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Exploring New Ideas to Promote and Improve Geothermal Direct Use in Indonesia

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ABSTRACT

Geothermal energy can be utilized for other direct use applications such as bathing, heating, drying agriculture products, and tourism objects. As one of the countries with vast geothermal energy potential, Indonesia can take advantage of its geothermal energy resources for both indirect and direct use. Unfortunately, geothermal direct use application in Indonesia is currently under-utilized compared to its geothermal potential and still behind some other countries.

The purpose of this study is to summarize and discuss the current geothermal direct use applications in Indonesia, whether it is established facilities (i.e., thermal bathing in Cipanas or coconut drying in Way Ratai) or facilities that are still undergoing construction and development (Lahendong Geothermal Edu Park, etc.) through literature review and interviews. The discussion will cover several aspects, such as the direct-use application, facilities' impact on various stakeholders, operation duration, and any identified challenges.

The summary is then compared with worldwide applications to seek any potential room for improvement or generate new ideas that might be applicable in Indonesia. These new ideas are then analyzed and ranked using a simple decision analysis tool. Finally, this paper is expected to provide a thorough summary of various geothermal direct use facilities around the world and demonstrates the possibilities of similar application and improvement in Indonesia's geothermal fields. The Multiple Criteria Decision Analysis (MCDA) is used in this study for decision-making. The results show that coffee and rice drying are the best direct use facility ideas to implement in Indonesia.

1. INTRODUCTION

1.1 Geothermal Energy Development in Indonesia

Located in The Ring of Fire, Indonesia has up to 23.357 GW of geothermal potential, where the most significant probable reserve of around 3.26 GW is identified in Sumatra Island. In early 2022, the utilization of geothermal for power generation in Indonesia is still at 2,286.05 MW, which is only 9,61% of the total potential (EBTKE, 2022). As stated in the RUPTL PLN document in 2021, to increase the geothermal energy portion in Indonesia's energy mix, the Government of Indonesia with PT PLN currently aims to achieve the 5,799 MW target in 2030 for installed capacity by geothermal energy (PLN, 2021).

With its exceptional geothermal energy potential, Indonesia can take advantage of its geothermal energy resources for indirect and direct use. Although Indonesia is amongst the leading world producers of geothermal for power generation, unfortunately, compared with other countries, geothermal direct use application in Indonesia is currently under-utilized. Out of 88 countries listed in the previous research by Lund et al. (2021), Indonesia is still in rank 74 worldwide for geothermal direct utilization and is still far from other countries (Figure 1).

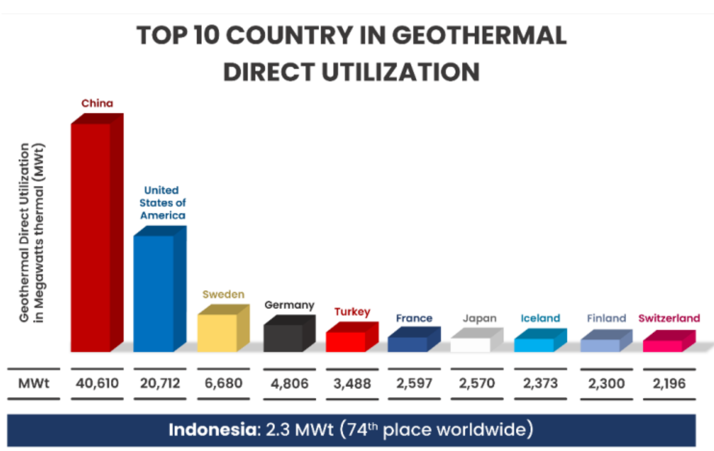


Figure 1: Worldwide leaders in geothermal direct utilization (modified from Lund, J. W. & Toth, A. N., 2021)

1.2 Why is Direct Use Important?

Geothermal energy plays an essential role in transforming sustainable energy systems. It has relatively low carbon emissions and can contribute to energy security (Shortall and Kharrazi, 2017). Geothermal energy was initially utilized directly from the source or called direct use (Alhamid *et al.*, 2015). Direct use is one of the most common forms and the oldest geothermal energy utilization (Lund, 2020). Developing direct use is not only about making investments but also empowering local communities and developers as geothermal entrepreneurs, as well as building awareness through proofs of concept (Murillo, 2021).

Obtaining agreement or acceptance from local people living in the project area is essential for geothermal energy utilization in the future (Cataldi, 2001). However, community rejection is still an issue in Indonesia's geothermal development, especially in the early exploration phase. Direct use can give the local people early understanding and awareness of how geothermal energy exploitation works. It can also stimulate economic development by involving local people in the operation of direct use facilities and opening geothermal tourism objects. Thus, creating a geothermal direct use facility can be an alternative way to engage with the local community and minimize public acceptance issues (Adityatama et al., 2019).

