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Economic Evaluation for Peer-to-Peer Concept Through Decentralised Thermal Energy Distribution

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Supply chain planning of energy is vital and associated with the coordination and cooperation between the participating bodies, such as suppliers, logistics providers, distributors, and customers. The supply chain of heat networks in an integrated industrial area combines supply and demand management across the facilities. The implementation poses significant challenges due to supply chain complexity, uncertainty in variables, and space area limitation of suppliers. This study proposed a Peer-to-peer (P2P) approach to evaluate the economic analysis of solar thermal network configurations. The economic viability is assessed in terms of the levelised cost of heat (LCOH), including the cost for solar collectors and storage facilities required. The analysis is applied to an illustrative case study to compare optimal smart thermal networks for decentralised and centralised scenarios. The P2P scenario is more cost attractive because the LCOH is 72 MYR/MWh, which is lower than scenarios 1 and 2. The payback periods for all scenarios are over 14.5 y. The investment cost for decentralised system with a P2P concept is MYR 2,363,655, while the centralise system is more costly at MYR 8,075,822.

1. Introduction

The solar energy system that converts solar irradiation into heat can be an alternative energy source for industrial heating applications. The industry can install a solar thermal system for heat generation to reduce the utilisation of fossil fuels. The incorporation of solar thermal integration into industrial processes was analysed by Fuentes-Silva et al. (2020). The authors evaluated the cost of the solar collector network and the expenditures associated with thermal storage. Due to the high investment cost and restricted area available, some organisations may be hesitant to install the system and opt to receive thermal energy from other sources. The company that installed the system can self-consume the generated thermal from solar collectors. The surplus of heat thermal can be sold to meet others' demands through centralised storage systems. The decentralisation of heat thermal requires a systematic mechanism for buying and selling activities. The energy trading depends on the amount of daily heat generation by the solar collectors and the amount of self-consumption at the prosumer, the consumer's heating demand, the necessary temperature range required, and the company's geographical locations.
Several studies have been discussed the decentralisation of energy produced by solar energy. In solar photovoltaic (PV) technology, the excess generated electricity is fed into the transmission grid via a secure platform and sold to other facilities. The application of peer-to-peer (P2P) technology in microgrids with solar PV distributed generation was proposed and studied by Huang et al. (2017). The authors developed a simulation framework that comprised a customer load profile, PV system, battery energy storage devices, feed-in tariffs, and retail prices for a local community of 30 households. According to the study, P2P reduced household electricity costs while also bringing in significant income for prosumers. Langer (2020) modelled an illustrative P2P market with tariffs for residential buildings combined with electrical and thermal storage. The author analysed the cost- and discomfort-minimising behaviour and evaluated the current levy regime in Germany. P2P frameworks also have been introduced for electricity markets to address the requisites of a well-formatted decentralised market. For instance, Rao et al. (2020) proposed a framework named locality electricity trading

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system (LETS) for residential prosumers with renewable energy resources, while Etukudor et al. (2020) proposed a one-to-one automated negotiation framework for P2P local trading of electricity. However, most recent solar energy studies have concentrated on developing and implementing the decentralisation of solar photovoltaic (PV) technologies than solar thermal technologies. Therefore, the advancement of solar thermal systems necessitates introducing thermal energy trading and ways that allow local prosumers to choose their pricing strategies in heat markets simultaneously. Several scholars envision a similar structure for thermal energy markets in this regard. Cao et al. (2018) proposed a decentralised market framework, enabling energy transactions between district heating and power networks. A thermal energy transaction framework for managing transactions amongst small-scale heat prosumers for district heating systems was presented by Davoudi et al. (2021). However, these frameworks only enabled the transaction of district heating networks and did not consider the transactions between the integrated solar thermal system in the industry.

