^{exp}	– Benefit of exporting heat out of the community	€/kWh
γ^{peak}	– Penalty on the size of the exporting peak of the community	€/kWh
A_{np}	– Inflow and outflow matrix	
α_n	– Fuel price for agent n	€/kWh fuel

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ρ	– Fuel efficiency	
λ_t^E	– Forecasted electricity price for time slot t	
r_i	– Minimum power-to-heat ratio	
χ_n^t	– Successful participation	
$\emptyset_n^t$	– Perceived price of energy	
Variables		
P_n	– Total heat dispatched by agent n	kWh
$P_{n,m}$	– Bilateral trade between agents n and m	kWh
$T_{n,m}$	– Heat trade net balance	kWh
$B_{n,m}$	– Heat bought from agent n to m	kWh
$S_{n,m}$	– Heat sold by agent n to agent m	kWh
q_t^{exp}	– Exported heat in time slot t	kWh
q_t^{imp}	– Imported heat in time slot t	kWh
$\bar{q}$	– Peak heat import to the community	kWh
P_t^N	– Heat injection in node N	kWh
P_t^P	– Heat energy flowing in each pipe P	kWh
$b_{t,n}$	– Binary variable indicating if the bid is accepted or not	
$\lambda_{n,m}^t$	– Market clearing price	€/kWh

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1 Introduction

The EMB3Rs platform has been designed to evaluate the reuse and trade of waste Heating and Cooling (HC) in a holistic perspective within an industrial process, energy system environment, or in District Heating and Cooling (DHC) systems under-regulated and liberalized market environment. The platform empowers industrial users and stakeholders to investigate the economic potential of their investment in the recovery of waste HC as an energy resource, based on the simulation of supply-demand scenarios. To this end, the platform is able to simulate multiple business and market models for DHC systems.

The EMB3Rs platform is composed of five complementary modules: Core Functionalities (CF), Geographical Information System (GIS), Techno-Economic Optimisation (TEO), Market Module (MM), and Business Module (BM). The CF aims to deliver sets of energy flows from sources, sinks and links as well as costs for excess heating and cooling recovery and use. The GIS identifies the possible network solutions according to some given characteristics and properties. It connects all sources and sinks and it gathers information about every pipe, providing data for each pair source/sink like losses, costs, network length and installed pipe capacity. The purpose of TEO is to find the most cost-effective way to the combination of available technologies to use excess heat. A source evaluates the best technologies to meet the demand for one determined sink, while complying with constraints related to regulation, heat available, load profiles, techno-economic characteristics of technologies and investment plans. The BM is directed to different ownership structures and market frameworks and it defines some parameters as net present value, levelized cost of heat and internal rate of return. Thus, the main goal is to set data exchanges between all modules, so they work as a whole.

The dedicated MM allows users to simulate current and future trends for the HC markets, allowing them to choose the best market framework aligned with the users' economic, environmental and social interests. The simulations allow users to assess the economic potential and environmental savings of their investment. This may especially be important for users who have invested or consider investing in waste heat recovery. Recently, peer-to-peer (P2P) and community-based markets have been presented as an alternative to existing pool energy markets, both for HC and electricity systems. Therefore, the MM models and implements the P2P and community-based market designs, in addition to the conventional pool market design. In this way, users can create, test and validate different market structures for selling and buying energy in DHC systems. The outputs of the market analysis enable users (e.g., industries, supermarkets and data centres) to estimate potential costs and revenues for different market participants from trading excess heat and cold, under different market designs.

Depending on the user's experience and motivation, different types of market analysis might be required. To address this, the MM consists of two sub-modules: the short-term and long-term market analyses. The short-term market analysis is intended to give an overview of individual agents' performance when subjected to different market features. In this design, users are able to change some parameters and easily and quickly check the effect of such changes on market outcomes. In this way, the effect of different market settings can be studied in case studies with short horizons. On the other hand, the long-term market analysis can be used to investigate market outcomes

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for agents in wider time ranges like months or years. This is more suitable when the user wants to evaluate the profitability of potential investments.

This report summarises the work conducted in WP3 related to the development and implementation of the MM. After this introduction, this deliverable presents the System Manual (Chapter 2) where all the theoretical models and equations behind the implemented markets are described, including different settings that are considered in the MM. Then, in Chapter 3, the User Manual is presented, which describes the MM in a more practical manner, including its functionalities, variables, inputs, outputs, etc. The detailed report of the MM and the summary simulation report for the platform are described in Chapter 4. Chapter 5 depicts the timeline of the MM developments, while Chapter 6 provides the main conclusions of the deliverable.

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2 System Manual

The main purpose of the MM is to provide a set of market structures capable of simulating existing and future markets for DHC systems. More precisely, three different market designs are available in the short-term market analysis: Pool, Peer-to-Peer, and community-based structures. This allows users to simulate current and future market approaches, and compare the outcomes. As discussed in the introduction, the MM comprises a short-term and long-term market analysis.

This System Manual describes the theoretical background for each market design, including the many different user options that have been implemented. This manual aims to support the user with sufficient knowledge of the implemented markets, accounting for a detailed explanation of the available settings and features.

The developed code is fully available under a GitHub repository. The optimization problems were implemented using CVXPY, which is a python-embedded modelling language for optimization problems, which allows the user to choose between several solvers. In this case, the SCIP and GUROBI solvers have been tested and used.

2.1Market Designs

The MM contributes toward the goal of the EMB3Rs project to evaluate the reuse and trade of waste heating and cooling, by simulation of current and future trends for heating and cooling markets. Through the market module, individual heat end-users or large heat prosumers like industries, supermarkets and data centres can assess the economic feasibility of future investments. In addition, users that are interested in the consumer perspective can investigate how the price of HC would evolve under different market and business models.

Following the shifts to liberalized markets to promote competition, the market module has been equipped with a range of market simulation options for users. This includes the traditional centralized pool market design and innovative market designs, the so-called consumer-centric markets (e.g., the peer-to-peer and community-based market designs). Figure 1 shows the structure of the selected market designs, based on [1] where the nodes represent agents operating in the market. From a market perspective, an agent is any producer, consumer or prosumer willing to participate in a market, e.g. a DHC market or other energy market, such as the electricity market. Here, we define a prosumer as an agent that is both a producer and (possibly flexible) consumer of heat.

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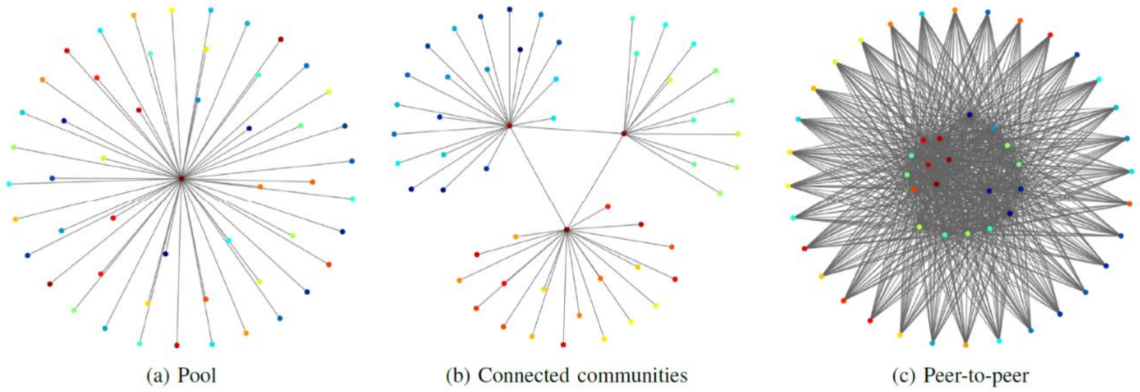

Figure 1 - Structure of the market designs in the EMB3Rs platform: a) conventional Pool, b) Community-based P2P, c) P2P [1][2].

The central node in design (a), the Pool market, represents the market operator responsible for running the market. Design (b), the community-based presents three central nodes that represent three communities as an example. Each central node represents a community manager who is responsible for communicating with all agents connected to its energy community. The final design (c) has no central nodes and is therefore fully decentralized. This market design leaves it to each agent to negotiate the price and energy of each transaction directly with the others. Each market has a different design that affects the determination of the market clearing price, the energy dispatch, and the settlement.

All the DHC market designs covered in this work follow the general stages of market operation illustrated in Figure 2. In the input data stage, the market requires that all market participants (producers, consumers and prosumers) submit their offers (demand and production) for each time interval. In the entire market module, it is assumed that the market is cleared on an hourly basis. All offers contain information about the expected maximum amount of thermal energy that the player wants to buy or sell on the market, as well as a price. This price represents the maximum cost it is willing to pay in case of a buying offer, or the minimum price the agent wants to receive in case of a selling offer. The price in a buying offer is commonly called *utility,* whereas the term *cost* is use in case of a selling offer*.*

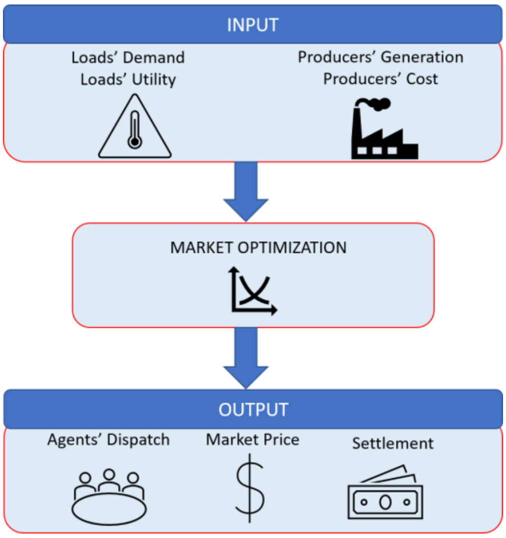

Figure 2 - Conventional market framework overview [3].

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In the market optimization stage, the market algorithms, namely, the Pool (section 2.1.1), P2P (section 2.1.2) and community-based market (section 2.1.3) designs, can be used to clear the market and find a solution to the problem. The market is then cleared every single hour. The market optimization returns the energy dispatched for each agent in the market, as well as the market-clearing prices, used to perform the settlement in the output stage.

2.1.1 Pool

In the Pool market (represented in Figure 3), the merit order mechanism is used to dispatch producers and consumers. As a result, the cheapest producers are scheduled first, as well as the highest-bidding consumers. Uniform pricing is applied, which means that all market participants pay/receive the same price per unit of energy. The price bid of the *marginal producer or consumer, i*.e. the agent that is scheduled partially, determines the market-clearing price. Each dispatched producer and consumer will then be paid and pay for the energy at the market-clearing price, respectively.

Figure 3 - Pool market design [3].

Mathematically, the pool market for a single hour/time step can be presented as a linear optimization problem:

$$\min_{D} \sum_{n\in\Omega_p} C_n\, P_n - \sum_{n\in\Omega_c} C_n\, P_n \quad (1a)$$

$$\underline{P_n} \le P_n \le \overline{P}_n, \forall n \in \Omega_n \quad (1b)$$

$$\sum_{n\in\Omega_n} P_n = 0 \;:\lambda \quad (1c)$$

$$P_n \le 0, \forall n \in \Omega_c \quad (1d)$$

$$P_n \ge 0, \forall n \in \Omega_p \quad (1e)$$

where the set of optimization variables $D = \{P_n \in \mathbb{R}\}_{n\in\Omega_n}$ represents the heat traded by each agent n. The objective of this linear program is to minimize the negative social welfare (equivalent to maximizing the social welfare), which is the difference between the total generation cost by generators and the total utility of consumers. The parameter C_n represents the agents' bid price; the parameters $\overline{P_n}, \underline{P_n}$ represent the lower and upper bound of the agents' energy offer, respectively; Ω_c represents the set of consumers, Ω_p represent the set of producers. Eq. (1b) constrains the energy dispatch for each agent so that it respects agents' offers boundaries. Eq. (1c) ensures the energy balance, where the supply must equal the demand. Eq. (1d) ensures that consumption is non-positive in the system, while (1e) ensures that the production

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variable from producers is non-negative. The dual variable λ of the market balance constraint in Eq. (1c) is the uniform market price.

2.1.2 P2P

The P2P market design proposes that any pair of agents (or "peers") can trade heat on a bilateral basis, without third party (coordinator) supervision [4], as represented in Figure 4. That is, each peer *n* can exchange with another peer *m* on an individual basis, defining the amount of energy to be bought or sold at a given price. Note that prosumers can trade with both producers and consumers, but such interaction is limited by the type of offer they submit on the market. The main advantage is that the privacy of peers is protected, as peers share limited information with those they want, taking full control of their own facilities [5]. The main disadvantage of this decentralized market is that the efficiency of the market is often reduced when considering consumer preferences [4], [6], [7].

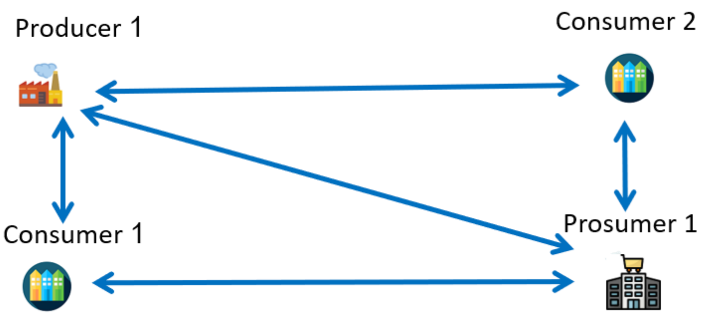

Figure 4 - P2P market design [3].