From a geothermal developer's point of view, direct use may contribute to maximizing the utilization of fluids as social responsibility, industrial approach with other investors or organizations that seek alternative energy to minimize environmental issues through geothermal direct use. In Indonesia, PT Pertamina Geothermal Energy (PGE) collaborated with Masarang Foundation to build a large-scale direct use facility for a palm sugar factory (Ardialim, 2021). PGE, along with BPPT and PTP Nusantara VIII, are also involved in the direct use facility for Malabar Tea Factory in Pengalengan, West Java (Suyanto, 2010). PT Geo Dipa Energi is also eager to study several opportunities about the direct use application, especially in Dieng. Hence, Indonesia needs to properly develop its geothermal direct utilization because it has many benefits for local people, developers, and other stakeholders.

1.3 Research Objectives and Methods

Through literature review and interviews, the purposes of this study are:

1. To summarize and discuss the current geothermal direct use applications in Indonesia, whether it is already established facilities (i.e., thermal bathing in Cipanas or coconut drying in Way Ratai) or facilities that still undergo construction and development (Lahendong Geothermal Edu Park, etc.). The discussion will cover several aspects, such as the direct-use application, facilities' impact on various stakeholders, operation duration, and any identified challenges.
2. To compare the summary with worldwide applications to seek any potential room for improvement or generate new ideas that might be applicable in Indonesia. These new ideas are then analyzed and ranked using a simple decision analysis tool.

Finally, this paper is expected to provide a thorough summary of various geothermal direct use facilities around the world and demonstrates the possibilities of similar application and improvement in various geothermal fields in Indonesia.

2. INDONESIA REGULATION GOVERNING GEOTHERMAL DIRECT USE

According to the Geothermal Law (Law No. 21/2014) mentioned in Table 1, geothermal energy needs to be developed for direct use, but its implementation in Indonesia is still deficient. The geothermal energy direct use applications can contribute significantly to the Government's energy diversification program and fossil fuel substitution, as well as increase the life standard of the local communities. Therefore, local governments have started identifying the direct use potential in major geothermal working areas in Indonesia (EBTKE, 2022). Table 1 shows the regulations that have become the basis of geothermal direct use business in Indonesia. It should be noted that each regulation does not eliminate each other but complements each other related to the direct use of geothermal energy.

Table 1: Geothermal direct use regulations in Indonesia

No.	Regulation	Year	Brief description of direct use
1	Law of the Republic of Indonesia No. 21 of 2014 about Geothermal (the Geothermal Law)	2014	The law establishes the principles of geothermal energy activities as follows: a. benefits; b. efficiency; c. justice; d. economic optimization in the utilization of energy resources; e. affordability; f. sustainable; g. independence; h. security and safety; and i. preservation of the environment. It also addresses the rights and obligations, licenses, and permits to regulate the use of geothermal energy. The focus is on environmental aspects and the involvement of local communities. The concept is local Government has authority to operate and manage the direct use of geothermal resources, while the central Government retains such jurisdiction for the indirect use of geothermal resources (Ministry of Maritime Affairs and Fisheries, 2020; Law of the Republic of Indonesia, 2014)

No.	Regulation	Year	Brief description of direct use
2	The Indonesian Government enacted Law No. 11 of 2020 regarding Jobs Creation (Omnibus Law)	2020	The Omnibus Law amends various provisions across numerous sectors, including amending 29 provisions and removing six provisions in Law No. 21 of 2014 regarding Geothermal (the "Geothermal Law"). Key changes: - Centralizing the direct use of geothermal resources and removal of permits in the form of *Izin Pemanfaatan Langsung* (IPL) - Removing the Production Fee for the Direct Use of Geothermal Resources - No Separate License for Indirect Geothermal Use in Water Conservation Areas - Criminal Provisions Under the Omnibus Law Output: The Omnibus Law focuses on business activities related to the direct use of geothermal resources. It gives the central Government the power to control the authorities granted to local governments. The Omnibus Law also seeks to encourage investment in the direct use geothermal sector by scrapping the production fee for the direct use of geothermal resources. The Omnibus Law eliminates the dual licensing regime in water conservation areas for indirect geothermal activities. But it will be necessary to monitor further implementation regulations for Omnibus Law closely. (EBTKE, 2022; Conventuslaw, 2020; SSEK, 2020)
3	Government Regulation No. 5 of 2021 regarding Implementation of Risk-Based Business Licensing	2021	This law regulate about regional otonomy related of direct use business with their respective administrative sanction. Every company that conducting geothermal exploitation business activities for direct use that violates the provisions on occupational safety and health, environmental protection and management, and/or regional taxes and levies shall be subject to administrative sanctions in the form of: written warning, temporary suspension of all geothermal business activities for direct use; and/or revocation of business license.
4	Minister of Energy and Mineral Resources Regulation No. 5 of 2021 regarding Standards for Business Activities and Products in the Implementation of Risk-Based Business Licensing in the Energy and Mineral Resources Sector	2021	This law regulates related to geothermal business licensing standards for direct utilization with KBLI licensing at the relevant ministries/institutions, general business requirements in the form of SLO, as well as procedures for obtaining SLO. Special Requirements or Technical Requirements for Products, Processes, and/or Services in the form of technical classifications of taking geothermal energy for direct use, equipment standards based on energy producing sources, competency standards for human resources, as well as the minimum facilities that must be met in taking geothermal energy for Direct Utilization based on the source of energy extraction, This regulation also stipulates conformity assessment and supervision of operational standards for geothermal energy extraction for Direct Utilization carried out by the Directorate General in charge of geothermal affairs and/or Regional Apparatus Work Units in charge of geothermal affairs for direct utilization in accordance with their respective authorities. This regulation also explains the Intake of geothermal energy for direct use is grouped based on the technique and method of taking geothermal energy