A typical integrated solar thermal system generally includes prosumer, consumer, and energy trader. The number and location of solar collectors, necessary storage capacities, demand, and distances all affect the costs of an integrated solar thermal networks supply chain. The optimal supply chain design is crucial, as a good design structure can considerably save investment and operational costs. An et al. (2021) developed a business feasibility evaluation model to estimate the ideal trading price of solar PV-generated power, maximising market players' earnings in P2P electricity trading. The optimisation of heat thermal trading for solar thermal heating networks also plays an essential role in ensuring the price is affordable to the consumer while the prosumer's heat demand is not interrupted. In addition, the government can support the P2P thermal energy market to accelerate solar thermal utilisation with suitable incentives and policies. Sing et al. (2018) evaluated the trade-off between solar utility temperature and solar collector efficiency. The authors also studied the efficiency and economic feasibility of the proposed system. Presently, no detailed study of a financial mechanism for energy trading for heat thermal generation and distribution from multiple solar thermal plants for the industry is performed. Therefore, an economic analysis using a P2P concept for the solar thermal energy trading model will be proposed and further developed to bridge the gap.

This study discussed a peer-to-peer (P2P) method for assessing the economics of solar thermal network configurations. based on decentralise and centralise scenarios. The approach would address the gaps in managing transactions between prosumer and consumer in thermal energy trading. The optimal configurations were determined based on levelised cost of heat (LCOH) and the cost of solar collectors and storage tanks installation in both scenarios for integrated solar thermal networks. The analysis is illustrated by a case study that requires a continuous hot water supply for the process.

2. Problem identification

In the conventional solar thermal system, prosumer generated thermal heat self-sufficiency for at own facility. Thermal self-sufficiency is the proportion of total demand in an industry met by locally generated heat from a solar thermal system. However, some industries have unsuitable roof conditions and area limitation constraints to install solar collectors and need to consider purchasing heat thermal from renewable alternatives from centralised heat thermal providers. The decentralisation of heat supply from centralised thermal storage to different heat demands can be met in an integrated solar thermal system by combining multiple sources. Rashid et al., 2019 indicated that a flexible heat integration is essential to ensure the ability to deliver heat at various temperature ranges. In addition, the future utilisation of solar thermal in industrial processes requires the application of automatic and intelligent systems with relatively low investment, maintenance and operating costs (Scolan et al., 2020). The system description and energy trading process consist of the supply sides (prosumer), demand-side (consumer), thermal energy storage (TES) and the distribution network boundary. The heat generated from prosumer, can be used for self-sufficiency. The surplus is stored in the TES before being transferred to the peer to reduce total costs and increase profit while reducing GHG. For prosumers, when its consumption is greater than its generation, a prosumer buys the deficit heat from other peer. In this regard, the prosumer can be a customer too if it requires extra heat. These factors have been the driving force to determine the optimal configurations for thermal energy trading. Different ownerships are available in each of these boundary circumstances, resulting in a plethora of possibilities and uncertainties in the practical integrated thermal networks. The supply-demand imbalances issues can be mitigated by implementing an optimisation action plan via centralised or decentralised solar thermal systems. Integrated solar thermal systems are typically complex and challenging to solve; thus, optimisation of the P2P concept based on solar thermal design and economic analysis is recommended to determine the ideal configuration.

3. Economic evaluation for centralised or decentralised solar thermal systems

In this study, the economic analysis for the integrated solar thermal networks consists of two main parts, which are technical design and economic assessment. Several parameters were determined to synthesise an ideal solar thermal network, including energy demand and the associate costs. In order to address the complex problem, various assumptions and simplifications were made. The demand temperature is assumed to be the same, and the daily energy demand load profile has a consistent trend throughout the year. The study also considers 5 % heat loss in the solar collector loop. For simplification, the distance, heat loss during storage and piping network was not considered. Furthermore, the expense of pipe networks was not taken into account. The methodology used in the study is shown in Figure 1.