This P2P market can be mathematically formulated for a single market period as the following linear optimization problem:

$$\min_{D} \sum_{n \in \Omega_n} C_n P_n \tag{3a}$$

$$P_n = \sum_{m \in \Omega_n} T_{n,m}\,, \ \forall\, n \in \Omega_n \tag{3b}$$

$$\underline{P}_n \leq P_n \leq \overline{P}_n, \forall n \in \Omega_n \tag{3c}$$

$$T_{n,m} + T_{m,n} = 0, \forall \{n,m\} \in \{\Omega_n\} : \lambda_{n,m} \tag{3d}$$

$$P_n \leq 0, \forall n \in \Omega_c \tag{3e}$$

$$P_n \leq 0, \forall n \in \Omega_p \tag{3f}$$

$$T_{n,m} = S_{n,m} - B_{n,m}\,, \forall \{n,m\} \in \{\Omega_n\} \tag{3g}$$

$$B_{n,m} \geq 0, \forall \{n,m\} \in \{\Omega_n\} \tag{3h}$$

$$S_{n,m} \geq 0, \forall \{n,m\} \in \{\Omega_n\} \tag{3i}$$

$$S_{n,m} = B_{m,n}, \forall \{n,m\} \in \{\Omega_n\} \tag{3j}$$

$$\sum_{m \in \Omega_n} S_{n,m} = P_n, \forall n \in \Omega_p \tag{3k}$$

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where $D = \{P_n \in \mathbb{R}\}_{n\in\Omega_n}$ represents the heat traded by each agent n. Like in the pool market, the goal is to maximize social welfare, which is the difference between the total generation cost by generators and the total utility of consumers (3a). The total heat traded by an agent n must equal the sum of the heat exchanges from that agent n to the other agents m (3b). It is assumed that any agent can trade with any other agent. Also, reciprocity is ensured in the bilateral trades in Eq. (3d), where $T_{n,m}$ and $T_{m,n}$ must be equal but of opposite sign. Equations (3g)-(3k) are included to prevent arbitrage so that each traded amount of energy is actually injected into the network. In this design, the market price is defined for each transaction $T_{n,m}$ separately. This price is here expressed through $\lambda_{n,m}$.

The P2P formulation includes a variable that represents the energy traded between any pair of agents. This variable can be used to add preferences that agents may have towards any of these trades, by introducing a penalty or benefit related to each trade. This is called product differentiation, meaning that a certain trade under specific criteria may or may not be advantageous for the system management. In this way, the objective function is augmented with the extra benefit or penalty that certain trades bring to the market participants. Conventionally, the product differentiation is represented as:

$$C_{n,m} = S_{n,m} c_{n,m.} \tag{4}$$

where $C_{n,m}$ represents the final penalty applied to the trade between agents n and m. $S_{n,m}$ represents the bilateral energy trade between agents n and m, and $c_{n,m}$ represents the initial penalty between these agents.

In order to apply product differentiation, the objective function must account for the penalty from (4). Thus, the objective function takes the following form:

$$\min_{D} \sum_{n\in\Omega_n} C_n P_n + \sum_{n\in\Omega_p} \sum_{m\in\Omega_c} C_{n,m} \tag{5}$$

where $D = \{P_n, C_n, C_{n,m} \in \mathbb{R}\}_{n,m\in\Omega_n}$.

For the product differentiation, only the objective function is changed - the equations (3b)-(3k) remain unchanged. Nevertheless, the determination of the product differentiation penalties (also called *trade preferences*) may be done in different ways.

In the MM, three types of trade preferences are implemented. The penalties related to these preferences are based on either the distance between agents, the thermal losses between agents, or the CO_2 emissions of producers. There is also the option where the user chooses the penalty that best suits the community principles. In this case, all agents participating in the market are under the same preference scheme.

2.1.2.1 Network Distance

In the physical network distance preference, the network distance between the selected agents is determined. The operator can select the distance penalty if it prefers to trade with the closest neighbours. The penalty is based on the sum of the length of all the pipes that make the path between agents. Thus, the penalty associated with the network distance is given by:

$$c_{n,m} = \frac{d_{n,m}}{TotDist} \tag{6}$$

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where $d_{n,m}$ represents the pipe distance along the path between agents n and m, while $TotDist$ is the summation of the length of all pipes that are part of the network.

2.1.2.2 Thermal Losses

Another option is thermal losses, where an operator can select the thermal losses penalty if it would like to increase the system energy efficiency by reducing losses.

The thermal losses penalty between two agents is given by the share that each agent has in the system losses considering the thermal flow in each pipe. This preference is used if the operator would like to increase the system's energy efficiency by reducing losses. The thermal flow and losses are determined in the GIS and TEO modules, so the thermal losses penalty for the transaction between two peers is given by:

$$c_{n,m} = \frac{l_{n,m}}{TotLoss} \quad (7)$$

where $l_{n,m}$ represents the thermal losses over the whole path between agents n and m.

2.1.2.3 CO_2 Emissions

The last option proposed for product differentiation is to penalise transactions based on the CO_2 emissions of a generator. This preference is used when an operator has environmental concerns and would prefer to buy HC that is low in CO_2 intensity. The EMB3Rs platform can provide standard levels of CO_2 per technology, and the penalties between agents n and m can be based on these levels. Here, the penalty is only associated with the heat source. Hence, the CO_2 penalty between agents n and m is given by the quotient between the emissions of agent n and the total system emissions:

$$c_{n,m} = \frac{E_n}{\sum_{n \in \Omega_n} E_n} \quad (8)$$

2.1.3 Community-based

The community-based market design (represented in Figure 5) intends to represent a more hierarchical structure of peer trades. In general, a community is composed of members who share common interests or are geographically close. In this semi-decentralized model, there is a community manager responsible for the community's energy management. In terms of privacy, it requires less exchange of information than the Pool market model, because the agents only have to share bids with the community manager, but more than the P2P market model. This system is often seen as a compromising solution between the centralized and decentralized approaches [8].

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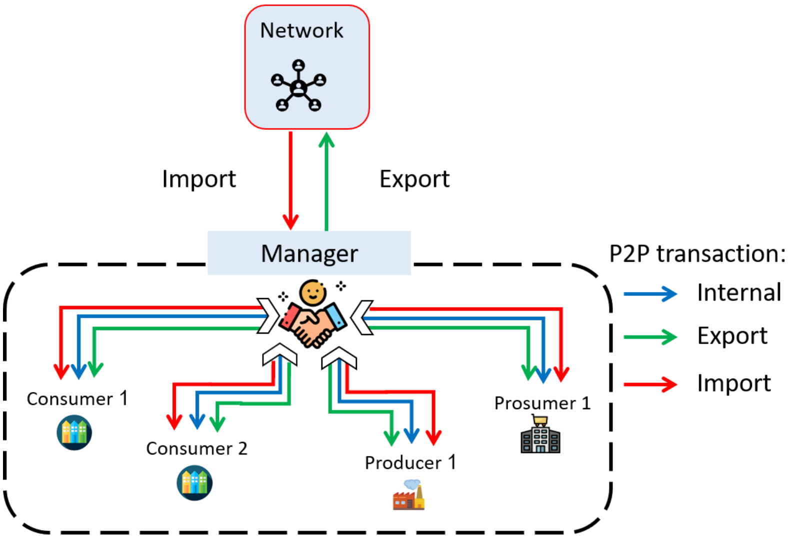

Figure 5 - Community-based market design [3].

The community manager supervises all the trading activities within the community, as well as works as an intermediary in the heating trade with the main grid [9]. The mathematical formulation is presented as:

$$\min_{D} \sum_{n \in \Omega_n} C_n P_n + g(q^{imp}, q^{exp}, \dots) \quad (9a)$$

$$q_t^{imp} \geq 0 \quad (9b)$$

$$q_t^{exp} \geq 0 \quad (9c)$$

$$q_t^{exp} - q_t^{imp} = \sum_{n \in \Omega_n} P_{t,n}, \forall t \quad (9d)$$

where P_n represents the internal trade of agent n within its own community. q_t^{exp} and q_t^{imp} represent the exported and imported quantities, respectively. (9b) and (9c) set the boundaries for imports and exports.

The objective function might have different targets (autonomy or peak shaving), according to user preference.

2.1.3.1 Autonomy

This objective should be selected if the community finds it important to be as self-sufficient as possible. The objective function will then steer the optimization in the direction of lower imports. The autonomy g function is given by:

$$g^{aut} = \gamma^{imp} \left\| q_t^{imp} \right\|_l + \gamma^{exp} \left\| q_t^{exp} \right\|_l \quad (10)$$

where l represents the l-norm. In the market module, the 2-norm has been implemented. The parameters γ^{imp} and γ^{exp} are chosen inputs.

No constraints need to be added.

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2.1.3.2 Peak Shaving

This objective should be selected if the community would like to have a low *maximum import* from outside the community. This may be because the community wants to have a low impact on the heat grid.

In case peak shaving is the community target, then the objective function changes and an additional constraint is added:

$$q_t^{imp} \leq \overline{q} \quad (11)$$

which means the peak is defined by the variable $\overline{q}$ and sets the maximum import. The peak shaving g function is given by:

$$g^{peak} = \gamma^{peak}\overline{q} + \sum_t \gamma_t^{imp} q_t^{imp} + \gamma_t^{exp} q_t^{exp} \quad (12)$$

2.1.4 Market extensions

2.1.4.1 Network-awareness

The previous market designs are network-agnostic, i.e., they do not consider the relation between trades and the physical district heating network. To account for the constraints that the network may pose on the possible trades, the pool market design in the MM can be augmented with a network-awareness feature.

The network-aware market ensures that flow *directions* are respected in the dispatch. Flow sizes are not considered. A set of nodes N and a set of pipelines P must be defined. Pipelines are defined by their starting and stopping node, i.e. $p = (n1, n2)$ is the pipeline connecting nodes $n1$ and $n2$, and its direction is from $n1$ to $n2$.

The heat injections at the nodes can be related to the heat flowing in each pipeline in the network as:

$$P_t^N = AP_t^P, \forall t \quad (13)$$

where P^N is the total power injection at node N , and the matrix $A \epsilon R^{NxP}$ is defined as:

$$A_{np} = \begin{cases} 1, & if\ p\ flows\ out\ from\ node\ n \\ -1, & if\ p\ flows\ in\ to\ node\ n \\ 0, & if\ p\ is\ not\ attached\ to\ node\ n \end{cases} \quad (14)$$

In order to respect direction in the network, the flow in all pipelines must be constrained to be positive:

$$P_{pt}^P \geq 0,\ \forall p, t \quad (15)$$

2.1.4.2 Electricity price dependence

Here, there is also the option to generate bids for Combined Heat and Power (CHP) plants, that are dependent on the (forecasted) electricity price. We use the optimal bid that was derived for CHPs in a sequential heat and electricity market setting in [10]. Hence, the price bid depends on the (forecasted) electricity price as:

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$$c_{nt}^{H} = \begin{cases} \alpha_n(\rho_n^E r_n + \rho_n^H) - \lambda_t^E r_n, if\ \lambda_t^E \leq \alpha_n \rho_n^E \\ \lambda_t^E \frac{\rho_n^H}{\rho_n^E}, if\ \lambda_t^E \geq \alpha_n \rho_n^E \end{cases} \quad (16)$$

where α_n is the fuel price for agent n, ρ is the fuel efficiency for either electricity or heat, λ_t^E is the forecasted electricity price, and r_n is the minimum power-to-heat ratio.

2.1.5 Offer types

2.1.5.1 Simple offer

Simple offers assume that all placed orders are for single hours, so that all market periods can actually be cleared independently. The volume to be bought or sold is specified by each agent, as well as a price associated with each order, and the time step the order is placed for. Therefore, for each time slot, a price-volume pair is created for each agent to be delivered to the market.

2.1.5.2 Block offer

Block offers consider that one agent offers a quantity for more than one time slot and the market must respect it. It has an all-or-nothing condition, which means it is fully accepted or fully rejected. This option can only be chosen for sources. It can be expressed as:

$$P_{t,n} = \overline{P_{t,n}} b_{t,n} \quad (17)$$

$$\sum_{t \in BID} b_{t,n} = BIDSIZE\, b_{0,n} \quad (18)$$

where (17) sets the accepted quantity in the market associated with a binary variable (indicating whether the offer is accepted or not). Eq. (18) establishes the all-or-nothing condition, implying that the binary variable must be in accordance and, therefore, have the same value for all time slots.

2.1.5.3 Energy budget

This feature assumes loads are flexible, but a fixed total load over a certain period is required. This is only valid for consumers. It is considered that the energy budget is valid for the entire period of simulation, which leads to the following:

$$\sum_t P_{t,n} = P_n^{tot}, \forall n \in \Omega_c \quad (19)$$

where P_n^{tot} is the total energy budget of agent n. In the market module, it is assumed that P_n^{tot} is equal to :

$$\sum_t \frac{1}{2}\left(\overline{P}_n + \underline{P}_n\right) \quad (20)$$

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2.2 Market Inputs

2.2.1 Short-term General Settings

In order to run a simulation, some general settings must be chosen by the user. Some of these are specific to the desired market design, namely Pool, P2P or Community-based market. Table 1 summarizes the expected General Settings and the possible options to choose from.

First of all, the user has to select the market design (e.g., Pool, P2P, or Community). For more details on the market design, interested readers are directed to the System Manual in section 2.1. Regardless of the selected market, the user must select the number of simulated hours, which can go up to 48h. In addition, a date to start the simulation is selected. This is used to select the correct inputs from other modules (TEO, CF), that will be used to create the agent bids. Next, the offer type is selected, which includes the simple, block or energy budget options (check section 2.1.5 for a detailed explanation).

There is an option to include electricity market dependence. This option makes the price and quantity bids of agents that are CHPs dependent on an input electricity price (forecast), as detailed in section 2.1.4.2.

The product differentiation option is only needed for the P2P market design. Here, the available options are CO_2 emissions, energy losses, distance or no preference, as detailed in section 2.1.2.

In case the Community market is selected, the user must provide several settings. The type of objective function must be chosen (either "autonomy" or "peakShaving"- check section 2.1.3), which will specify what goal the community is trying to achieve. In addition, the user must input three parameters representing the penalty for importing heat, the reward for exporting heat, and the penalty for the size of the peak import. Default values are presented for these parameters, but, optionally, the user can modify them.

In case the user simulates a Pool market, there is an option to include network operating conditions in the market. If this option is selected, the dispatch determined by the market will respect the thermal energy flow *directions* in the network. Note that this does not mean the sizes of thermal energy flows will be feasible, as this needs to be checked by a network operator. If necessary, the network operator would have to re-dispatch.

Table 1 - Short-term general settings.