3. GEOTHERMAL DIRECT USE IN INDONESIA

3.1 Current Geothermal Direct Use Applications in Indonesia

Natural hot springs in Indonesia have been used for swimming pools, medication, and other purposes (Lund & Toth, 2021). One of the oldest geothermal direct use facilities is the Hot Spring Resort in Cipanas and Ciater, established around 1970. Not for tourism, Indonesia also has geothermal direct use facilities for industrial applications such as mushroom cultivation and tea drying in Pengalengan, coconut (copra) drying in Way Ratai, and palm sugar processing in Lahendong, as shown in Table 2. Currently, the agricultural product seems to have to most potential since most of the geothermal natural resources in Indonesia are in the highlands. But there is a geothermal direct use facility for aquacultural cultivation in Way Ratai, Lampung, where they grow catfish in a mixture of geothermal fluid and freshwater (Surana et al., 2010). There is also a facility for educational purposes that is not established yet and still facing some issues, which is the Lahendong Geothermal Education Park. Objectives for each of the current geothermal direct use facilities in Indonesia and their challenges are presented in Table 2.

Table 2: Geothermal direct use facilities in Indonesia

No.	Facility Name	Location and year established	Sector impacted	Brief description of the facility's objectives	Challenges	References
1.	Lahendong Geothermal Education Park	Tomohon, North Sulawesi (undergoing construction and development)	Tourism and Education	Educate about geothermal science, appreciate the indigenous folklores behind them, and introduce the role of geothermal for sustainable energy.	Lack of public support and the government's role is not optimal.	(Roeroe et al., 2015)
2.	Kampung Sumber Alam (KSA) Hot Spring Resort	Cipanas, West Java (1970)	Tourism and Balneology	Recreational lodging facility in the form of a hot spring resort with concept of Sundanese culture.	Demands of customers keep changing; competition has become fiercer due to many other resorts established in Cipanas.	(Pratama and Wibowo, 2012)
3.	Sari Ater Hotel and Resort	Ciater, Subang, West Java (1974)	Tourism and Balneology	Prevention and healing of various skin diseases using natural hot springs. There are also other facilities such as restaurants and hotels	Accessibility to Subang is getting less convenient in terms of transportation because traffic jams often occur.	(Sulistiana et al., 2019); (Susanto et al., 2019)
4.	Sipoholon Thermal Bathing	North Tapanuli, South Sumatra (1980)	Tourism and Balneology	This natural tourist attraction was formed by the eruption of Mount Marimbang, which contains sulfur. Many visitors believe that the content can be used to cure various diseases. In addition to treatment, this bath is also often used as a place to take pictures.	The owners feel less attention from the government because there is no financial support or socialization on improving their baths and increasing visitors.	(Marpaung, 2019)

No.	Facility Name	Location and year established	Sector impacted	Brief description of the facility's objectives	Challenges	References
5.	Mushroom cultivation	Pengalengan, West Java (1999)	Agriculture	Replace the need for LPG gas in mushroom growing media sterilization process and increase the local community's welfare by selling the mushroom.	Difficulty in acquiring land, the distance of geothermal resource from product to be processed, and post-harvest product handling.	(Fadli et al., 2015); (Surana, et al., 2010); (Sumotarto, 2001)
6.	Coconut Drying	Way Ratai, South Lampung (Pilot Plant by BPPT, 2003 and 2008)	Agriculture	Dry coconuts into copra using geothermal to prevent smoke contamination and increase its quality.	The utilization of a downhole heat exchanger could be a concern because the unit price is relatively high.	(Roeroe et al., 2013); (Surana et al., 2010)
7.	Tea Weathering and Drying	Malabar Tea Factory, Pengalengan, West Java (2010)	Agriculture	Drying tea leaves using hot brine replaces Industrial Diesel Oil (IDO).	The average value of SSI is 1.40, so silica scaling might occurs (SSI > 1). Smaller-scale industries might face a problem with the utilization of heat exchangers because of their cost. Malabar Tea Factory needs 4 heat exchangers for 5 drying machines.	(Suyanto et al., 2010)
8.	Catfish Growing	Way Ratai, Lampung (2010)	Aquaculture	Grow large catfish in the geothermal fluid and freshwater mixture.	Although it is reported that the fishes have grown better, the geothermal water composition might change at a particular time due to natural causes and affect the fishes.	(Surana et al., 2010); (Lund, 2020)
9.	Palm Sugar Processing	Lahendong, North Sulawesi (2006)	Agriculture	Utilize steam waste heat from the power plant through the exhaust pipes for crystal palm sugar production	A decrease in brine and steam pressure leads to palm sugar production decline. The operation was suspended due to this issue. Brine quality tends to contain silicate and cause scaling on pipes.	(Roeroe, et al., 2013); (Darma et al., 2021); (Sambodho, 2021)
10.	Space Heating	Patuha Field, West Java (2010)	Tourism	The heated fresh steam from a steam generator is utilized for space heating to keep the incubation room warm.	The need for space heating in Indonesia is minimal since it is tropical.	(Surana et al., 2010)

