Market integration analysis of heat recovery under the EMB3Rs platform: An industrial park case in Greece

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***Abstract*—District heating is a system for distributing heat from a central source, such as a boiler plant or a combined heat and power plant, to multiple industries, buildings or homes within a defined geographic area. This system can use different energy sources, including fossil fuels, biomass, solar thermal, and geothermal energy, to provide customers with heating, hot water, and other services. In light of these benefits, this work aims to present a thorough study of a Greek industrial park case. The work is supported by the EMB3Rs platform that allows performing a feasibility analysis of the system. In particular, this work explores the market module of this platform to provide a detailed market analysis of energy exchange within the Greek industrial park. The results pinpoint the effectiveness of the platform in simulating different market designs, centralized and decentralized market designs, making it clear the potential benefit the sources in the test case may achieve by engaging in a market environment. Different options for market clearing are considered in the study, for instance, including CO_2 signals to reach carbon neutrality or community preferences to increase community autonomy. One can conclude that excess heat from existing sources is enough to cover other industries/facilities' heat demand, leading to environmental benefits as well as a fairer financial profits allocation.**

***Index Terms*—Thermal Market, P2P, EMB3Rs Platform, District Heating**

I. INTRODUCTION

Several studies have been conducted to improve efficiency and to show the effectiveness of District Heating & Cooling (DHC) systems. For example, the work in [1] predicts the short and long-term heating demand in nursing homes in the Nordic countries through linear regression and artificial neural networks. Based on the findings, the authors propose installing heat pumps in low-temperature District Heating (DH) to meet the load requirements. In contrast, the authors in [2] study the heat losses in a District Heating Network (DHN) in Wales according to the hours of operation. They found heat losses can be around 1-2% during day time and increase to 8-12% at night. In this methodology, pipe configurations like size and insulation materials are also mentioned. Differently, [3] optimizes a DH system accounting for computational burdens and trying to find ways to speed up the process. The authors replace the conventional mixed integer linear programming with merit order methods, considering the tricky CHP and heat storage modelling. The study states that it is possible to reduce up to 3 times the computational time, without loss of accuracy, using different merit order variants. Via the EnergyPRO software, a study assesses the replacement of a natural gas boiler with DH at Tallinn University [4]. It analyzes the connection to an already existing high-temperature DHN or a low-temperature energy cascade. Both solutions comprise a reduction by hundred tonnes of CO_2 just as losses reduction and efficiency improvement.

Like several industries, data centres can also play an important role in this field, as a high amount of excess heat is generated, due to high energy consumption patterns. Sorknæs *et al.* [5] specify the transition to the 4th generation DH, by lowering the network temperatures and increasing the synergies with other energy sectors. This study focuses on the Danish DHN, especially in the data centres and its cooling solutions. The authors claim this transaction could save more than 200 M€. Likewise, the authors in [6] also assess the data centres cooling systems (Cloud Computing Industrial Park) and the waste heat which can be provided by cooling water from the condenser of the power plant or returned chilled water from the data centres' cooling system.

Another major topic is legislation and the never-ending development of DH systems. The specific laws and regulations that apply to DH systems can vary depending on

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the country, region, or municipality in which the system is located. Werner *et al.* [7] reviews the DHC in Sweden including market, technical, supply, environmental, institutional and future contexts. The main findings pinpoint: (i) the higher use of district heating over a lower use of cooling, (ii) high supply through renewable and recycled resources and (iii) reduction of carbon footprint. In terms of institutional context, the Swedish government has played a significant role in promoting the development and expansion of DHC systems. This has included financial support for the development of new systems and the implementation of regulations and incentives to encourage the use of DHC. The fifth generation of DHC is proposed in [8], in which the models from thermal, fluids and control are developed under the Modelica language. Applied to the first Swedish DHN with heating and cooling demand as well as bidirectional energy flows, this model allows energy sharing between interconnected buildings, reducing the energy purchased and reducing energy losses.