Name	Description	Units	Data Type
md	Market design. Represents the market design the user intends to simulate. Pool, P2P and Community are the options.		String
nr_of_hours	Represents the simulation horizon period.	Hours	Integer
start_datetime	Date of the format "dd-mm-yyyy".		String

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offer_type	Represents the offer type, which can be related to all agents or only to some agents. Simple, Block and energyBudget are the options		String
prod_diff	The option related to product differentiation, namely, by encouraging or penalizing some market transactions, according to user preferences. noPref (No Preferences), co2Emissions (CO_2 Emissions), networkDistance (Network Distance) and losses (Energy Losses) are the options.		String
el_dependent	Only available for Pool market True or False.		Boolean
el_price	If el_dependent=True, an electricity price (forecast) must be entered for all market hours.	€/kWh	Array
Network	"none" or "direction"		String
Objective	Only if "md = community". Should be one of ["autonomy", "peakShaving"].		String
Community settings	Include g_peak, g_exp, g_imp. g_exp must be nonpositive, while g_imp and g_peak must be nonnegative.		Dictionary

2.2.2 Short-term Parameters

After the General settings are defined, other parameters must be provided. These parameters are not only linked to the individual agents and their characteristics, but also the network features. Some can be defined by the user, others come from other EMB3Rs modules, namely CF, TEO and GIS. For example, the name and CO_2 emissions of each agent are imported from TEO. Table 2 summarizes the parameters for the short-term simulation. The information related to the bids, namely prices and quantities must be mandatorily provided for each agent and each time step.

The model uses sets related to the time slices for the simulation and the agents' names. These sets are automatically created within the module, based on the agents' bids (which come from the TEO module) and the user-selected market horizon.

Under some settings, GIS data is necessary to run the market. This is the case when the user chooses to include "network = directions", or whether a P2P market considering technical losses or network distances preferences is selected. The GIS module provides information on the linked nodes and correspondent distances.

If the user has chosen to include block offers, a dictionary with the block offer information must be provided by the user.

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Table 2 - Short-term parameters.

Name	Description	Units	Data Type
agent_ids [n]	This parameter contains the id of each agent. This is imported from TEO.		Array
co2_emissions [n]	CO_2 emissions by agent, imported from TEO. This list is only required when preferences on CO_2 Emissions are selected in the P2P market.	Kg.CO2/kWh	Array
gmax [t,n]	The maximum production each agent offers in the market. Values must be provided for each agent and each time step. A constant value for each agent is imported from the TEO module, but an optional user input can override the imported values.	kWh	Array
lmax [t,n]	The maximum consumption each agent offers to purchase in the market. Values must be provided for each agent and each time step. This load profile is imported from the TEO module.	kWh	Array
cost [t,n]	The offer price is related to the production, which represents the minimum price the agent wants to receive per unit of energy. Values must be provided for each agent and each time step. This is imported from the TEO module.	€/kWh	Array
util [t,n]	The bid price is related to consumption. Values must be provided for each agent and each time step. This is a user input.	€/kWh	Array
gis_data	All the network data that is required to run the MM under the Distance or Losses product differentiation features. It must be a dictionary with the linked agents, the total length between them, and the total costs associated with each pipeline. This is also used in case the network feature is selected in the Pool market. It is imported from the GIS module.		Dictionary
block_offer	A dictionary with agent IDs as keys. The values include the time steps when the block offer is active. Not all agent IDs need to be included, only the IDs of agents that submit block bids are needed. This is a user input.		Dictionary

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is_in_community	A Boolean for each agent specifies whether it is part of the community or not. This input is required when the Community market is chosen. This is a user input.		Array
is_chp	A Boolean for each agent specifies whether it is a CHP or not. This input is mandatory in case the user selects the electricity dependence option. This input is derived from agent IDs provided by the TEO, so the user does not need to input this.		Array
chp_pars	For each agent that is a CHP, some parameters must be specified. This input is mandatory in case the user selects the electricity dependence option, otherwise, it is not needed. This is a user input.		Array

2.2.3 Long-term General Settings

In order to run a simulation, some pre-defined inputs must be inserted by the user. These inputs are related to the desired market design, namely a centralised or decentralised structure and the simulation time horizon. The latter is defined by the combination of horizon basis (weeks, months or years), data profile (hourly or daily) and recurrence, which will define the number of instances to run. In addition, a date to start the simulation is selected. This is used to select the correct inputs from other modules (TEO, CF) that will be used to form agent bids. Afterwards, the user can also select the yearly demand rate, denoting the increase or decrease in the demand over the simulated years. The product differentiation option is only needed for the decentralised design. Here, the available options are CO_2 emissions, distance or no preference. Table 3 summarises the general settings and the options for each input.

Table 3 - Long-term general settings.

Name	Description	Data Type
md	Represents the market design the user intends to simulate. Centralized or Decentralized are the options.	String
horizon_basis	Represents the simulation horizon period. Weeks, Months or Years are the options	String
data_profile	Represents the level of data aggregation, which can be considered as hourly or daily grouped. That is, it sets whether the optimization process is simulated on an	String

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	hourly or daily basis for the entire time horizon. Note that this option influences the computational effort of the MM. Hourly or Daily are the options.	
recurrence	Represents the number of periods selected in the horizon_basis.	Integer
start_datetime	A data of format “dd-mm-yyyy”.	String
yearly_demand_rate	The expected yearly demand rate change. The demand can increase or decrease over the years so a float number within the range [-1,1] is expected.	Float
prod_diff_option	The option is related to product differentiation, namely, by encouraging or penalizing some market transactions, according to user preferences. noPref (No Preference), co2Emissions (CO_2 Emissions) and networkDistance (Network Distance) are the options.	String

2.2.4 Long-term Parameters

After the General settings are defined, other parameters must be provided. These parameters are not only linked to the individual agents and their characteristics, but also the network features. Some can be defined by the user, or come from other EMB3Rs modules, namely CF, TEO and GIS. Here the name and emissions of each agent are included. Then the information related to the bids, namely prices and quantities, whether one agent is willing to sell or buy energy, must be provided for each agent and each time step.

The model uses sets related to time slices for the simulation and agent’s names. These sets are automatically created within the module, based on the agents’ bids (which come from the TEO module) and the user-select market horizon.

Under some settings, GIS data is necessary to run the market. This is the case if the user has chosen a decentralized market with a distance-based preference. This GIS module provides information on the linked nodes and correspondent distances. Table 4 summarizes the parameters for the long-term simulation.

Table 4 - Long-term parameters.

Name	Description	Units	Data Type
agent_ids [n]	Represents each agent id. This is imported from TEO.		Array

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co2_emissions [n]	CO_2 emissions by agent, imported from TEO. This list is only required when preferences on CO_2-Emissions are selected in the decentralized model.	Kg.CO2/kWh	Array
gmax [t,n]	The maximum production each agent offers in the market. Values must be provided for each agent and each time step. A constant value for each agent is imported from the TEO module.	kWh	Array
lmax [t,n]	Maximum consumption each agent offers to purchase in the market. Values must be provided for each agent and each time step. This load profile is imported from the TEO module.	kWh	Array
cost [t,n]	The offer price is related to the production, which represents the minimum price the agent wants to receive per unit of energy. Values must be provided for each agent and each time step. This is imported from the TEO module.	€/kWh	Array
util [t,n]	This bid is related to consumption. One value must be provided for each agent, or a constant value to be allocated to each agent.	€/kWh	Array
gis_data	The network data to run the platform under the distance product differentiation feature. It must be a dictionary with the linked agents, the total length between them and the total cost associated with each pipeline. Such information is imported from the GIS module.		Dictionary

2.3 Market Outputs

Each market simulation will yield some results like the traded energy and market clearing price. In addition, there are also some findings to be calculated, namely:

2.3.1 Social Welfare

Social welfare comprises all market agents and is computed by summing the scheduled quantity times the price bid of that agent.

$$SW = \sum_{n \in \Omega_n} C_n \, P_n \qquad (21)$$

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2.3.2 Settlement (SE)

The settlement corresponds to the revenue for producers and payment for consumers. This quantity is outputted for each agent individually.

For the pool market, it is computed as:

$$SE_n = \sum_{m \in \Omega_n} \lambda \; P_{n,m} \tag{22}$$

For the P2P market, this is computed as

$$SE_n = \sum_{m \in \Omega_n} \lambda_{n,m} \; P_{n,m} \tag{23}$$

For the community, it is computed as:

$$SE_n = \sum_{m \in \Omega_n} \lambda \; P_{n,m} \tag{24}$$

2.3.3 Agent Operational Cost

This quantity can be computed for each producer/consumer, and is equal to the scheduled quantity times the price bid of that producer/consumer:

$$Agent\ Operational\ Cost = \sum_{m \in \omega_m} C_n G_n \tag{25}$$

2.3.4 Quality of Experience (QoE)

Quality of Experience (QoE) is a measure that evaluates the fairness of market outcomes. This is based on agent satisfaction according to the perceived price of energy σ_n^t per time t. Firstly, σ_n^t is calculated for each agent based on:

$$\sigma_n^t = \sum_{m \in \Omega_n} \lambda_{n,m}^t \, P_{n,m}^t \tag{26}$$

Then, the QoE indicator is computed as:

$$QoE = 1 - \frac{\sigma^t}{\sigma_{max}^t} \tag{27}$$

where σ^t is the standard deviation of perceived prices and $\sigma_{max}^t = \emptyset_{max}^t - \emptyset_{min}^t$ represents the maximum price deviation.

2.3.5 Average Dispatched Generation (ADG)

ADG is the share of the maximum energy that is dispatched, averaged over time, calculated as

$$ADG_n = \frac{1}{T} \frac{\sum_{t \in T} P_n^t}{\overline{P_n^t}} \tag{28}$$

where $\overline{P_n^t}$ is the maximum available energy quantity for a certain agent at a specific time.

2.3.6 Successful Participation in the Market (SPM)

SPM indicates the level of participation in the market. In the first step successful participation χ_n^t is calculated:

$$\chi_n^t = \begin{cases} 1, P_n^t > 0 \ (dispatched) \\ 0, P_n^t = 0 \ (not\ dispatched) \end{cases} \quad (29)$$

In the second step, SPM (%) is calculated, for each source, considering all time slots as:

$$SPM_n = \frac{1}{T} \sum_{t \in T} \chi_n^t * 100 \quad (30)$$

It is also possible to define Unsuccessful Participation in the Market (USPM) for each agent by:

$$USPM_n = 100\% - \text{SPM} \quad (31)$$

2.3.7 Find the Best Price

This feature finds the price that an agent should submit in the market to ensure the highest possible revenue, which is valuable information. Through this analysis, the agent can determine what price should be submitted in the market to ensure higher profit, revenue, or participation. The analysis can also show the effect of the market power of a specific agent on the market outcomes.

It is computed through the last price from a source accepted in the market and it is assumed that the remaining agents will not behave differently.

2.3.8 Short-term General Outputs

With regard to the outputs, it is possible to get and visualize some variables, as well as the simulation status. In addition, several other outputs are calculated based on performances to assist and aid the user to assess the results. Table 5 describes and enumerates the short-term market outputs.

Table 5 - Short-term general outputs.

Name	Description	Units	Data Type
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array
Pn [t,n]	The net balance for each agent for each time step.	kWh	Array

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optimal	Boolean indicating whether the optimal solution was found or not.		Boolean
Settlement [t,n]	The settlement is obtained by multiplying the energy dispatched by the price of each transaction. It is calculated for each agent for each time step. More details can be found in 2.3.2.	€	Array
social_welfare [t]	Social Welfare for each hour is obtained by multiplying the energy dispatched by the bid of each agent and then grouping the results by time step. A value is presented for each time step. More details can be found in 2.3.1.	€	Array
shadow_price [t,n] or [t,n,n]	Presents the market clearing price. Presents one value per time step, if the Pool market design is simulated. Outputs one value per transaction and per time step, if P2P market design is simulated.	€/kWh	Array
Market plot	Yields a plot with the offers' merit order for all agents, for a single selected time step. It is only available if the Pool market is the simulated design.		Figure
QoE [t]	Indicates the fairness level for each market result. The closer this indicator is to 1, the fairer the results will be to consumers. Outputs one value per time step. This value is only available in the P2P market design. More details can be found in 2.3.4.		Array

2.3.9 Long-term General Outputs

With regard to the outputs, it is possible to get and visualize some variables as well as the simulation status. In addition, several other outputs are calculated based on performances to assist the user to assess the results. Table 6 describes and enumerates the long-term market outputs.

Table 6 - Long-term general outputs

Name	Description	Units	Data Type
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array

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Pn [t,n]	Represents the net balance for each agent for each time step.	kWh	Array
optimal	Boolean indicating whether the optimal solution was found or not.		Boolean
Settlement [t,n]	The settlement is obtained by multiplying the energy dispatched by the price of each transaction. It is calculated for each agent for each time step. More details can be found in 2.3.2.	€	Array
agent_operational_cost [t,n]	The agent operating cost is obtained by multiplying the energy dispatched by the bid of each agent. It is calculated for each agent for each time step. More details can be found in 0.	€	Array
social_welfare [t]	The social welfare is obtained by multiplying the energy dispatched by the bid of each agent and then grouping the results by time step. A value is presented for each time step. More details can be found in 2.3.1.	€	Array
shadow_price [t,n,n] or [t,n]	Represents the market clearing price. It presents one value per time step if the centralized market design is selected. Outputs one value per transaction and per time step, if the decentralized market design is selected.	€/kWh	Array
SPM	This KPI indicates the percentage of successful participation in the market by sources and sinks. One value is presented per agent. More details can be found in section 2.3.6.		Array
ADG	This KPI indicates the average dispatched production by a source. The dispatched production by period is based on the ratio between the available capacity and the actual dispatched production. One value is presented per source. More details can be found in section 2.3.5.		Array
expensive_prod	Indicates the best price an agent must offer in the market to achieve higher revenue. The output will be one value since one agent and time step must be selected. More details can be found in 2.3.7.	€/kWh	Float
QoE [t]	Indicates the fairness level for each market result. The closer this indicator is to 1, the fairer the results will be. Outputs one value per time step. This value is only available in the decentralized market design. More details can be found in 2.3.4.		Array

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2.4Interactions with other modules

2.4.1 Short-term

In the integrated version of the platform, different modules are run sequentially. The modules interact and exchange data. In particular, the short-term collects data from the CF, GIS and TEO modules. Figure 6 depicts the data exchange between the MM and the other modules of the EMB3Rs platform.