No.	Facility Name	Location and year established	Sector impacted	Brief description of the facility's objectives	Challenges	References
11.	Darajat Pass	Darajat Field, West Java	Tourism	The heated freshwater flows to the water boom and area hotel.	Needs more improvement to attract more visitors in the future	(Geo Dipa Energi, 2022)

3.2 Geothermal Direct Use Proposed Ideas

Besides the existing direct utilization facilities, some research papers proposed ideas for direct use that have not been implemented yet in Indonesia or globally. The description for each direct used proposed idea and its challenges is presented in Table 3.

Table 3: Geothermal direct use proposed ideas

No.	Proposed idea / concept	Sector impacted	Brief description of the facility's objectives	Challenges	References
1.	Making candles	Manufacture	Melting the paraffin using geothermal heat for making candles.	The cost of a heat exchanger might not be feasible for small-scale industries.	(Cuadra, 2021)
2.	Aquaponics system	Aquaculture and Agriculture	Aquaponics is a farming system that integrates aquaculture and hydroponic cultivation — the greenhouse uses geothermal heat to reach an optimum temperature for the plants to grow, and the fish farm utilizes residual geothermal heat supplied by the greenhouse.	The fishes and plants need specific temperatures for maximum growth. However, maintaining the temperature from a geothermal well or manifestation without a heat exchanger might be challenging.	(Bodejin et al., 2021)
3.	Extracting Cajuput Oils	Manufacture	The residual geothermal heat in the form of brine is used as an alternative to extract eucalyptus oil on a small scale.	The brine contains sulfur and other chemicals that can contaminate cajuput oil so that it cannot be flashed and need a heat exchanger. The cost of a heat exchanger might not be feasible for small-scale industries.	(Hendrasakti et al., 2022)
4.	COVID-19 Vaccine Cold Storage Box	Medicine	The vaccine cold storage box uses absorptive refrigeration, utilizing geothermal brine for desorber power.	If the distance between a heat source and the cold storage location is too far, it will increase the capital cost and cause heat loss.	(Hendrasakti et al., 2022)

No.	Proposed idea / concept	Sector impacted	Brief description of the facility's objectives	Challenges	References
5.	Plastic Recycle Program	Environmental	PT Geo Dipa Energi (GDE) proposed plastics recycling mini-factories. It uses a mini well-head generator to operate the plastics recycling machine.	The plastic recycling machine's output still needs further process to make it into economic goods. It causes the financial impact could not be felt directly by the local community.	(Asokawaty et al., 2021)

3.3 Summary of Challenges

Possible challenges that can make geothermal direct use facility development difficult in Indonesia based on the discussion in Table 2 and Table 3 is summarized below:

3.3.1. Is there any demand?

Before discussing the technical aspects, one of the most important things we need to identify when initiating a geothermal direct use facility is its demand in the desired area. Currently, assessing the demand is still difficult, and most published papers related to direct use did not include this in their discussions. On this occasion, we will take an example of the coconut drying facility in Way Ratai, South Lampung, where BPPT and PT Pertamina Geothermal Energy have already built a pilot plant for this geothermal direct use facility. Even though it is located in a coconut plantation area and has immense potential (Roeroe et al., 2013; Surana et al., 2010), the demand for that facility remains a question: "Will the farmers come to the facility to dry their coconuts?". There is a possibility that the local farmers will prefer to dry the coconut manually since Indonesia is a tropical country that gets enough heat from the sunlight during the day. It can be a reason that makes the geothermal developer uncertain about the prospect of direct use facility.

3.3.2. Community issues

Lack of community support, fear, and misunderstanding of geothermal direct utilization make collaboration more challenging and delay the direct use pilot project. One of the geothermal direct use facilities facing this issue is the Lahendong Geothermal Education Park (GEP) in Tomohon, North Sulawesi, which is not yet established. According to Roeroe et al. (2015), inhibition of GEP is due to the lack of coordination between all stakeholders. The development has not become a priority because some stakeholders and the community did not fully understand the facility's substance.