Following the recent changes in DHC systems is market liberalization. This has also been on focus to bring extra benefits for those who are able to join it. For instance, the proposed market structure for DH systems in [9] aims to create an organizational framework that allows for the effective operation of the DH system by establishing clear roles and responsibilities for the various agents involved. The operator of the heat market acts as the central coordinating body responsible for managing the overall operation of the DH system. This includes overseeing the information system that connects the various agents, such as producers and consumers, and ensuring that the system is running efficiently. There may also be other agents involved in the market, such as intermediaries or operators who facilitate the buying and selling of heat, or regulatory agencies that oversee the operation of the market. [10] gives an overview of the centralised DH systems in Moldova. Similarly, [11] also proposes a market framework based on marginal cost pricing by allowing external producers to provide waste heat to the network, which would allow cost reduction and fuel savings if the proper business models were implemented. [12] explores the best frameworks to enhance competitiveness in DH. Likewise, the prices relative to consumers are also studied and can be lowered based on an opening market structure from the producer side.

In light of these, this work aims to provide a comprehensive study of an industrial park in Greece, by taking advantage of the EMB3Rs platform and its correlated modules. With real data and profiles from sources and sinks, an analysis is conducted to operate the DH in a decentralized manner and to show all the benefits it can bring. More precisely, this analysis follows the recent advances in the fifth generation DHC systems by operating the market and energy exchanges in a decentralized manner.

The rest of the manuscript is organized as follows: Section II describes the EMB3Rs platform and its functionalities; Section III details the Market Module (MM) of the EMB3Rs platform used to perform the simulations; Section IV describes the case study as well as the main findings of this work; and finally, Section V gathers the main conclusions.

II. EMB3RS PLATFORM

The EMB3Rs platform [13] is a valuable tool for evaluating the potential for reusing and trading waste heating and cooling in different contexts, including industrial processes and DHC systems. By simulating different supply-demand scenarios, network patterns and business and market models, the platform can help users and stakeholders understand the economic potential of investing in the recovery of waste heating and cooling as an energy resource.

It is important to consider the social, environmental, and economic impacts of waste heating and cooling recovery when evaluating its potential. In addition to the potential economic benefits, waste heating and cooling recovery can also help reduce greenhouse gas emissions and improve energy efficiency.

It is also important to consider the regulatory and market environment in which the waste heating and cooling recovery are taking place. The EMB3Rs platform's ability to simulate different market models for DHC systems under regulated, liberalized and decentralized market conditions can be particularly useful in this regard.

The five modules of the platform work together (Figure 1) to provide a comprehensive perspective on the potential for waste heating and cooling recovery in various contexts. The Core Functionalities (CF) module helps to identify potential sources and sinks of excess heating and cooling, as well as the costs associated with recovery and use. The Geographical Information System (GIS) module helps to identify and evaluate potential network solutions for connecting sources and sinks, taking into account factors such as losses, costs, network length, and installed pipe capacity. The Techno-Economic Optimization (TEO) module helps to identify the most cost-effective technologies for using excess heat, considering factors such as regulation, available heat, load profiles, and techno-economic characteristics of technologies. The Business Module (BM) is designed to consider different ownership structures and market frameworks and evaluate key metrics such as net present value, levelized cost of heat, and internal rate of return. The MM allows users to simulate current and future trends for the heating and cooling markets and assess the economic potential and environmental savings of their investments. By using the MM, users can choose the best market framework for their specific economic, environmental, and social interests, helping them to make informed decisions about their investments in waste heating and cooling recovery.

Overall, the EMB3Rs platform can be a useful tool for evaluating the potential for waste heating and cooling recovery and helping to inform decision-making about investments in this area.

III. MARKET MODULE

The primary function of the MM is to furnish a range of market configurations that are able to imitate real and

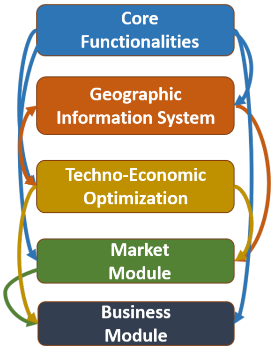

Fig. 1: Interactions between the different modules in the EMB3Rs platform.

prospective markets for DHC systems. Specifically, three different market structures are offered: (i) a Pool, (ii) a Peer-to-Peer, and (iii) a community-based structure. This enables users to simulate current and future market strategies (centralized and decentralized), and compare the results. In the EMB3Rs platform, the MM includes both short-term and long-term market analysis. Following the shift to liberalized markets to encourage competition, the MM has been furnished with a variety of market simulation choices for users. This includes the classic centralized pool market design and innovative market designs, namely consumer-centric markets (e.g., the peer-to-peer and community-based market designs).