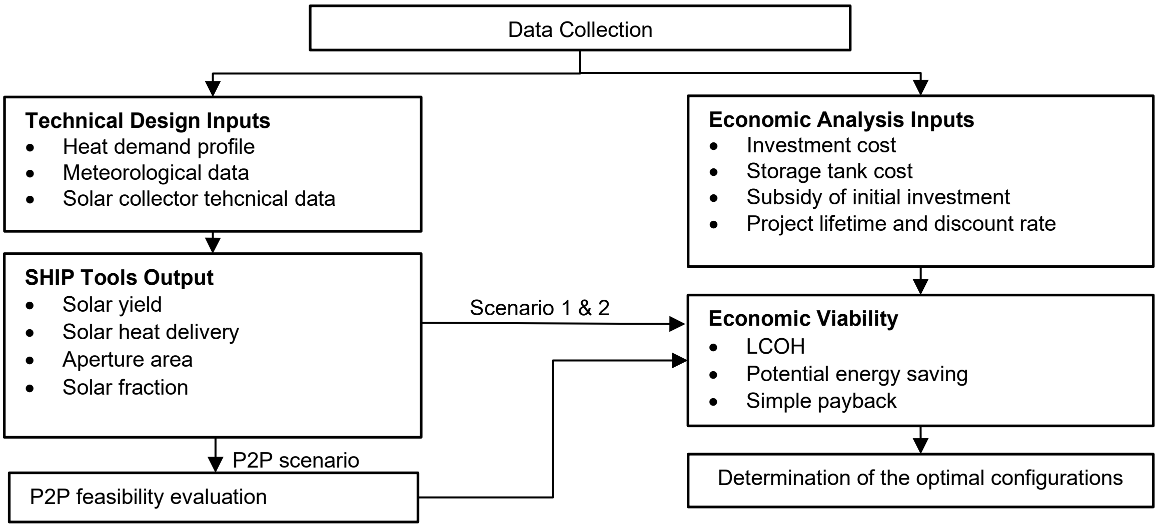

Figure 1: The methodology for the economic viability analysis

3.1 Establishment of data

The meteorological, solar collector information and heat demand profile database were established in this study for technical design inputs data. First, the meteorological data, including the daily solar radiation atmospheric and solar collector information, was collected to predict the solar collector's heat generation. The inclination for the solar collector is assumed at 10 °. Next, the demand information is collected.

3.2 Estimation of heat generation

The SHIP Tools developed by AEE - Institute for Sustainable Technologies will simulate annual energy gains. The tool designs and analyses solar heat in industrial processes and calculates annual costs based on climate and hourly demand. The thermal heat generation was determined based on the meteorological and solar collector information mentioned in Section 3.1. In addition, several additional assumptions have been made. This paper assumed the location for solar collectors is installed in the same area. Therefore, regional factor was not considered.

3.3 Economic analysis

This study also used SHIP Tools to calculate the LCOH, which determined the minimal heat thermal trading price to ensure profit to energy consumers. The LCOH is calculated by dividing all expenditures paid over the solar collector's life cycle by the total heat generated by the solar collector in Eq(1).

$$LCOH = \frac{I_c - S_o + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t} - \frac{RV}{(1+i)^n}}{\sum_{t=1}^{n} \frac{M_{th}}{(1+r)^t}} \quad (1)$$

where I_c stands for the investment cost, A_t for the annual operating cost in year y, RV for the residual value of the investment, M_{th} stands for substituted energy, r for the yearly reduction of yield, *i* for discount rate the annual heat thermal generation of the solar collector in year and *t* for the service life of the solar collector. Meanwhile, the storage cost was calculated based on horizontal vessel cost calculation from Seider et al. (2019).

3.4 P2P feasibility evaluation

For the P2P scenario, the hourly solar yield can be determined from SHIP Tools for each plant base and time period. The hourly process demand is then evaluated. After self-consumption, the calculated solar surplus for all plants can be defined as Eq(2).

$$Excess\ solar\ heat = Solar\ yield - Process\ demand \quad (2)$$

The amount of solar surplus shall be evaluated to identify possible heat transfer to peers. The decision making is carried out based on the highest percentage of possible heat transfer to a peer.

4. Case study

The proposed economic analysis methodology is applied to solar thermal systems based on three types of thermal energy trading: conventional (scenario 1) and centralisation (scenario 2), and decentralisation (scenario 3) as illustrated in Figure 2. Scenario 1 consists of three plants with individual solar thermal facilities. In scenario 2, the heat was supply to TES and managed by a third party (energy trader), while the energy flow in this scenario 3 is unidirectional. The total amount of heat thermal that can be supplied to other plants is determined and compared with scenario 2. All plants have an existing backup thermal energy supply from fossil fuels and require heat demand temperature to heat the process from 60 °C to 85 °C.