3.3.3. Road access and infrastructure

Although not all mentioned in Table 2, most of the current direct use application in Indonesia is in the form of thermal bathing utilizing natural hot springs. For tourism and recreational purposes, road access to the facility and infrastructure is a crucial aspect that must be considered. Well-known hot springs in Indonesia, such as Cipanas, Ciater, and Ciwidey, are located in a place that can be found and accessed easily accessed by tourists. In Sipoholon, North Tapanuli, South Sumatra, there hot springs are located in Hutabarat and Situmeang Habinsaran village. Tourists rarely visit the hot springs in Hutabarat Village because they are far from the protocol road and the road to the location is damaged and relatively small. The hot springs in Situmeang Habinsaran village are more frequently visited by tourists because they are located on the side of the protocol road (Marpaung, 2019).

3.3.4. Post-harvest handling and marketing of the product

Geothermal direct use for industrial applications such as agricultural and aquaculture cultivation has different challenges compared to tourism facility. Some products need extra careful handling and limited marketing time. Once harvested, they should be marketed within a few hours to prevent them from degrading quickly. A commercial agricultural or aquaculture industry must provide a preservation plant and ensure that the harvested product will be preserved soon enough (Sumotarto, 2001).

3.3.5. Economic feasibility

Some cases are facing economic feasibility issues from the additional cost of using a heat exchanger because the financing will be difficult especially if it is a small-scale industry. Furthermore, if the distance of the facilities from the power plant location is too far, it might lead to heat loss and expensive piping costs. There is also a possibility that the geothermal fluid has high silica content and corrosive properties, which causes the production pipes to be vulnerable to scaling and corrosion and increase the maintenance cost.

3.3.6. Inadequate research and development

There are a lot of research about geothermal direct use in Indonesia, such as Prasetya et al. (2017), Prasetyo et al. (2018), Hendrarsakti et al. (2022), Ahmad et al. (2022), etc. Still, the development is too low due to some factors mentioned before. Most research about direct use in Indonesia only explains the practical method. It rarely includes their weaknesses and the challenges that must be faced for the facility to be commercialized.

3.3.7. Inadequate human competency

Some geothermal direct use facilities utilize modern technology such as heat exchangers. Local people or communities need to be educated so that they can operate the facility and make a profit from it. However, mostly the socialization events held by geothermal developers are not continuous and are only kept for several occasions, thus making them less effective and unable to give adequate understanding to the local people (Adityatama, 2018). The capability of local people to innovate or develop geothermal direct use business also needs to be increased. Challenges also arise at the local government level because the competence of existing human resources is still lacking, while they are the ones who provide PBPL and funding.

3.3.8. Government policies

There are some points regarding government policies for direct use that need to be improved:
a. There are business models that are not included in the KBLI code.
b. Technical standards for each type of direct use.
c. The problem of incentives for direct use, including the benefits of the community in substituting from LPG/fuel to direct geothermal use. Direct use becomes less attractive when there are no incentives such as carbon tax/carbon price.

4. GEOTHERMAL DIRECT USE COMPARISON BETWEEN INDONESIA AND WORLDWIDE

Table 4 compares Indonesia and worldwide geothermal direct use applications to seek any potential room for improvement or generate new ideas that might be applicable in Indonesia.

Table 4: Comparison of geothermal direct use between Indonesia and Worldwide.

No.	Facility	Sector	Worldwide application	Indonesia application	References
1.	Swimming Pool, Bathing, and Sauna	Tourism and Balneology	- Rumonge, Burundi - Gulf of Suez, Egypt - Addis Abba, Ethiopia - Olkaria, Kenya - Ranomafana, Madagascar - Nkhotakota, Malawi - Ikogosi, Nigeria - Cape Town, South Africa - Beijing, China - Beppu, Japan	- Lahendong, North Sulawesi - Wayang Windu, West Java - Darajat, West Java - Cipanas, West Java - Ciater, West Java - Sipoholon, South Sumatra	(Lund & Toth, 2021); (Roeroe et al., 2015); (Surana et al., 2010)
2.	Industrial Process Heat	Industrial, Production, Manufacture	- Eburru, Kenya (Pyrethrum drying) - Akita Prefecture, Japan - Sankamphaeng, Thailand - Amatitian, Guatemala - Thorverk, Iceland (Seaweed drying) - Soultz, France (Biorefinery) - Gyor, Hungary (Audi Motor Hungary)	- Wai Ratai, Lampung (Coconut drying) - Lahendong, North Sulawesi (Coconut drying) - Pengalengan, West Java (Tea weathering) - Lahendong, North Sulawesi (Palm sugar processing)	(Lund & Toth, 2021); (Roeroe et al., 2013); (Japan International Cooperation Agency, 2007); (Darma et al., 2021)
3.	Agricultural Cultivation	Agriculture	- Hokkaido, Japan (Mangos, tomatoes) - Bad Blumau, Austria (Tomatoes, peppers) - Macedonia, Greece (Tomatoes, spirulina) - Poddebice, Poland (Algae) - Eastern Slovenia (Flowers)	- Pengalengan, West Java (Mushroom cultivation)	(Lund & Toth, 2021)
4.	Fish Farming	Aquaculture	- Sahara, Algeria - Beijing, China - Fukushima, Japan (Shrimp)	- Wai Ratai, Lampung (Catfish growing)	(Lund & Toth, 2021); (Surana et al., 2010)
6.	Greenhouse Heating	Agriculture	-Naivasha, Kenya (Roses) - Baharia, Egypt - Beijing, China - Kebili, Tunisia (Cucumber and melons)	No record in Indonesia	(Lund & Toth, 2021); (Mohamed, 2013);