From the CF module, the maximum capacity bids for sinks are retrieved. From the TEO, of the market module retrieves data related to sources, including emissions-related data. Finally, from the GIS the network-related data come, comprising all the nodes and edges.

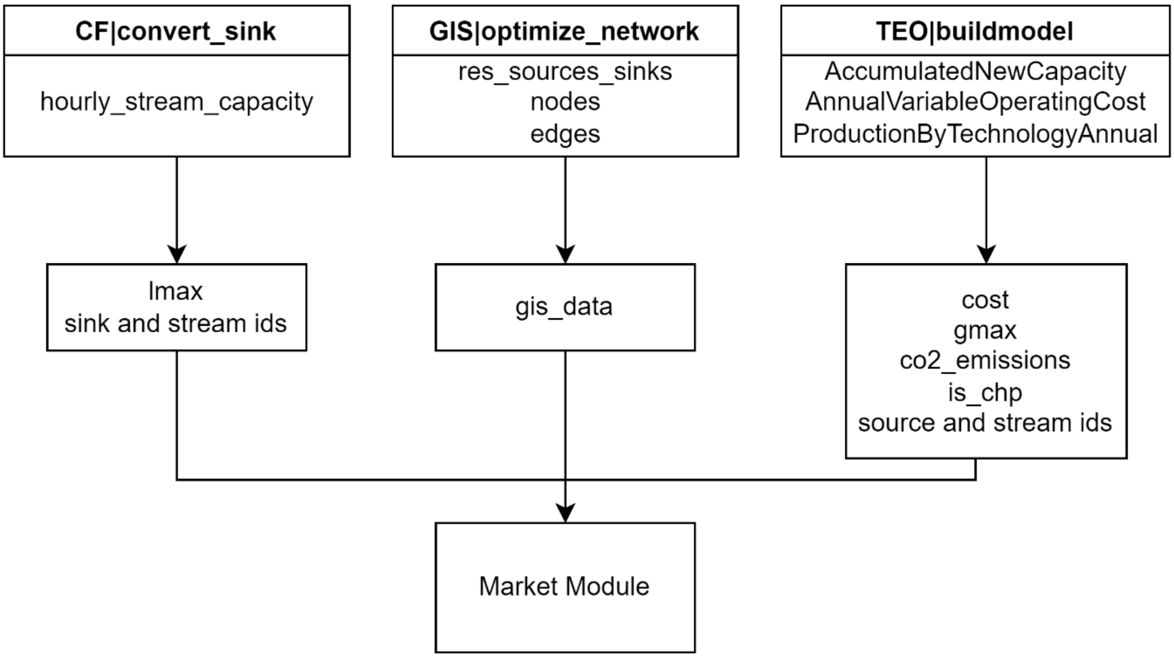

Figure 6 - Diagram for short-term data exchange with other modules of the EMB3Rs platform.

2.4.2 Long-term

In the integrated version of the platform, different modules run sequentially. The modules interact and exchange data. In particular, the long-term analysis through the MM collects data from CF, GIS and TEO modules, and sends some results to the BM. Figure 7 visualizes the data exchange between the MM and other modules.

From the CF module, the maximum capacity bids for sinks are retrieved. From the TEO, MM retrieves data related to sources, with the inclusion of emissions-related data. In addition, from the GIS MM retrieves the network-related data, comprising all the nodes and edges. Finally, outflowing data from the BM is related to the market price, dispatch of each agent and operational costs.

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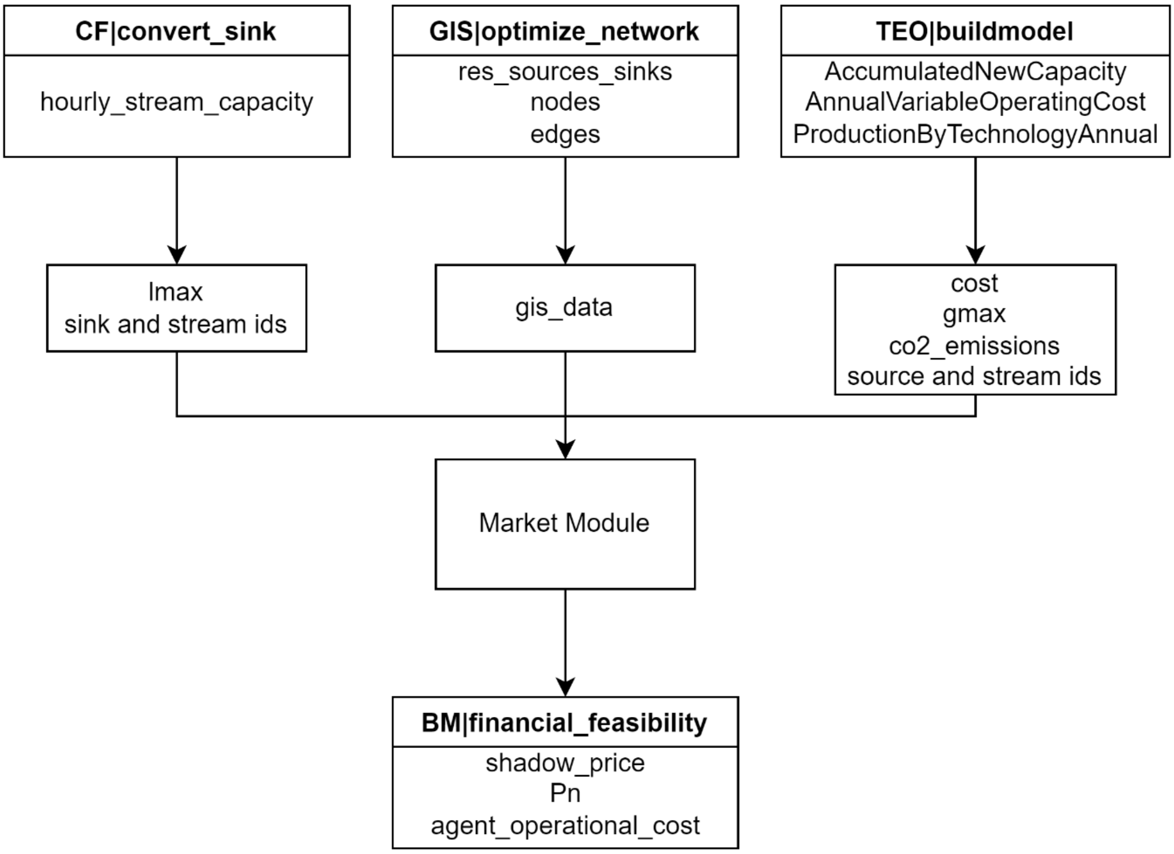

Figure 7 – Diagram of long-term data exchange with other modules of the EMB3Rs platform.

2.5Market Analysis

In the MM, users have two forms of market analysis, short-term and long-term market analysis. A simplified overview of the MM modules' inputs and outputs for each of the two forms of analysis is given in Figure 8.

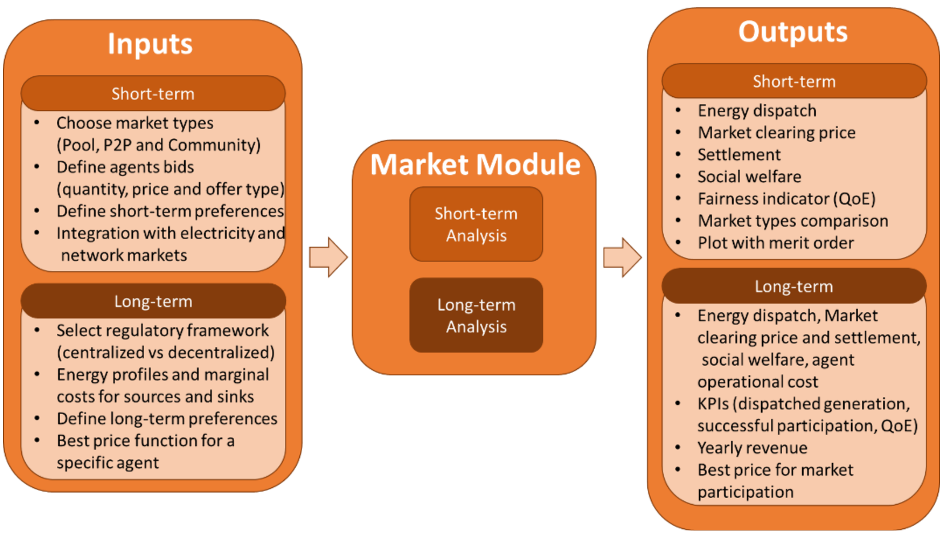

Figure 8 - Simplified overview of inputs and outputs for the MM, considering the short-term and long-term analysis.

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2.5.1 Short-Term Market Analysis

The short-term analysis aims to simulate the market for a time horizon between 1 hour and 48 hours (simulating at most two consecutive days). Additionally, this analysis includes a detailed representation of the agents and may consider the DHC network. It also includes the option to model the effect of electricity prices on producer price bids. This option can be relevant for test cases that consider heat sources such as CHPs and heat pumps.

The market simulation will return the total social welfare, a fairness indicator, market clearing price, energy dispatch and revenue/cost per agent and hour. Through the short-term market analysis, the user can evaluate the market performance under high granularity. It can also compare the performance of the three market designs (Pool, P2P and Community-based) per hour and assess the impact on each agent. For example, the user may want to know which hours the consumers are flexible by adopting a dynamic offering price. Another scenario is seeing the hours where the selling of waste heat from a specific prosumer is most profitable. In this scenario, the user can see the prosumer performance in different market designs, and even re-simulate with different offering prices.

2.5.2 Long-Term Market Analysis

The long-term analysis aims to simulate the market for long time horizons, such as weeks, months or years. Depending on the selection, it is limited to 52 weeks, 12 months and 20 years. It can capture seasonal effects, as well as the expected growth of heat consumption. The user can define certain market operating conditions, such as:

- Market structure (Centralized or Decentralized);
- Yearly increase (or decrease) rate of heat consumption

In addition, this long-term analysis can consider the aggregation of input data to model the agents of a specific test case. For instance, if the user selects daily recurrence, while the input data is hourly, the generation/load profiles will be aggregated for each day of the simulation. These daily profiles will define the energy quantity per agent, where the MM will set a fixed level of flexibility. Additionally, the offering price is now a single value for all market periods in a day. This option can be selected in highly demanding simulations, like yearly simulations, to improve computational performance.

This market simulation will also return the total social welfare, market clearing price, energy dispatch and revenue/cost per agent. Through this analysis, the user can evaluate the performance of different market participants under the long-term horizon. The yearly revenue/cost and yearly successful energy dispatch per agent will be displayed. The user can later use these metrics in the Business Module to calculate the profit from specific waste heat technologies. Finally, the simulation can also identify the offering price that returns the best revenue for a particular producer. In this way, the impact of market power on market outcomes can be studied.

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3 User Manual

This document describes step-by-step how to use the MM from the user's standpoint. It includes a detailed and practical guide for the setup of a case study for simulation, considering both short-term and long-term market analysis.

3.1 Module Requirements and Specifications

The market module was developed in Python 3.8 and to run it the following packages and versions are required:

- pandas=1.2.0
- numpy=1.20.1
- setuptools=51.1.2
- cvxpy=1.1.7
- matplotlib=3.3.4
- ast
- matplotlib
- itertools
- heapq
- statistics
- datetime

3.2 Module Features

3.2.1 Short-Term Market Analysis

3.2.1.1 Module Structure

The short-term market is structured in three phases, as depicted in Figure 9. Each phase is detailed as follows:

- The inputs are divided into 3 categories, namely, settings, agent data and network. There is a class for each of these categories, which is used to create an object that contains all required inputs for each category. More precisely, the categories are:
  - Settings – contains choices including market design, number of hours to simulate, offer type, product differentiation option, network type, electricity-dependent and electricity price. In case a community-based market is simulated, the Settings object will also contain input parameters for this market type;
  - AgentData – contains costs, utility, maximum production and consumption for each agent and each hour. It also contains an id for each

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agent. Optionally, it contains CO_2 emissions for each agent, whether each agent is a CHP or not, and the block offer. For CHP agents, it includes input parameters needed for the CHP bid model;

  - The Network objects contain a representation of the entire network, as well as the distance and losses between pairs of agents.

- For each of the market designs, there is a separate function that creates the market optimization problem and solves it. The outcome is stored in an object of the Result class.
- The Result class contains values of primal and dual variables that will be needed either as output directly or for the computation of other outputs. The Result object will also contain the output values that are computed from these optimized variables, such as the QoE, settlements and social welfare. In addition, if the Pool market is the one simulated, a merit order graph can be produced.

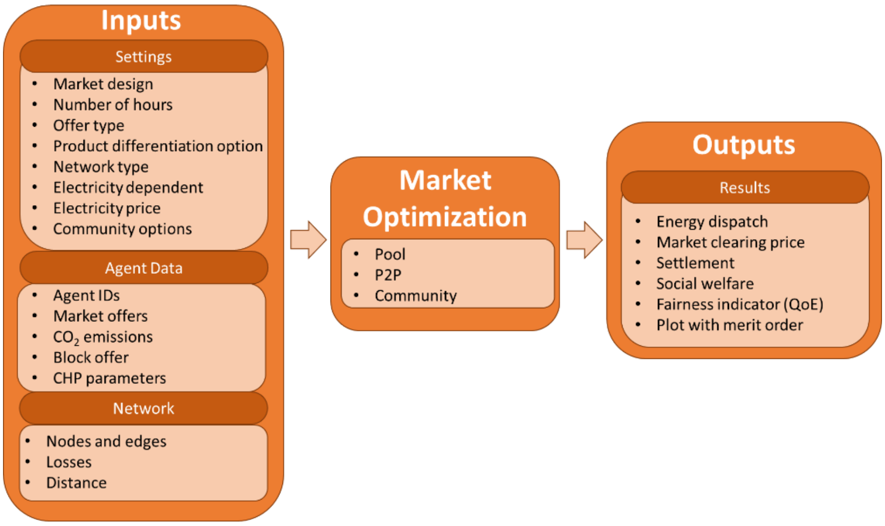

Figure 9 – Short-term market structure.

3.2.1.2 General Settings

In order to run a simulation, some general settings must be chosen by the user. Some of these are specific to the desired market design, namely Pool, P2P or Community-based market. Table 7 summarizes the expected General Settings and the possible options to choose from. Figure 10 presents an expected visual interface for the general settings.