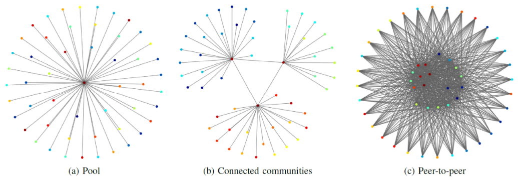
(a) Pool (b) Connected communities (c) Peer-to-peer

Fig. 2: Structure of the different market designs in the EMB3Rs platform [14].

Figure 2 represents the selected market design structures. In design (a), the Pool market, the central node represents the market operator who is responsible for managing the market. In design (b), the community-based market, there are 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 their energy community. The final design, which is fully decentralized (distributed), has no central nodes. This market design requires each agent to negotiate the price and energy of each transaction directly with the others. Each market has a distinct design that impacts the calculation of the market clearing price, the energy dispatch, and the settlement.

The MM requires some inputs from the user and other modules so, during the input data phase, the market requires all market participants (producers, consumers, and prosumers) to submit their offers (demand and production) for each time interval. The entire MM assumes that the market is cleared on an hourly basis. All offers include information about the anticipated amount of thermal energy that the player wants to buy or sell on the market, as well as a price. This price reflects the maximum cost the player is willing to pay in the case of a buying offer or the minimum price the agent is willing to accept in the case of a selling offer. The price in a buying offer is also known as the utility. In the market optimization stage, the market algorithms - the Pool, P2P, and community-based market designs - can be used to clear the market and find a solution to the problem. The market is then cleared every hour and the optimization returns the energy dispatched for each agent and the market clearing prices, which are used to calculate the settlement in the output stage. Further detail on MM mathematical formulations can be found in [14].

In addition, the short-term side of the MM also features some extensions as the network-awareness, to account for the network flows, and the electricity dependence, to generate CHP's bids based on the forecasted electricity price. Different types of offers are also allowed as the block offer, where an agent offers a quantity for more than a one-time slot and the market must respect it. It is like an all-or-nothing condition, which means it must be fully accepted or fully rejected. An energy budget feature is also allowed by fixing a specific load during a certain period, even with some load flexibility. For instance, a sink can meet some required load during the day, but with some flexibility from the market to dispatch when it suits best.

The two market simulation horizons are summarized in Figure 3 and are based on the following:

- The short-term analysis aims to simulate the market for a time horizon ranging from 1 hour to 48 hours (simulating up to two consecutive days). 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 short-term market analysis, the user can evaluate the market performance at a high level of detail. 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.
- The long-term analysis aims to simulate the market for extended time horizons, such as weeks, months, or years. It can capture seasonal effects, as well as the anticipated growth of heat consumption. 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 over the long-term horizon. The yearly revenue/cost and yearly successful energy dispatch per agent will be displayed. The user can then use these metrics in the BM to calculate the profit from specific waste heat technologies. Finally, the simulation can also identify the offering price that yields the best revenue for a particular producer. In this way, the impact of market power on market outcomes can be studied.

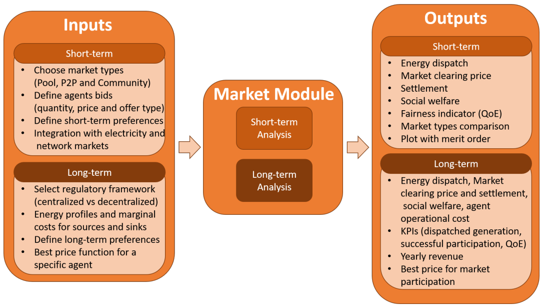

Fig. 3: Simplified overview of inputs and outputs for the MM, considering short-term and long-term market analysis.