No.	Facility	Sector	Worldwide application	Indonesia application	References
7.	Space Heating/Cooling	Tourism and Private Use	- Baharia, Egypt - Blantyre, Malawi - Tianjin, China - Mumbai, India	- Patuha, West Java	(Lund & Toth, 2021); (Surana et al., 2010)

5. RANKING OF NEW CONCEPTS FOR INDONESIA APPLICATION

5.1. Decision-Making Process

The Multiple Criteria Decision Analysis (MCDA) is used in this study for decision-making. MCDA is suitable for more complex decision-making since it does not require monetized measurements. To make a good decision, a person must consider all the alternatives and weigh each option's strengths and weaknesses. The processes for implementing MCDA are shown in Fig. 2.

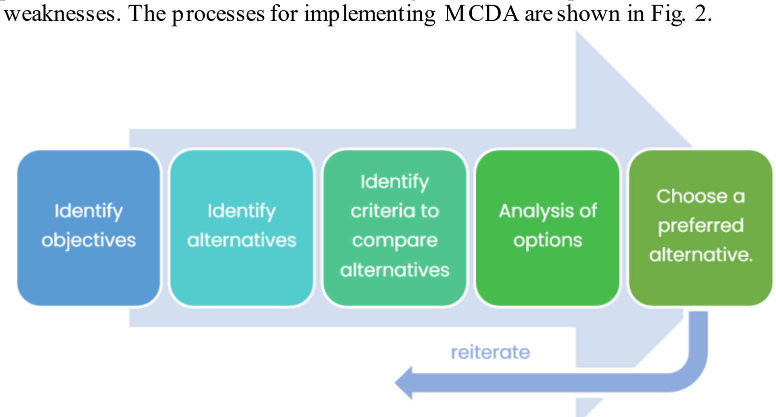


Figure 2. Processes for implementing MCDA.

5.2. Define Alternatives

The early step for applying the MCDA method is to define as many ideas as possible for the decision maker to consider in Indonesia's direct use applications. In this study, the authors have defined 9 (nine) ideas that might be applicable in Indonesia (Table 5).

Table 5: List of direct use facilities.

No.	Direct Use Facility	KBLI Code	Why choose this facility?
1	Seaweed Drying	10291	Indonesia is the second largest seaweed producer after China, with an export volume in 2020 of 195,574 tons (Directorate General of Aquaculture, 2021). Although direct use application for drying seaweed is not implemented in Indonesia yet, the seaweed drying plant at Thorverk is the largest industrial user of geothermal energy in Iceland (Lund & Toth, 2021).
2	Fish Drying	10211	The Central Statistics Agency (BPS) said that fish caught in the sea in 2015 reached six million tons from all waters in Indonesia. This shows the potential of marine fish in Indonesia is very large. However, some fishermen do not sell the fish in fresh condition but process them first into dried salted fish. One of the largest dried fish producers in Iceland, Haustak, buys 1.3 kg/s of steam from the nearby Reykjanes power plant to produce 2,500 tonnes of dried products annually from 12,000 tonnes of raw material (Lund & Toth, 2021).
3	Wood Drying/Preservation	16102	The increasing population growth of Indonesia, the tropical environmental climate, and the fact that 80% to 85% of Indonesian wood species are less durable to non-durable, as well as the increasing income per capita of the population, will increase the use of wood preservation technology in Indonesia (Rudi, 2002). Geothermal direct use can be a good alternative energy source for drying technology. Semi-technical wood drying facility utilizing geothermal was installed in the Podhale region, Poland (Lund & Toth, 2021).
4	Rice Drying	10631	As a country where most of the population consumes rice as the main food ingredient, the rice plant is certainly one of the largest commodities in Indonesia. But unfortunately, there are still many processes of processing