First of all, the user has to select the market design (e.g., Pool, P2P, or Community). For more details on the market design, interested readers are directed to the System Manual in section 2.1. Regardless of the selected market, the user must select the number of simulated hours, which can go up to 48h. In addition, a date to start the simulation is selected. This is used to select the correct inputs from other modules (TEO, CF), that will be used to create the agent bids. Next, the offer type is selected, which includes the simple, block or energy budget options (check section 2.1.5 for a detailed explanation).

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There is an option to include electricity market dependence. This option makes the price and quantity bids of agents that are CHPs dependent on an input electricity price (forecast), as detailed in section 2.1.4.2.

The product differentiation option is only needed for the P2P market design. Here, the available options are CO_2 emissions, energy losses, distance or no preference, as detailed in section 2.1.2.

In case the Community market is selected, the user must provide several settings. The type of objective function must be chosen (either "autonomy" or "peakShaving"- check section 2.1.3), which will specify what goal the community is trying to achieve. In addition, the user must input three parameters representing the penalty for importing heat, the reward for exporting heat, and the penalty for the size of the peak import. Default values are presented for these parameters, but, optionally, the user can modify them.

In case the user simulates a Pool market, there is an option to include network operating conditions in the market. If this option is selected, the dispatch determined by the market will respect the thermal energy flow *directions* in the network. Note that this does not mean the sizes of thermal energy flows will be feasible, as this needs to be checked by a network operator. If necessary, the network operator would have to re-dispatch.

Table 7 - Short-term inputs.

Name	Description	Units	Data Type
md	Market design. Represents the market design the user intends to simulate. Pool, P2P and Community are the options.		String
nr_of_hours	Represents the simulation horizon period.	Hours	Integer
start_datetime	Date of the format "dd-mm-yyyy".		String
offer_type	Represents the offer type, which can be related to all agents or only to some agents. Simple, Block and energyBudget are the options		String
prod_diff	The option related to product differentiation, namely, by encouraging or penalizing some market transactions, according to user preferences. noPref (No Preferences), co2Emissions (CO_2 Emissions), networkDistance (Network Distance) and losses (Energy Losses) are the options.		String
el_dependent	Only available for Pool market True or False.		Boolean

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el_price	If el_dependent=True, an electricity price (forecast) must be entered for all market hours.	€/kWh	Array
Network	“none” or “direction”		String
Objective	Only if “md = community”. Should be one of [“autonomy”, “peakShaving”].		String
Community settings	Include g_peak, g_exp, g_imp. g_exp must be nonpositive, while g_imp and g_peak must be nonnegative.		Integers

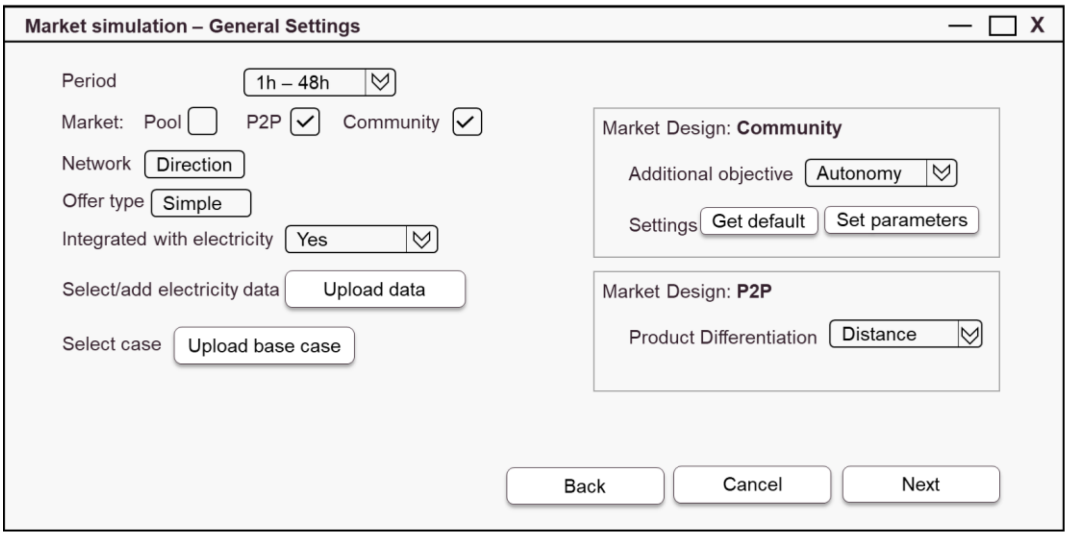

Figure 10 – Preliminary sketch of short-term general settings visual interface.

3.2.1.3 Parameters

After the General settings are defined, other parameters must be provided. These parameters are not only linked to the individual agents and their characteristics, but also the network features. Some can be defined by the user, others come from other EMB3Rs modules, namely CF, TEO and GIS. For example, the name and CO_2 emissions of each agent are imported from TEO. Table 8 summarizes the parameters for the short-term simulation. The information related to the bids, namely prices and quantities must be mandatorily provided for each agent and each time step.

The model uses sets related to the time slices for the simulation and the agents’ names. These sets are automatically created within the module, based on the agents’ bids (which come from the TEO module) and the user-selected market horizon.

Under some settings, GIS data is necessary to run the market. This is the case when the user chooses to include “network = directions”, or whether a P2P market considering technical losses or network distances preferences is selected. The GIS module provides information on the linked nodes and correspondent distances.

If the user has chosen to include block offers, a dictionary with the block offer information must be provided by the user.

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Table 8 - Short-term parameters.

Name	Description	Units	Data Type	Data Source
agent_ids [n]	This parameter contains the id of each agent.		Array	CF (sinks), TEO (sources)
co2_emissions [n]	CO_2 emission intensity by agent. This list is only required when preferences on CO_2 Emissions are selected in the P2P market.	Kg.CO2/kWh	Array	TEO
gmax [t,n]	The maximum production each agent offers in the market. Values must be provided for each agent and each time step.	kWh	Array	TEO
lmax [t,n]	The maximum consumption each agent offers to purchase in the market. Values must be provided for each agent and each time step. This load profile is imported from the CF module.	kWh	Array	CF
cost [t,n]	The offer price is related to the production, which represents the minimum price the agent wants to receive per unit of energy. Values must be provided for each agent and each time step.	€/kWh	Array	TEO
util [t,n]	The bid price is related to consumption. Values must be provided for each agent and each time step.	€/kWh	Array	User
gis_data	All the network data that is required to run the MM under the Distance or Losses product differentiation features. It must be a dictionary with the linked agents, the total length between them, and the total costs associated with each pipeline. This is also used in case the network feature is selected in the Pool market.		Dict	GIS
block_offer	A dictionary with agent IDs as keys. The values include the time steps when the block offer is active. Not all agent IDs need to be included, only the IDs of agents that submit block bids are needed.		Dict	User

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is_in_community	A boolean for each agent specifies whether it is part of the community or not. This input is required when the Community market is chosen.		Array	User
is_chp	A boolean for each agent specifies whether it is a CHP or not. This input is mandatory in case the user selects the electricity dependence option. This input is derived from agent IDs provided by the TEO.		Array	TEO
chp_pars	For each agent that is a CHP, some parameters must be specified. This input is mandatory in case the user selects the electricity dependence option, otherwise, it is not needed.		Array	User

3.2.1.4 Variables

To run a simulation, some variables are used to represent the agents' behaviour within each market section. Ln, Gn and Pn are related to individual agents and are computed both for all models. Snm, Bnm and Tnm are related to the trades between peers but are only computed in the decentralized model. Also, a dual variable is obtained, representing the market clearing price for each transaction. Table 9 presents all the output variables computed by the MM. For more details on each market formulation, including a detailed explanation and interrelation between the variables, interested readers are directed to section 2.1.

Table 9 - Short-term variables.

Name	Description	Units	Data Type
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array
Pn [t,n]	The net balance for each agent for each time step.	kWh	Array
Snm [t,n,n]	Amount sold by agent n to agent m, for each agent, for each time step. This variable is only calculated in the P2P market design.	kWh	Array
Bnm [t,n,n]	Amount bought by agent n to agent m, for each agent, for each time step. This variable is only calculated in the P2P market.	kWh	Array

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Tnm [t,n,n]	The net balance for each bilateral trade, for each agent, for each time step. This variable is only calculated in the P2P market.	kWh	Array
b[t,n]	Binary variable indicating whether a bid is fully accepted or fully rejected. This variable is only calculated if the block offer is selected.		Array
shadow_price [t,n] or [t,n,n]	This variable is the dual variable of the balance equation corresponding to the market clearing price. For the Pool market design, there is a single value per time step. On the other hand, the P2P market design outputs one value per transaction and per time step. In the community market, there is a price for internal trade, and a price for trade with the outside, for each time step. The theory behind this variable is explained for each market throughout section 2.1.	€/kWh	Array

3.2.1.5 Outputs

With regard to the outputs, it is possible to get and visualize some variables, as well as the simulation status. In addition, several other outputs are calculated based on performances to assist and aid the user to assess the results. Table 10 describes and enumerates the short-term market outputs.

Table 10 - Short-term outputs.

Name	Description	Units	Data Type
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array
Pn [t,n]	The net balance for each agent for each time step.	kWh	Array
optimal	Boolean indicating whether the optimal solution was found or not.		Boolean
Settlement [t,n]	The settlement is obtained by multiplying the energy dispatched by the price of each transaction. It is calculated for each agent for each time step. More details can be found in 2.3.2.	€	Array
social_welfare [t]	Social Welfare for each hour is obtained by multiplying the energy dispatched by the bid of each agent and then grouping the results by time step. A value is presented for each time step. More details can be found in 2.3.1.	€	Array

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shadow_price [t,n] or [t,n,n]	Presents the market clearing price. Presents one value per time step, if the Pool market design is simulated. Outputs one value per transaction and per time step, if P2P market design is simulated.	€/kWh	Array
Market plot	Yields a plot with the offers' merit order for all agents, for a single selected time step. It is only available if the Pool market is the simulated design.		Figure
QoE [t]	Indicates the fairness level for each market result. The closer this indicator is to 1, the fairer the results will be to consumers. Outputs one value per time step. This value is only available in the P2P market design. More details can be found in 2.3.4.		Array

Figure 11 – Preliminary sketch of short-term results visual interface.

3.2.1.6 Interaction and integration with other modules

In the integrated version of the platform, different modules are run sequentially. The modules interact and exchange data. In particular, the short-term collects data from the CF, GIS and TEO modules. Figure 12 depicts the data exchange between the MM and the other modules of the EMB3Rs platform.

From the CF module, the maximum capacity bids for sinks are retrieved. From the TEO, of the market module retrieves data related to sources, including emissions-related data. Finally, from the GIS the network-related data come, comprising all the nodes and edges.

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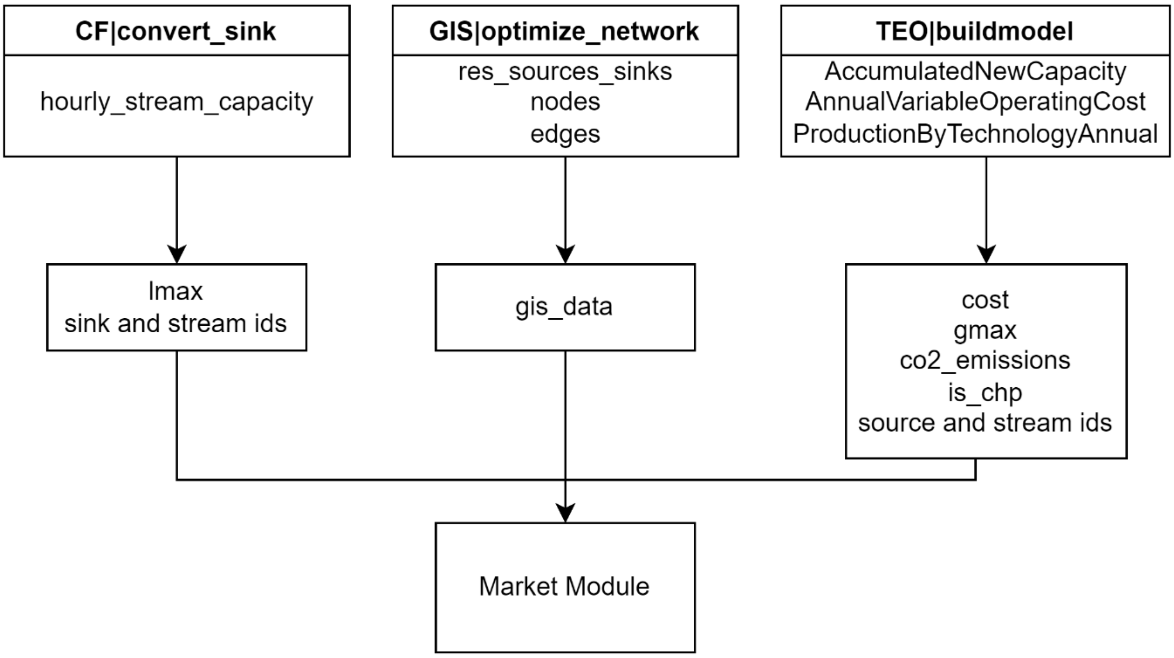

Figure 12 – Diagram for short-term data exchange with other modules of the EMB3Rs platform.

3.2.1.7 Running a test example

This section presents a simple test case and the instructions to create a simulation so any user can test and validate autonomously its own examples. The simulations were performed in an HP 64-bit operating system, with Intel processor i7-4600 CPU @ 2.10 GHz 2.70 GHz, with 8.00 GB RAM. With the properties described below, it should not take longer than 3 seconds to run the simulation.

3.2.1.7.1 Test case description

For this particular case, a typical Danish district heating network including 31 consumers, 3 producers (Grid, Data Center and Heat Pump) and 1 prosumer (Supermarket) is considered. The input data, for one entire year, considering agents with different patterns are available at Mendeley Data [11]. The network operating point is in line with the Danish networks, with average annual supply temperatures around 78 ^{o}C and return temperatures around 43 ^{o}C. Data curation about demand and supply capacity and offers can be found in [3]. Figure 13 illustrates the network.