IV. CASE STUDY

A. Case Description

Here, by taking advantage of the EMB3Rs platform and its modules, a detailed heat market analysis of an industrial park located in Northern Greece is provided. The case study comprises four sources (Stonemill, Polymers, BioIn, Iron&Steel) and 9 sinks (Beverage, Packaging, MilkCheese, Fisheye MUW, Fisheye Steam, Refricompany, Town Hot Water, Office Building, Tomatoes Greenhouse). Each source comprises two streams with different technologies. The Town Hot Water is in the village of Agios Georgios located approximately 5 km from the industrial park. The heat transfer of the excess heat of industrial sources is water and the heat produced will be used to directly cover the hot water needs of the industrial processes, the pre-heating needs of the make-up water of their steam boilers and also the hot water and heating needs of the village of Agios Georgios. In addition, the usual heat supplier is also considered to cover the demand in case of heat shortage from other sources. The network-related data as distances were retrieved from the GIS module and the CO_2 emissions were retrieved from the TEO module. The technologies, profiles and costs used in this case study are available at [15].

B. Main Results

Table I presents the results for a one-year simulation and shows the net balance and settlement for each market agent (positive for sources and negative for sinks). The settlement considers the market clearing price between each transaction and the energy dispatched in each time frame, which is then aggregated yearly.

Firstly, one can see the Heat Supplier does not participate in the market, which means that all other technologies are able to supply the demand of the industrial park, plus the Agios Georgios village. This is a great indicator, that in fact, liberalized markets and excess heat reuse can be a viable way forward. The dispatched load from the sinks is equal to the total demand in all market designs, indicating that no loss of comfort or stoppage in industrial processes occurs.

There are sources getting different dispatches based on the CO_2 emissions. For instance, Polymers' dispatch through the natural gas heat recovery boiler decreases and on the contrary the dispatch through excess heat increases, which means that the former is a higher CO_2 emitter. The Iron%Steel present exactly the opposite behaviour. In the remaining sources, no differences are noted, pinpointing the neutral and balance emissions between the technologies. Interestingly, the differences noted (compared with the Decentralized) are between the same sources but with different technologies, which present the same monetary bid, which means the penalty can differentiate between two technologies (with the same price) but is not enough to change the dispatch between sources (with different prices). Thus, by raising the penalty factor, different dispatches between sources could be observed.

A similar behaviour is found when looking at the Network Distance preference, where peers prioritize trading with the closest ones. Polymers and mainly Iron&Steel lose some market share since they are the farthest sources. With regard to the different technologies from the same source, the loss/gain in market share is proportional given the same location.

The settlement is calculated based on the market clearing price and energy dispatched, for each agent. The sources get the same revenue when comparing the decentralized and the CO_2 emissions because there are only exchanges in the technologies and not in the source. In the Network Distance, a higher penalty is considered and consequently the market clearing price increases too, which leads to settlement higher values.

Table II provides two indicators, related to market participation. Successful Participation in the Market (SPM) indicates the level of participation of one agent in the market (whether at its full capacity or not) and Average Dispatched Generation (ADG) indicates how much from the available capacity is dispatched on average. Further detail on these indicators can be found in [14]. Through the SPM indicator, it becomes clear the high dependence on Iron%Steel to cover the sinks demand, since it has a higher share over the year, except when considering the network distance and the higher penalties on this agent which makes the SPM from the excess heat technology to drop to 58,08%. However, with the ADG indicator, one can see that Iron%Steel participation is partial most of the time, i.e., a small amount of the total available capacity is used in the market (proved by the 34,91% and 27,96% participation in the network distance). This highlights the importance of this agent since it is the last in the merit order curve, however, the sinks resort to it most of the periods. Polymers is the agent with higher indicators, which is related to fairer and constant prices all year. Other agents present higher variations in prices depending on the seasonality, which leads to lower shares in the indicators around 50%, except for the network distance, since those agents take the place of the Iron&Steel for reasons previously clarified.

V. CONCLUSION

This work presented a market analysis in an industrial park in Greece. Using the EMB3Rs platform, it was possible to retrieve all required data to run and explore the effects of possible market liberalization in the industrial park. The

TABLE I: Net Balance and Settlement for all agents and market designs, for a full-year simulation.