No.	Direct Use Facility	KBLI Code	Why choose this facility?
			rice into rice, such as drying grain which is done conventionally. One example of geothermal direct use application for rice drying facility is in Kotchany, Macedonia, where the geothermal water comes from Podlog springs (Popovska, 2003).
5	Coffee Drying	10761	Indonesia is the fourth largest coffee bean-producing country after Brazil, Vietnam, and Colombia, with an average production of around 700 thousand tons per year, or about 9% of world coffee production (Ministry of Industrial 2019). Thus, geothermal direct use application for coffee drying facility hopefully can boost the production in the future.
6	Tobacco Drying	12091	The tobacco products industry (IHT) is one of the domestic strategic sectors with high competitiveness and continues to contribute to the national economy significantly. The contribution of the tobacco products industry is quite high after the food and beverage industry. In East Java, this industry has become the leader (Ministry of Industrial, 2017).
7	Milk and Dairy Processing	10591	The opportunity for the milk processing industry in Indonesia is very good, considering that Indonesia, with a population based on the 2010 census, reached 237.6 million people. From the supply side, milk production in Indonesia is currently very low. 90% of milk production is produced from smallholder farms, so the quality and productivity cannot meet domestic demand for milk, so most of it still has to be imported (Sanny, 2011).
8	Cajuput Oil Extraction	20294	The Central Statistics Agency (BPS) noted that eucalyptus oil production in Indonesia reached 25.06 million liters in 2020. This number increased by 229.5 percent compared to the previous year, which was 7.6 million liters. The increment was allegedly due to high public demand for eucalyptus oil during the Covid-19 coronavirus pandemic (Hendrasakti, 2021).
9	Candles Manufacture	32909	Candles not only act as a lighting tool when there is no electricity, but candles can also be home decorations and become useful tools to assist in the therapeutic process and can support a healthy lifestyle that uses them. The candle-making machine can be built in any geothermal field and put at the service of local communities for their benefit. The developer or owner of the geothermal field can decide whether to sell the steam or give it for free so that people from the local communities can serve it to commercialize candles (Cuadra, 2021).

5.3. Define Objectives and Criteria

The next step is to define the objective of the decision. In this study, the objective of this "Getting Suitable Direct Use Facility" decision analysis is to determine Indonesia's most practical direct use facility ideas. **Error! Reference source not found.** shows the value tree and the criteria of the decision analysis. The criteria used to compare the alternatives are:

1. Required Temperature for Direct Use Facility

Each geothermal direct use facility has its required temperature to optimize the process (Fig. 3). If the required temperature is low, we might have more options to determine the origin of geothermal energy for extraction. Facilities like milk processing and timber drying typically need a relatively higher temperature to operate, leading to higher costs since extracting the heat directly from manifestations is no longer possible, and they need either use heat from drilling a well or make use of geothermal powerplant's excessive brine. Nevertheless, cascade and combined uses can enhance the feasibility. For example, use geothermal water first and after that for space heating (ESMAP, 2012).

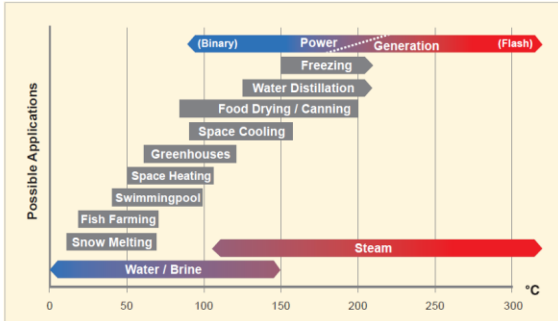


Figure 3. Modified Lindal diagram (Gehringer and Lokhsa, ESMAP, 2012)

2. Product's Durability

The product's durability after being processed in the direct use facility needs to be considered because it is related to post-harvest handling and marketing of the product. Some products need extra careful handling and limited marketing time. Once harvested, they should be marketed within a few hours to prevent them from degrading quickly. A commercial agricultural or aquaculture industry must provide a preservation plant and ensure that the harvested product will be preserved soon enough (Sumotarto, 2001). The value of this criterion uses a direct rating from various references and the author's discussion. The alternative with the longest durability is preferable.

3. Existing Related Industry

Demand for geothermal direct use facilities is difficult to assess since it might vary between the areas and the information from published papers is very limited. But, we take an approach to know the possible demand by researching the existing related industry that might cooperate to use the facility. The data for this criteria is taken from the Ministry of Industrial's official website (kemenperin.go.id/direktori-perusahaan).

Based on the discussion above, a performance matrix of each criterion is shown in Table 6.

Table 6: Performance matrix with measurement of each criterion

PERFORMANCE MATRIX	Criterion-1	Criterion-2	Criterion-3
Direct Use Facility	Estimated Required Temperature	Product Durability	Existing Related Industry (based on MoI database)
	Deg. Celcius	Direct Rating	Count
Seaweed Drying	70	75	21
Fish Drying	60	50	46
Timber Drying	160	90	85
Rice Drying	60	75	88
Coffee Drying	65	25	141
Tobacco Drying	80	25	61
Milk and Dairy Processing	90	25	66
Cajuput Oil Extraction	100	90	41
Candles Manufacture	60	90	15

Table 7 shows the matrix of scores for each criterion; for the quantifiable criteria, the value is derived using the linear function.