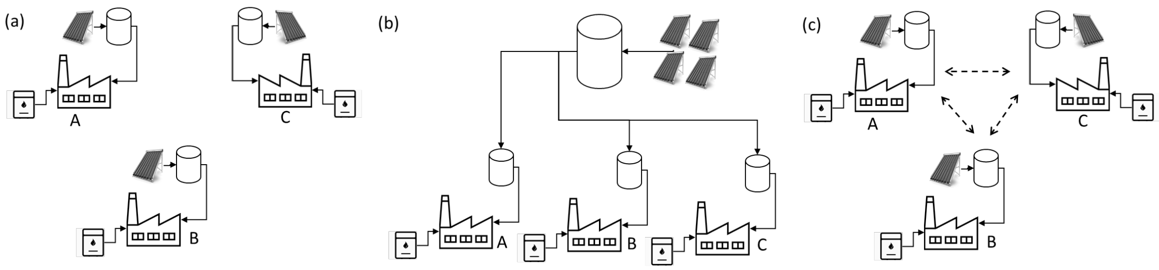

Figure 2: Scenarios for the types of thermal energy trading (a) conventional (b) centralisation and (c) decentralisation (P2P)

4.1 Inputs profile and simulation parameters setting

The energy simulation software SHIP tools was used to estimate the investment cost. The tool analyses solar heat in the industrial process and determines the yearly economic analysis of the proposed design based on the climate and hourly process demand. The solar irradiation profile used in this case study was obtained from Photovoltaic Geographical Information System (PVGIS). The location was set to Johor Bahru, Malaysia, and the ambient temperature used was 30 °C. From the solar irradiation profile, solar collector efficiency and solar collector output are calculated. The type of solar collector chosen was Arcon HT-SA 28/10. The detailed parameters are listed in Table 1. Figure 3 shows the daily thermal energy demand trend that the solar collectors in the decentralised system and has been used to calculate the demand for the centralised system.

Table 1: Simulation inputs data in SHIP Tools

Parameter	Process demand (kWh)	Mass flow (kg/s)	Daily operation hours (h/d)
Scenario 1: Plant A	445	4.24	8
Scenario 1: Plant B	250	2.38	24
Scenario 1: Plant C	620	5.90	16
Scenario 2	1,315	12.52	24

4.2 Economic evaluation

The solar collector price varies with different solar collector types. This study sets solar collector prices to 1,612 MYR/m².gross for flat plate collectors (FPC). The capital cost of solar collectors is calculated by multiplying the collector field size and corresponding solar collector price per area based on the known solar collector field size. Calculation of storage is based on only one day of thermal energy required to be stored. The discount rate is 3 %, the project lifetime (21 y), and the subsidy of initial investment is assumed to be 20 % of the investment.

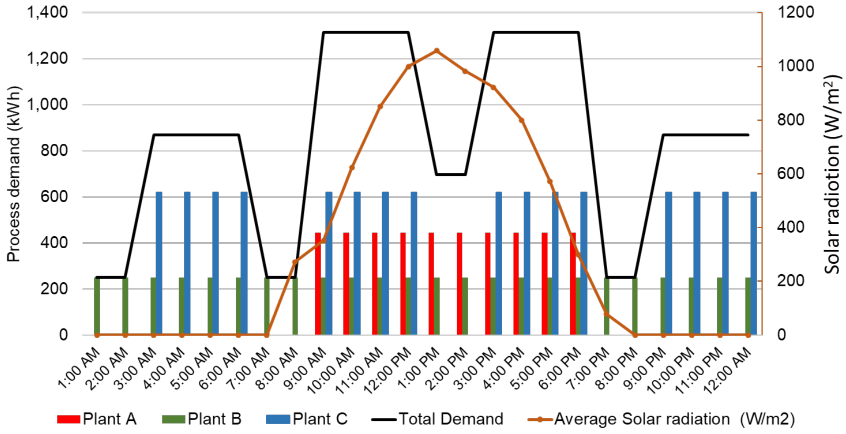

Figure 3: Solar irradiation and process demand for all plant

5. Results and discussion

Table 2 shows the evaluation of the solar collector output for scenarios 1 and 2. By evaluating the demand and area of each plant in scenario 1, the aperture area and gross area can be determined. The solar fraction for both scenarios is 52 % and the storage volume required in scenario 1 is 1.18 m^3 for Plant A, 57.80 m^3 (Plant B) and 57.11 m^3 (Plant C). For scenario 2, a higher storage tank (161.15 m^3) is required to fulfil plant A, B and C. Based on the design specification, the investment cost is given in Table 3, which scenario 2 is higher than scenario 1. The LCOH for scenario 2 is 81.2 kWh/m²y, while the LCOH for scenario 1 is in the range of 80 - 86 kWh/m²y. The LCOH for scenario 2 is slightly higher due to the higher installed gross area to fulfil the total demand, while plants A and C in scenario 1 have lower LCOH due to area limitations. The payback period for both scenarios is over 15 y.