Agent (Technology)/Market Design	Net Balance (kWh)			Settlement (€)		
	Decentralized	Decentralized CO_2 Emissions	Decentralized Network Distance	Decentralized	Decentralized CO_2 Emissions	Decentralized Network Distance
Grid (Natural Gas Boiler)	0	0	0	0	0	0
Stonemill (Multiple Heat Exchanger)	3088485	3088485	3088485	10344731	10344731	10385785
Polymers (Natural Gas Heat Recovery Boiler)	1738028	1737419	1737005	5830628	5828727	5854270
BioIn (Multiple Heat Exchanger)	131694	131694	131694	442492	442492	444092
IronSteel (Multiple Heat Exchanger)	4335606	4454115	4934160	14567634	14965826	16661560
Stonemill (Excess Heat)	3158954	3158954	3158954	10580762	10580762	10621778
Polymers (Excess Heat)	1735816	1736425	1736838	5823726	5825627	5853440
BioIn (Excess Heat)	131694	131694	131694	442492	442492	444620
IronSteel (Excess Heat)	3871992	3753482	3273437	13009891	12611700	11054216
Beverage (Single Heat Exchanger)	-150342	-150342	-150342	-505151	-505151	-507222
Packaging (Single Heat Exchanger)	-170519	-170519	-170519	-572947	-572947	-574828
MilkCheese (Single Heat Exchanger)	-412822	-412822	-412822	-1387078	-1387078	-1394267
Fisheye MUW (Single Heat Exchanger)	-2452800	-2452800	-2452800	-8228506	-8228506	-8264520
Fisheye Steam (Heat Pump)	-12264000	-12264000	-12264000	-41142528	-41142528	-41321342
Refricompany (Absorption Chiller)	-1044000	-1044000	-1044000	-3507840	-3507840	-3527773
Town Hot Water (Single Heat Exchanger)	-1022000	-1022000	-1022000	-3428544	-3428544	-3455752
Office Building (Single Heat Exchanger)	-188140	-188140	-188140	-632106	-632106	-633222
Office Building (Absorption Chiller)	-255776	-255776	-255776	-859138	-859138	-860869
Tomatoes Greenhouse (Single Heat Exchanger)	-231867	-231867	-231867	-778517	-778517	-779966

TABLE II: SPM and ADG for all agents and market designs, for a full-year simulation.

Agent (Technology)/Market Design	SPM (%)			ADG (%)		
	Decentralized	Decentralized CO_2 Emissions	Decentralized Network Distance	Decentralized	Decentralized CO_2 Emissions	Decentralized Network Distance
Grid (Natural Gas Boiler)	0	0	0	0	0	0
Stonemill (Multiple Heat Exchanger)	49,86	49,86	75,34	49,86	49,86	75,34
Polymers (Natural Gas Heat Recovery Boiler)	100	100	100	100	99,96	97,5
BioIn (Multiple Heat Exchanger)	50,14	50,14	67,95	50,14	50,14	67,95
IronSteel (Multiple Heat Exchanger)	97,81	94,79	99,73	53,17	54,62	34,91
Stonemill (Excess Heat)	49,86	49,86	75,34	49,86	49,86	73,57
Polymers (Excess Heat)	100	100	100	99,87	99,91	97,04
BioIn (Excess Heat)	50,14	50,14	67,95	50,14	50,14	67,95
IronSteel (Excess Heat)	78,63	76,71	58,08	47,48	46,03	27,96

results point to the successful implementation, proving that the industries are able to supply a fair share of the heat demand in the area. This brings benefits, not only to the environment but also to both sources and sinks, because the former can sell some waste heat, that otherwise would be lost and the latter can buy heat at cheaper prices. Conversely, the product differentiation mechanisms also allow for a decrease in the CO_2 emissions by 3% allowing sinks to opt for the low-emitter sources. The other option, related to the network distance can also play an important role as long as the peers trade with the closest ones, which reduces overall heat losses. Iron&Steel, which is the least preferable peer to trade using the distance, loses about 40% of the market share. In short, this study allowed conducting an analysis to prove the benefits of market-sharing resources in DH systems and the financial benefits they can bring. Future work will focus on the technical part of this type of implementation, not only by recurring and analysing the other EMB3Rs modules but also with further studies.

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