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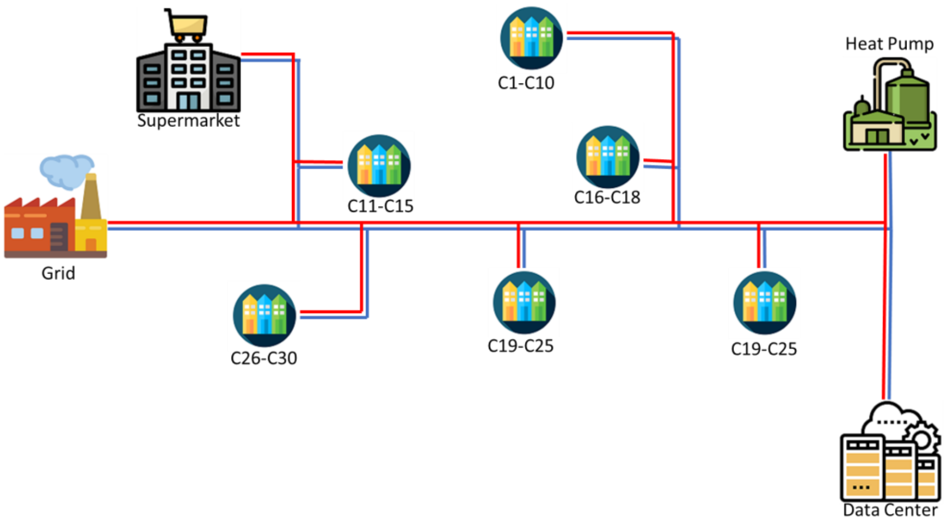

Figure 13 – Illustrative example of a district heating network.

3.2.1.7.2 General settings and data

Following the description of the short-term market analysis, to run a short case, the P2P market design and 1-hour simulation are selected. The offer type is simple, and CO_2 emissions are considered in the product differentiation feature. The network and electricity features are not considered. All the settings related to the community are also not considered, since this example intends to simulate a P2P market. The remaining data and formats coming from other modules like lmax, gmax, cost, co2_emissions and agent_ids are adapted according to [3].

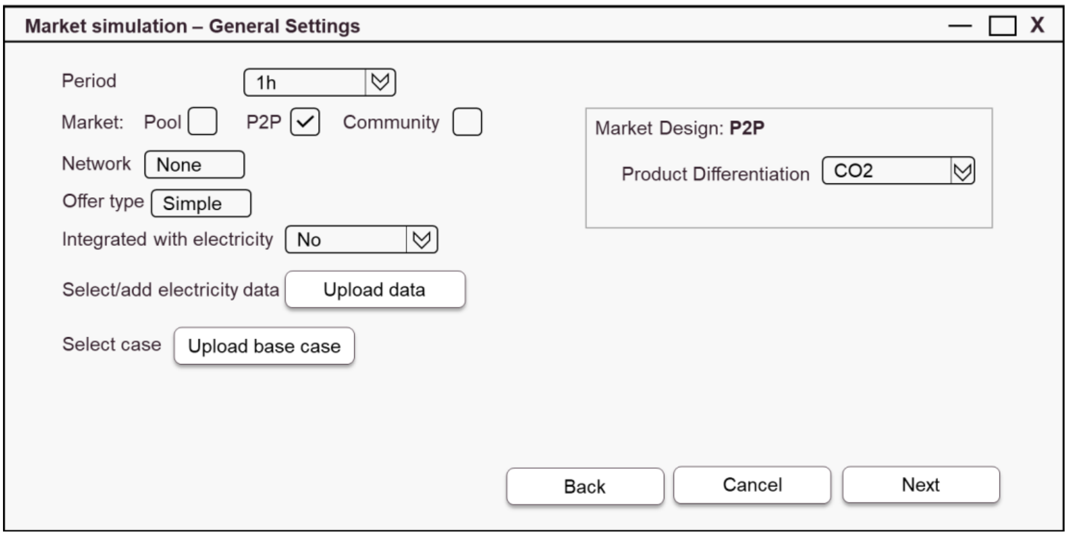

Figure 14 - Short-term general settings visual interface of a test case.

3.2.1.7.3 Results

The outputs from 3.2.1.5 are computed and Table 11 aggregates the P_n results. Out of simplicity, the remaining results are not shown here but are available in the following link.

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Table 11 – Short-term test example net balance for each agent (P_n).

Agent	Pn	Agent	Pn	Agent	Pn	Agent	Pn	Agent	Pn
Grid	0,00	C4	-0,99	C11	-1,69	C18	-1,22	C25	-1,41
Supermarket	16,22	C5	-3,75	C12	-0,25	C19	-0,75	C26	-1,4
Data Center	24,79	C6	-1,99	C13	-0,83	C20	-0,13	C27	-0,06
Heat Pump	0,00	C7	-0,86	C14	-0,68	C21	-0,24	C28	-3,24
C1	-2,58	C8	-1,26	C15	-1,73	C22	-0,86	C29	-0,68
C2	-1,03	C9	-0,78	C16	-2,06	C23	-1,31	C30	-2,33
C3	-0,28	C10	-0,7	C17	-2,24	C24	-1,33	C31	-2,35

3.2.2 Long-Term Market Analysis

3.2.2.1 Module Structure

The long-term market module is structured as follows:

- The inputs are divided into 3 categories, namely, settings, agent data and network. There is a class for each of these categories, which is used to create an object that contains all needed inputs for each category.
    - Settings contain choices including market design, product differentiation option, horizon basis, recurrence, data profile and yearly demand rate.
    - AgentData contains costs, utility, maximum production and consumption for each agent and each hour. It also contains an id for each one. Optionally, it contains CO_2 emissions for each agent.
    - The network object contains a representation of the entire network, as well as the distance and losses between pairs of agents.
- For each of the market designs, there is a separate function that creates the market optimization problem and solves it. The outcome is stored in an object of the Result class.
- The Result class contains values of primal and dual variables that will be needed either as output directly or for the computation of other outputs. The Result object will also contain the output values that are computed from these optimised variables, such as the QoE, settlements, social welfare, ADG, SPM and agent operational cost, as detailed in section 2.2. In addition, a method is also included to find the best price an agent must submit to maximize expected revenue.

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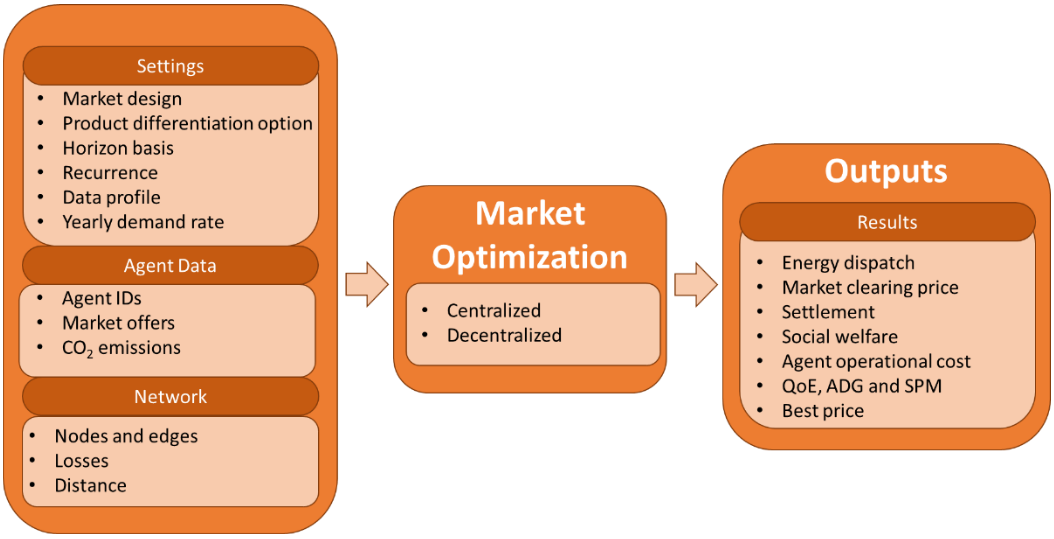

Figure 15 - Long-term market structure.

3.2.2.2 General Settings

In order to run a simulation, some pre-defined inputs must be inserted by the user. These inputs are related to the desired market design, namely a centralised or decentralised structure and the simulation time horizon. The latter is defined by the combination of horizon basis (weeks, months or years), data profile (hourly or daily) and recurrence, which will define the number of instances to run. In addition, a date to start the simulation is selected. This is used to select the correct inputs from other modules (TEO, CF) that will be used to form agent bids. Afterwards, the user can also select the yearly demand rate, denoting the increase or decrease in the demand over the simulated years. The product differentiation option is only needed for the decentralised design. Here, the available options are CO_2 emissions, distance or no preference. Table 12 summarises the general settings and the options for each input.

Table 12 – Inputs for the long-term market analysis.

Name	Description	Data Type
md	Represents the market design the user intends to simulate. Centralized or Decentralized are the options.	String
horizon_basis	Represents the simulation horizon period. Weeks, Months or Years are the options	String
data_profile	Represents the level of data aggregation, which can be considered as hourly or daily grouped. That is, it sets whether the optimization process is simulated on an hourly or daily basis for the entire time horizon. Note that this option influences the computational effort of the MM. Hourly or Daily are the options.	String

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recurrence	Represents the number of periods selected in the horizon_basis.	Integer
start_datetime	A data of format “dd-mm-yyyy”.	String
yearly_demand_rate	The expected yearly demand rate change. The demand can increase or decrease over the years so a float number within the range [-1,1] is expected.	Float
prod_diff_option	The option is related to product differentiation, namely, by encouraging or penalizing some market transactions, according to user preferences. noPref (No Preference), co2Emissions (CO_2 Emissions) and networkDistance (Network Distance) are the options.	String

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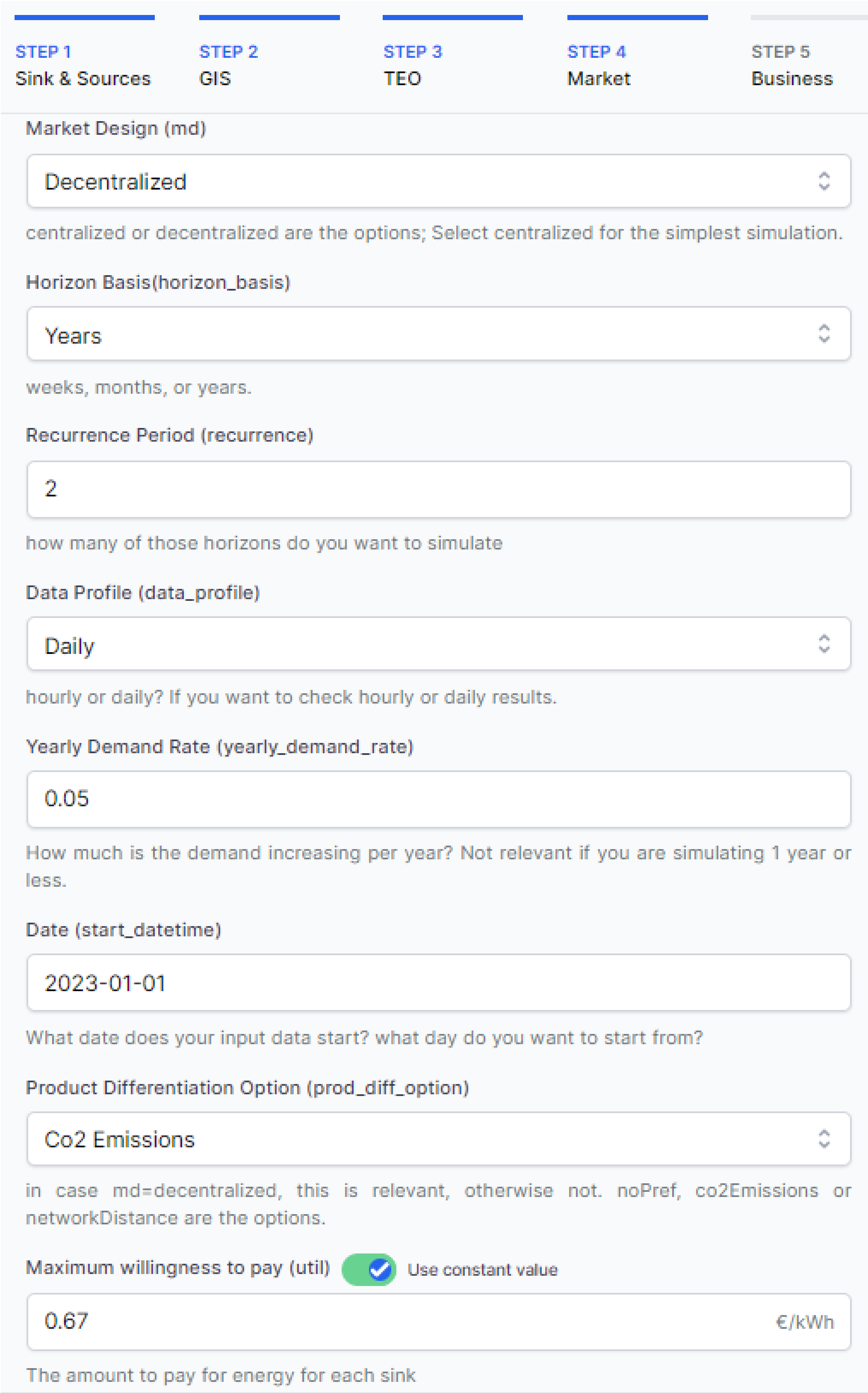

Figure 16 – Sketch of long-term general settings visual interface.

3.2.2.3 Parameters

After the General settings are defined, other parameters must be provided. These parameters are not only linked to the individual agents and their characteristics, but

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also the network features. Some can be defined by the user, or come from other EMB3Rs modules, namely CF, TEO and GIS. Here the name and emissions of each agent are included. Then the information related to the bids, namely prices and quantities, whether one agent is willing to sell or buy energy, must be provided for each agent and each time step.

The model uses sets related to time slices for the simulation and agent's names. These sets are automatically created within the module, based on the agents' bids (which come from the TEO module) and the user-select market horizon.

Under some settings, GIS data is necessary to run the market. This is the case if the user has chosen a decentralized market with a distance-based preference. This GIS module provides information on the linked nodes and correspondent distances. Table 13 summarizes the parameters for the long-term simulation.