Table 7: Matrix of score of each criterion

MATRIX OF SCORE	Criterion-1	Criterion-2	Criterion-3

Direct Use Facility	Estimated Required Temperature	Product Durability	Existing Related Industry (based on MoI database)
	Deg. Celcius	Direct Rating	Count
Seaweed Drying	56	75	21
Fish Drying	63	50	46
Timber Drying	0	90	85
Rice Drying	63	75	88
Coffee Drying	59	25	141
Tobacco Drying	50	25	61
Milk and Dairy Processing	44	25	66
Cajuput Oil Extraction	38	90	41
Candles Manufacture	63	90	15

5.4. Specify weighs for each different criterion

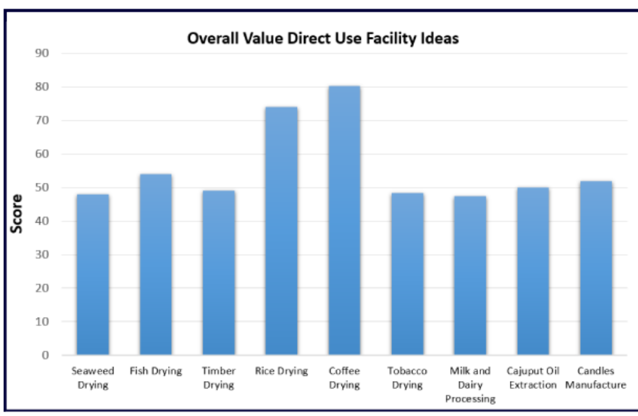
The next step is to weigh each alternative accordingly to the criteria. "Estimated Required Temperature" (Criterion-1) is given the highest weight in this study because this criterion significantly impacts the feasibility of direct use facility as stated in section 5.3. The developer needs a picture of the demand for the facility before investing in it. That is why "Existing Related Industry" (Criterion-3) is weighed second. Since the "Product's Durability" (Criterion-2) might be insignificance for non-agricultural products, it is weighed third. The detailed information is shown in Table 8.

Table 8: Weight of each criterion

WEIGHT	Criterion-1	Criterion-2	Criterion-3
	Estimated Required Temperature	Product Durability	Existing Related Industry (based on MoI database)
Weight	100	50	80
Normalized Weight	43.48	21.74	34.78

5.4. Overall score for each alternative

The last step is deriving the overall scores for each of the alternatives for the decision problem given by our value tree (Figure 4).



Direct Use Facility	Overall Score	Normalized Score
Seaweed Drying	4806.52	48.07
Fish Drying	5404.35	54.04
Timber Drying	4913.04	49.13
Rice Drying	7408.70	74.09
Coffee Drying	8029.35	80.29
Tobacco Drying	4839.13	48.39
Milk and Dairy Processing	4741.30	47.41
Cajuput Oil Extraction	5013.04	50.13
Candles Manufacture	5195.65	51.96

Figure 4: Bar Chart of Normalized Scores of Each Alternative and Overall Scores of Each Alternative.

The coffee drying and rice drying facility are the best ideas based on the MCDA. It does make sense since those facilities need a relatively lower temperature to operate and possibly have higher demand because of the reasons mentioned in Table 5. However, further study is needed to validate the results of this study. To ensure the MCDA's reliability, sensitivity analysis for each criterion needs to be conducted to see whether the decision maker put an unbalanced weight or score on one criterion.

6. CONCLUSION AND WAY FORWARD

After discussions above, several aspects can be concluded as follows:

1. Currently, most of Indonesia's direct use application is thermal bathing utilizing natural hot springs for tourism and balneology purposes; some are located in Cipanas, Ciater, and Sipoholon. There are at least 7 established direct use applications in Indonesia related to industrial applications (agricultural cultivation and drying, fish farming, space heating) in Pengalengan, Way Ratai, Lahendong, and Patuha, where one of them is the Lahendong Geothermal Education Park which still undergoing development.
2. Typical geothermal direct use application challenges in Indonesia are demand for the facility, community issues, land acquisition issues, road access and infrastructure, post-harvest handling and market of the product, economic feasibility, inadequate research and development, inadequate human competency, and government policies.
3. Some worldwide geothermal direct use applications have not been implemented in Indonesia, which can generate new ideas that might be applicable. The coffee drying and rice drying facility are the best ideas based on the MCDA.

The authors realize that the feasibility of various ideas offered later in this study still requires further research or pilot projects with more detailed field-specific concepts. We expect to gain constructive input for consideration in future works by publishing this report.

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