Table 2: Results of technical specification for solar collector output and storage

	Unit	Scenario 1 (A)	Scenario 1 (B)	Scenario 1(C)	Scenario 2
Solar yield	MWh/y	605	1,211	1,513	4,136
Solar heat delivery	MWh/y	566	1,130	1,417	3,872
Installed aperture area	m²aperture	676	1,352	1,690	4,620
Installed gross area	m²gross	733	1,466	1,832	5,007
Installed storage volume	m³	1.18	57.80	57.11	161.15

Table 3: Results of economic evaluation

	Unit	Scenario 1 (A)	Scenario 1 (B)	Scenario 1 (C)	Scenario 2
Investment costs	MYR	1,181,828	2,363,655	2,954,569	8,075,822
Storage installation cost	MYR	96,450	499,949	499,949	824,544
Annual final energy savings	kWh/m².y	77,774	156,857	198,380	532,343
Simple payback	MWh/y	14.8	16.8	15.8	15.06
LCOH	kWh/m².y	80	86	80	81.2

An evaluation was conducted for a P2P scenario based on an hourly basis as solar heat depends on time per day. As shown in Table 4, the solar yield for plant B is 9,384 kWh/d is higher than other plants because the solar collector area is larger. Thus, it has a huge solar surplus (6,840 kWh/d). The solar fraction for all plants is between 40 – 44 %, obtained by dividing the solar heat delivery over daily demand.

Table 4: P2P analysis based on hourly basis energy demand

Parameter	Daily demand (kWh/d)	Solar yield (kWh/d)	Solar heat delivery (kWh/d)	Solar fraction (%)	Solar surplus (kWh/d)
Plant A	4,452	3,128	1,946	44	1,182
Plant B	5,998	9,384	2,543	42	6,840
Plant C	9,912	7,820	3,973	40	3,847

By matching hourly solar surplus with the daily demand of the P2P scenario, plant A can get 3,513 kWh/d from plant B, which can fulfil 79 % of its demand or 2,270 kWh/d from plant C (51 %) as shown in Table 5. Plant A has better options to purchase heat from plant B or C compared than own solar thermal system (44 %). Plant C can install the solar system or purchase from plant B with a slightly lower solar yield (34 %). If plants A and C are interested in purchasing from plant B, only 3,336 kWh/d can be transferred to plant C to fulfil 34 % of its demand. From the remaining solar surplus of 3,504 kWh/d, only 2,078 kWh/d can be transferred to plant A to satisfy 47 % of its demand. For this scenario, only plant B can install the solar thermal system with a capital investment of MYR 2,363,655 for plants A and B via the P2P concept with LCOH of 72 MYR/MWh.

Table 5: Matrix of feasibility P2P matching percentage based on solar thermal sources

Variable (%)	Peer A	Peer B	Peer C
Plant A	-	79	51
Plant B	19	-	26
Plant C	11	34	-

6. Conclusions

The economic analysis for two solar thermal network configurations, centralised and decentralised through the P2P concept, has been examined. The comparison is performed to an illustrative case study to compare optimal thermal networks from decentralise and centralise scenarios based on LCOH and the area required for solar collector installation. The LCOH for the P2P scenario (72 MYR/MWh) is lower than scenarios 1 and 2. The investment cost for decentralised system with a P2P concept is MYR 2,363,655 with (39 % solar fraction), while the centralise system is more costly at MYR 8,075,822 (52 % solar fraction). For future studies, the proposed integrated solar thermal systems can be extended using P2P interactions in both scenarios to address the financial mechanism to determine the optimal trading price at a larger distribution level.

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