Table 13 – Parameters of the long-term market analysis.

Name	Description	Units	Data Type	Data Source
agent_ids [n]	Represents each agent id. This is imported from TEO.		Array	CF (sinks), TEO (sources)
co2_emissions [n]	CO_2 emissions by agent, imported from TEO. This list is only required when preferences on CO_2-Emissions are selected in the decentralized model.	Kg.CO2 /kWh	Array	TEO
gmax [t,n]	The maximum production each agent offers in the market. Values must be provided for each agent and each time step. A constant value for each agent is imported from the TEO module, but an optional user input can override the imported values	kWh	Array	TEO
lmax [t,n]	Maximum consumption each agent offers to purchase in the market. Values must be provided for each agent and each time step. This load profile is imported from the TEO module.	kWh	Array	CF
cost [t,n]	The offer price is related to the production, which represents the minimum price the agent wants to receive per unit of energy. Values must be provided for each agent and each time step. This is imported from the TEO module.	€/kWh	Array	TEO

util [t,n]	This bid is related to consumption. One value must be provided for each agent, or a constant value to be allocated to each agent.	€/kWh	Array	User
gis_data	The network data to run the platform under the distance product differentiation feature. It must be a dictionary with the linked agents, the total length between them and the total cost associated with each pipeline. Such information is imported from the GIS module.		Dictionary	GIS

3.2.2.4 Variables

To compute the MM through the long-term market analysis, some variables are used to represent the agents' behaviour within each market section. Ln, Gn and Pn are related to individual agents and are computed both for centralized and decentralized modes. Snm, Bnm and Tnm are related to the trades between peers but are only computed in the decentralized model. Also, a dual variable is obtained, representing the market clearing price for each transaction. Table 14 shows all the variables used for the different market designs in the MM, considering the long-term market analysis.

Table 14 – Variables of the long-term market analysis.

Name	Description	Units	Data Type
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Pn [t,n]	Represents the net balance for each agent for each time step.	kWh	Array
Snm [t,n,n]	Amount sold by agent n to agent m, for each agent, for each time step. This variable is only computed in the decentralized market.	kWh	Array
Bnm [t,n,n]	Amount bought by agent n to agent m, for each agent, for each time step. This variable is only computed in the decentralized market.	kWh	Array
Tnm [t,n,n]	Represents the net balance for each bilateral trade, for each agent, for each time step.	kWh	Array
shadow_price [t,n,n] or [t,n]	Represents the market clearing price. Presents one value per time step, if the centralized market design is chosen. Outputs one value per	€/kWh	Array

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	transaction and per time step, if the decentralized market design is the selected one.		

3.2.2.5 Outputs

With regard to the outputs, it is possible to get and visualize some variables as well as the simulation status. In addition, several other outputs are calculated based on performances to assist the user to assess the results. Table 15 describes and enumerates the long-term market outputs.

Table 15 – Outputs for the long-term market analysis.

Name	Description	Units	Data Type
Gn [t,n]	Amount sold in the market for each agent for each time step.	kWh	Array
Ln [t,n]	Amount purchased in the market for each agent for each time step.	kWh	Array
Pn [t,n]	Represents the net balance for each agent for each time step.	kWh	Array
optimal	Boolean indicating whether the optimal solution was found or not.		Boolean
Settlement [t,n]	The settlement is obtained by multiplying the energy dispatched by the price of each transaction. It is calculated for each agent for each time step. More details can be found in 2.3.2.	€	Array
agent_operational_cost [t,n]	The agent operating cost is obtained by multiplying the energy dispatched by the bid of each agent. It is calculated for each agent for each time step. More details can be found in 2.3.3	€	Array
social_welfare [t]	The social welfare is obtained by multiplying the energy dispatched by the bid of each agent and then grouping the results by time step. A value is presented for each time step. More details can be found in 2.3.1.	€	Array
shadow_price [t,n,n] or [t,n]	Represents the market clearing price. It presents one value per time step if the centralized market design is selected. Outputs one value per transaction and per time step, if the decentralized market design is selected.	€/kWh	Array

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SPM	This KPI indicates the percentage of successful participation in the market by sources and sinks. One value is presented per agent. More details can be found in section 2.3.6.	%	Array
ADG	This KPI indicates the average dispatched production by a source. The dispatched production by period is based on the ratio between the available capacity and the actual dispatched production. One value is presented per source. More details can be found in section 2.3.5.	%	Array
expensive_prod	Indicates the best price an agent must offer in the market to achieve higher revenue. The output will be one value since one agent and time step must be selected. More details can be found in 2.3.7.	€/kWh	Float
QoE [t]	Indicates the fairness level for each market result. The closer this indicator is to 1, the fairer the results will be. Outputs one value per time step. This value is only available in the decentralized market design. More details can be found in 2.3.4.	%	Array

Figure 17 gives an example of the dashboard concerning the results available in the long-term market analysis.

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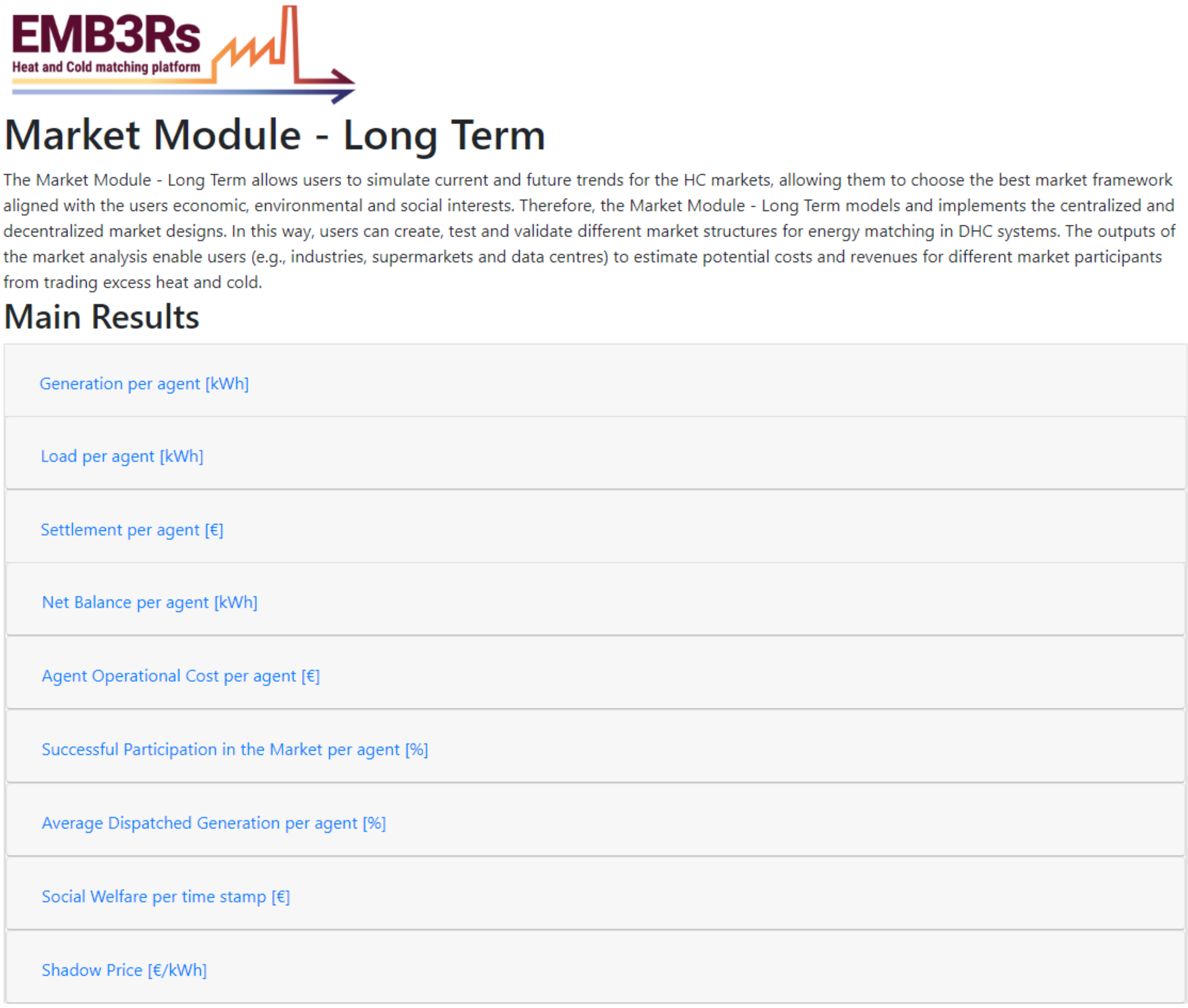

Figure 17 – Sketch of long-term results visual interface.

3.2.2.6 Integration and Interactions with other modules

In the integrated version of the platform, different modules run sequentially. The modules interact and exchange data. In particular, the long-term analysis through the MM collects data from CF, GIS and TEO modules, and sends some results to the BM. Figure 17 visualizes the data exchange between the MM and other modules.

From the CF module, the maximum capacity bids for sinks are retrieved. From the TEO, MM retrieves data related to sources, with the inclusion of emissions-related data. In addition, from the GIS MM retrieves the network-related data, comprising all the nodes and edges. Finally, outflowing data from the BM is related to the market price, dispatch of each agent and operational costs.

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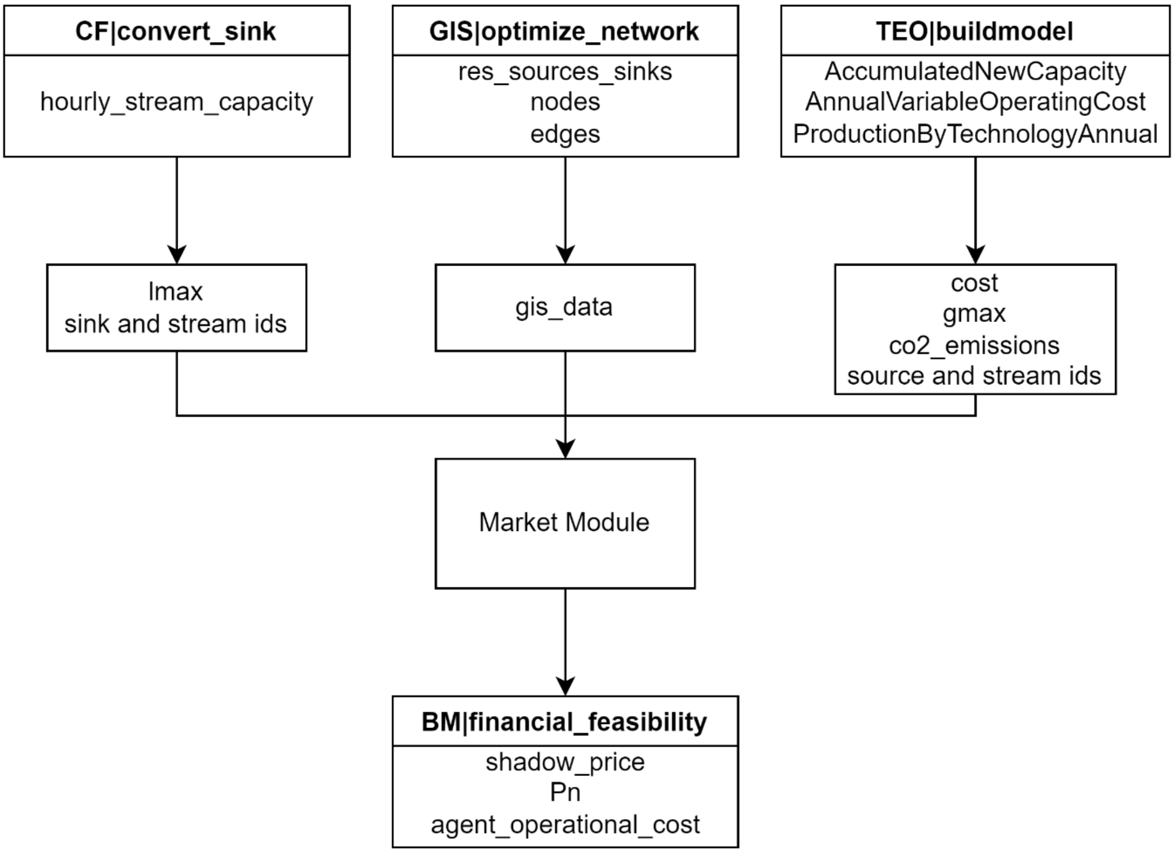

Figure 18 – Diagram of the long-term data exchange with other modules of the EMB3Rs platform.

3.2.2.7 Running a test example

This section presents a simple test case and the instructions to create a simulation so any user can test and validate autonomously its own examples. The simulations were performed in a 64-bit operating system, with Intel processor i7-4600 CPU @ 2.10 GHz 2.70 GHz, with 8.00 GB RAM. With the properties described below, it should not take longer than 10 seconds to run the simulation.

3.2.2.7.1 Test case description

Here, the same technical data set and case characterization as in 3.2.1.7.1 is used.

3.2.2.7.2 General Settings and data

To run a small test case, the centralized market design is selected here, with months as a horizon basis option. A daily data profile is considered and recurrence as 2. This means a two monthly simulation will be performed, with daily data, which gives 60 iterations in total. Yearly demand rate growth is irrelevant for this scenario since only two months are considered. The remaining data and formats coming from other modules like lmax, gmax, cost, co2_emissions and agent_ids are adapted according to [3].

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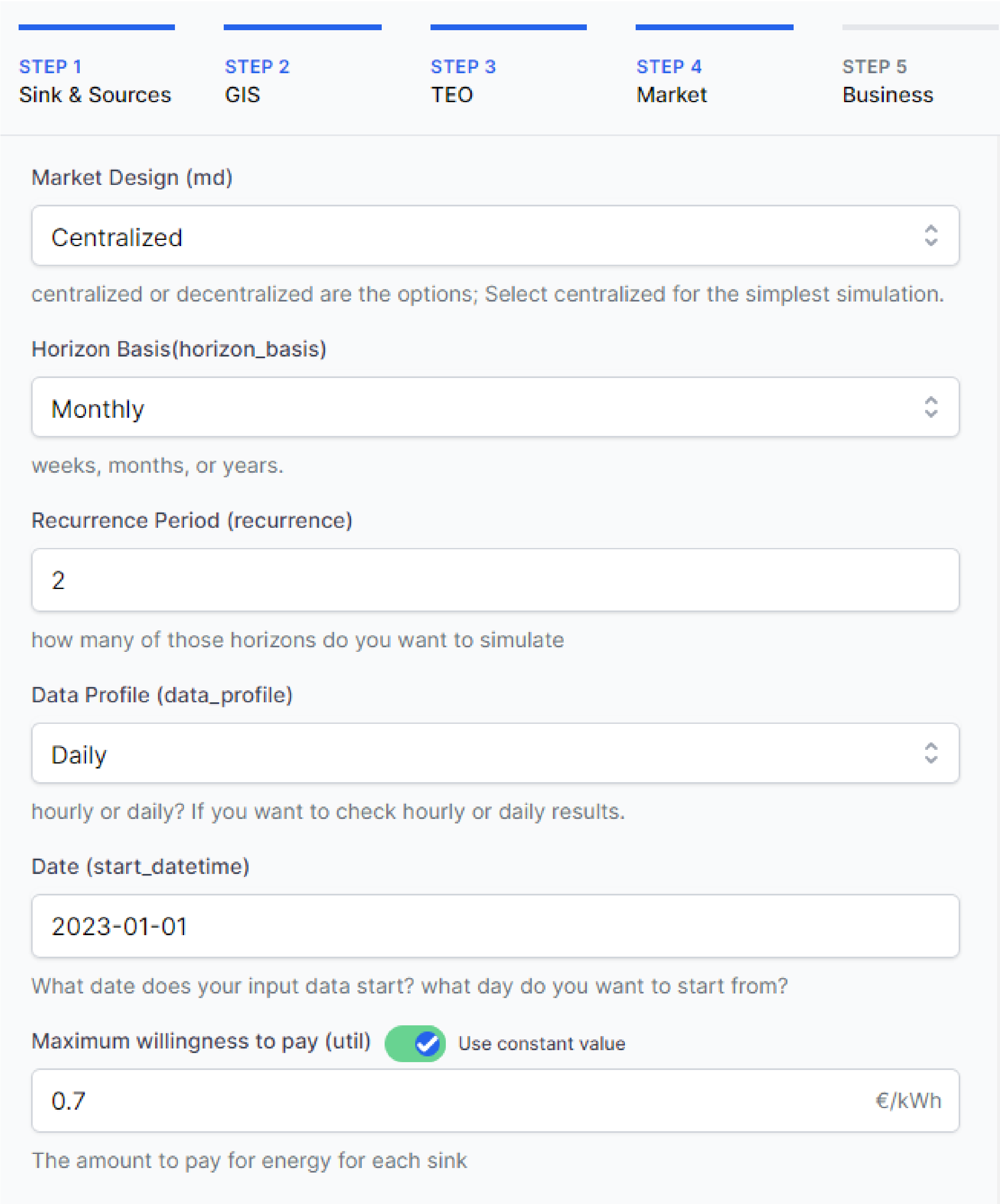

Figure 19 – Sketch of long-term general settings visual interface of a test case.

3.2.2.7.3 Results

All result sets from 3.2.2.5 are computed. Table 16 and Table 17 show some of the results, namely ADG and SPM. Out of simplicity, the remaining results are not shown here but are available in the following link.

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Table 16 - Long-term test case ADG indicator.

Average Dispatched Generation per agent [%]

ADG is the share of the maximum energy that is dispatched, averaged over time, calculated as:

$$ADG_n = \frac{1}{T}\frac{\sum_{t \in T} P_n^t}{\bar{P}_n^t}$$

where $\bar{P}_n^t$ is the maximum available energy quantity for a certain agent at a specific time.

	Grid	Supermarket	Data Center	Heat Pump
0	0.0	66.1	61.24	0.0

Table 17 - Long-term test case SPM indicator.

Successful Participation in the Market per agent [%]

SPM indicates the level of participation in the market. In the first step successful participation is calculated:

$$\chi_n^t = \begin{Bmatrix} 1, & P_n^t > 0 & (dispatched) \\ 0 & P_n^t = 0 & (notdispatched) \end{Bmatrix}$$

In the second step, SPM (%) is calculated, for each source, considering all time slots as:

$$SPM_n = \frac{1}{T}\sum_{t \in T}\chi_n^t * 100$$

	Grid	Supermarket	Data Center	Heat Pump
0	5.08	20.34	100.0	0.0

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4 Reports

This section presents the reports and configurations with the main findings from the MM to be delivered together with the other modules, as well as the particular report related to the MM.

4.1 Contributions to the Main Simulation Report

Some results from the MM will be delivered to the main report simulation. Within the short-term structure, settlement and market clearing price will be available in the main simulation report. In the long-term, adding to the settlement and market clearing price, will be ADG and SPM indicators.

Table 18 - MM contribution to the main simulation report.

Market Structure	Name	Description	Formatting
Short-term	Settlement	Revenue/payment for each agent	Table with dimension [t,n]
Short-term	Market clearing price	Market price	Table with a single value per time step if the market design is the Pool. Table with matrix [n,n] per time step if the market design is P2P.
Long-term	Settlement	Revenue/payment for each agent	Table with dimension [t,n]
Long-term	Market clearing price	Market price	Table with a single value per time step if the market design is centralized. Table with matrix [n,n] per time step if the market design is decentralized.
Long-term	ADG	Heat dispatched on average for each agent	Table with one value per source.
Long-term	SPM	Level of participation in the market for each agent (%)	Table with one value per agent.

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4.2Detailed Module Report

In addition, the remaining outputs from 413.2.1.5 and 3.2.2.5 are included in the detailed module report.

Market Structure	Name	Description	Formatting
Short-term	Gn	Heat sold in the market	Table with dimension [t,n].
Short-term	Ln	Heat bought in the market	Table with dimension [t,n].
Short-term	Pn	Heat net balance	Table with dimension [t,n].
Short-term	Social welfare	Social welfare per simulated time slot	One value per time slot. Table with dimension [t].
Short-term	QoE	Fairness indicator for each time slot	One value per time slot. Table with dimension [t].
Short-term	Market plot	Plot with merit order.	Figure retrieved from simulation output. Only available if the market design is the Pool.
Long-term	Gn	Heat sold in the market	Table with dimension [t,n].
Long-term	Ln	Heat bought in the market	Table with dimension [t,n].
Long-term	Pn	Heat net balance	Table with dimension [t,n].
Long-term	Agent operational cost	Operational cost per simulated time slot	Table with dimension [t,n]
Long-term	Social welfare	Social welfare per simulated time slot	One value per time slot. Table with dimension [t].
Long-term	Find the best price	Finds the best price an agent must offer to achieve higher revenue	One value.

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Long-term	QoE	Fairness indicator for each time slot	One value per time slot. Table with dimension [t].

4.3 Module Report Configuration

All the outputs of the module report and simulation summary report have been defined in the previous sections. So far, it is not expected that the user can change what outputs are presented in each report, concerning the MM.

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5 Module Development Timeline

The MM module was developed in various stages, starting with conceptualization, the different market designs operating isolated, then the short-term and long-term splitting, until the final implementation in the platform, integrated with other modules. A summary of the conducted activities and timeline (until M35) can be found in Figure 20. After that, the bulk of the work has been focused on the integration on the platform.

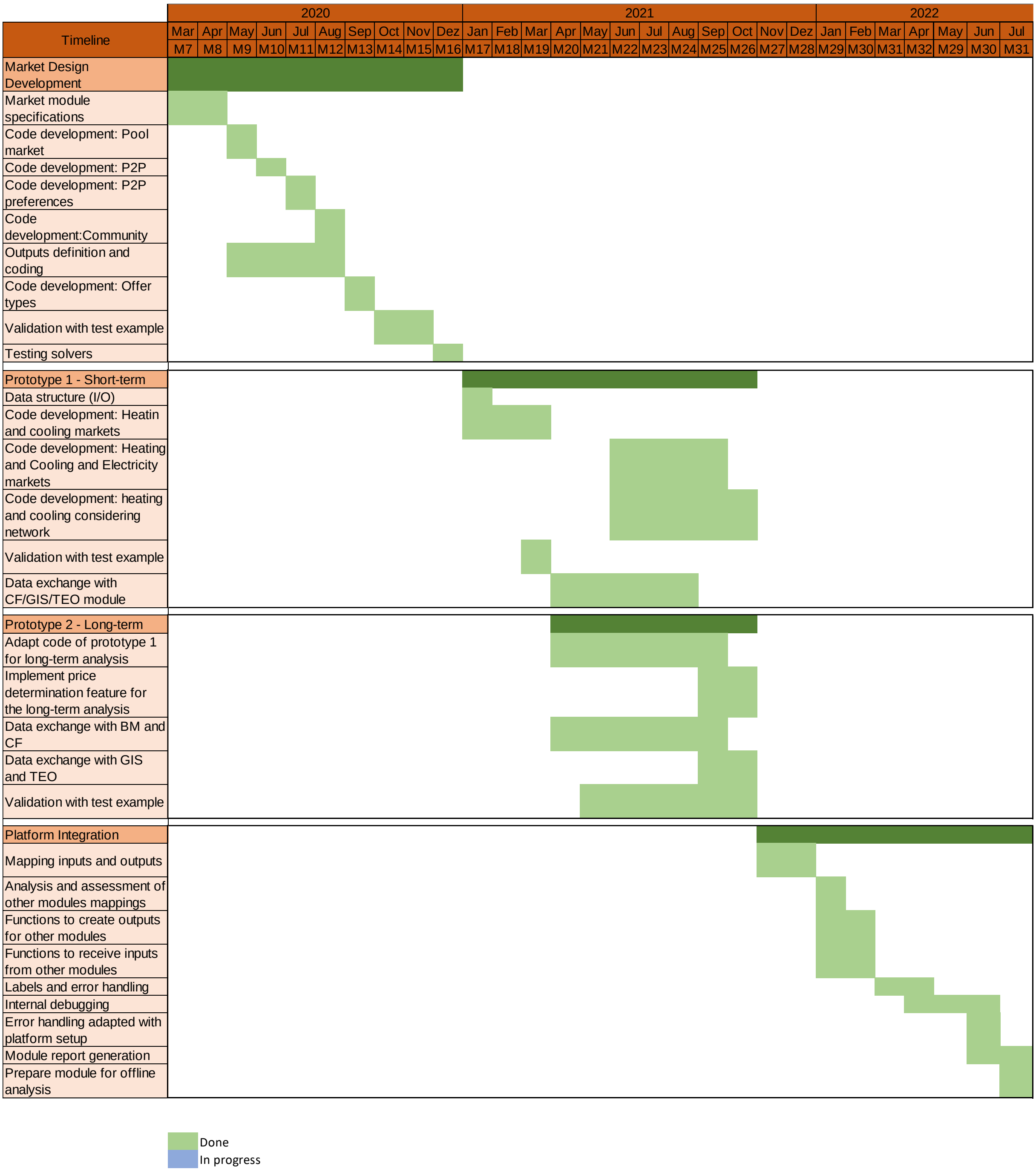

Figure 20 - Market module timeline.

In the first stage (Market Design Development), after the market specifications were defined, the coding process started by applying individually the different markets. So,

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the pool, P2P and community designs were developed jointly with the P2P preferences and the offer types. Afterwards, the expected results were also defined mathematically and computed. The code was tested and validated with a simple test example to check if all implementations were running accordingly. Finally, the possibility to use a free-solver was introduced, to ease the implementation process, which led to some adjustments in the code.

Then, (Prototype 1 – Short-term) a specific structure envisioning the platform integration, started to be developed with the definition of all required inputs and outputs. Some additional features were added to the previous developments, such as the inclusion of electricity markets and the physical network. These new features and the old ones were also tested with a small example under the new structure. Following this, the discussion with other modules started, trying to understand what would be the requirements and data exchange.

In the third stage (Prototype 2 – Long-term) the long-term developments started by adapting the code from the short-term. Some additional features were also implemented, such as finding the best price. The required information exchange was also considered in cooperation with the other modules. Here, also every feature was tested within a simple test case.

In the final stage (Platform integration) the inputs and outputs mappings have been defined, to ease the perception of other modules and the developers. The mappings from other modules were assessed to identify required changes and then the functions both to send and collect data were built. Labels to describe each parameter and error handling processes were established.

In addition, a platform-wide error handling procedure was established, which we also implemented in the market module, along with a report generation in HTML, which is returned once the full simulation is completed.

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6 Conclusions

This report summarises the work conducted in tasks 3.1 “Individual Module Development” and 3.3 “Modules and Common Platform Components Integration, Improvement and Validation” for the development and implementation of the MM. The work covers the definition of two manuals about the use and working principles of the MM to be incorporated into the EMB3Rs platform. The System Manual details the theoretical concepts and definitions behind the adopted energy market designs, while the User Manual provides a practical guide for the user to use the MM.

The System Manual describes all the theoretical background for each market design and analysis in order to support the user with sufficient knowledge of the implemented MM. More precisely, the concept and mathematical formulation of the Pool, P2P and Community market designs are detailed, as well as all the available options in the MM. The used optimisation models are specified, including their parameters, variables, constraints, and objective functions. The explanation of the expected outputs and KPIs for both short-term and long-term market analysis are also included, showing the use of such outcomes for the user. This manual also explains the value of the short-term and long-term market analysis for the user, depending on the settings and the user’s objectives for the assessment.

Complementarily, the User Manual provides a step-by-step guide for the user to learn how to use the MM. This guide contains all the inputs required for running the market optimisation processes, taking into account each option of the different market designs. In addition, it shows the available market options and preferences the user can select for both short-term and long-term analysis, as well as all the expected outputs from the MM. An illustrative test case is provided, allowing the user to test the MM.

For each market analysis, a MM report has been defined including all the outputs available for the defined market analysis. However, not all the market outputs are introduced in the simulation summary report, only the most representative of the market results are provided. Detailed outputs of the MM are provided in the MM report.

In short, this document provides the system and user manuals related to the MM, which include a full description of all MM features, as well as a guide to support users for operating the MM in the EMB3Rs platform. It also describes the outputs defined for the internal MM report and the simulation summary report of the platform, as well as the timeline of the MM developments.

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This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°847121