

## Analysis of Geothermal Direct Use in Agriculture and the Social Economic Effects on Local Communities

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**Abstract.** The direct use of geothermal energy offers a promising solution to diverse energy requirements. However, the focus on utilizing geothermal direct use is less explored in Indonesia. The vast geothermal potential suggests more exploration for direct applications, especially in the agricultural industry. This study analyzes the performance of geothermal direct use utilization at two locations: PLTP Wayang Windu (coffee drying) and PLTP Lahendong (drying agricultural products and palm sugar production), with the socioeconomic effect on local communities in the geothermal work area based on literature review. In Wayang Windu, 147°C brine is processed through a closed heat exchanger system, producing 32.65 kW of energy to dry 1,000 kg of coffee for 12.5 hours. In Lahendong, heat waste is used to make a 12-ton/day palm sugar. Heating efficiency for Paddy drying of the dryer is 82.50%, and total drying efficiency reached 51.10%. This direct use of utilization has the potential to reduce carbon emissions from the production process that still uses fossil fuels or wood. Local communities welcomed the direct use of geothermal technology for drying agricultural products. It is also essential to ensure the regulatory and policy landscape surrounding the geothermal work area is safe and sustainable for public.

**Keywords:** *agricultural industry, brine, geothermal direct use, geothermal work area*

### 1 Introduction

Earth's internal heat or geothermal energy stands out as a promising solution to diverse energy requirements towards cleaner and potentially renewable energy in Indonesia. The direct use of geothermal energy involves using the heat energy from the Earth's interior immediately, bypassing the need to convert it into electricity or other energy forms. As well as the nation's commitment to curbing carbon emissions and ensuring energy security, Indonesia longed for a crucial role in geothermal exploration and development initiatives.

As the demand for sustainable energy solutions continues to surge and receive considerable attention, the exploration of these diverse geothermal direct use applications becomes nothing less than imperative. Indonesia has potential and opportunities to exploit geothermal reservoirs for various purposes beyond power generation, such as district heating, greenhouse cultivation, industrial processes, and even aquaculture. However, it remains relatively untapped and requires concerted efforts from various stakeholders. Therefore, the study of underexplored potential along with its benefits, challenges, and business models associated with harnessing geothermal energy directly plays a crucial role.

The utilization of geothermal energy in Indonesia remains largely concentrated on electricity generation, while direct use applications particularly involving low to medium temperature fluids such as brine discharged from separators have yet to be fully optimized. In two phase geothermal systems, brine with considerable residual enthalpy is typically reinjected into the reservoir without undergoing further thermal utilization. However, this fluid still holds potential for alternative applications, such as drying agricultural products and processing agro-industrial goods. The lack of technical strategies to directly utilize separator brine reflects a gap in geothermal energy management, particularly in regions with high agricultural commodity potential and consistent thermal energy demand.

The direct use of geothermal energy utilizing low to medium temperature thermal fluids ( $<150^{\circ}\text{C}$ ) typically originates from brine discharged from separators in two phase systems. This application has the potential to replace fossil fuels in the drying processes of rice, corn, coffee, and other agro industrial products, while also serving as a solution to the limited availability of traditional fuels such as firewood. Several pilot initiatives in Indonesia have demonstrated the technical and social feasibility of this scheme, including palm sugar production at the Lahendong Geothermal Power Plant in Tomohon [1] and the use of brine for coffee drying at the Wayang Windu Geothermal Power Plant [2]. However, to date, the adoption of this technology has not been systematically integrated into the overall management strategy of geothermal work area.

The acceptance of local communities in various aspects are determines the successful application of these technologies and the existence geothermal power plant. So, people need to become beneficial, especially for those who live in a geothermal work area. By analyzing existing utilization, this paper contributes to enlarge the discourse on suitable business model in integrating geothermal direct use in agricultural. Further, the idea of direct use utilization of geothermal energy is expected to boost the economy and secure foods nation by improving the quality and adding some innovation.

## **2 Objectives and Methods**

This study is based on a literature review of previous research related to the direct use of geothermal energy and its potential application for agroindustry. This study aims to:

1. To analyze geothermal direct-use business models and their potential applications in agricultural products at two locations: coffee drying in PLTP Wayang Windu and agricultural products drying and palm sugar making in PLTP Lahendong.
2. To identify socioeconomic effects from geothermal direct utilization for the local communities surrounding the geothermal work area.
3. To explore the array of business models that could facilitate the implementation of geothermal direct use projects, especially in agriculture.

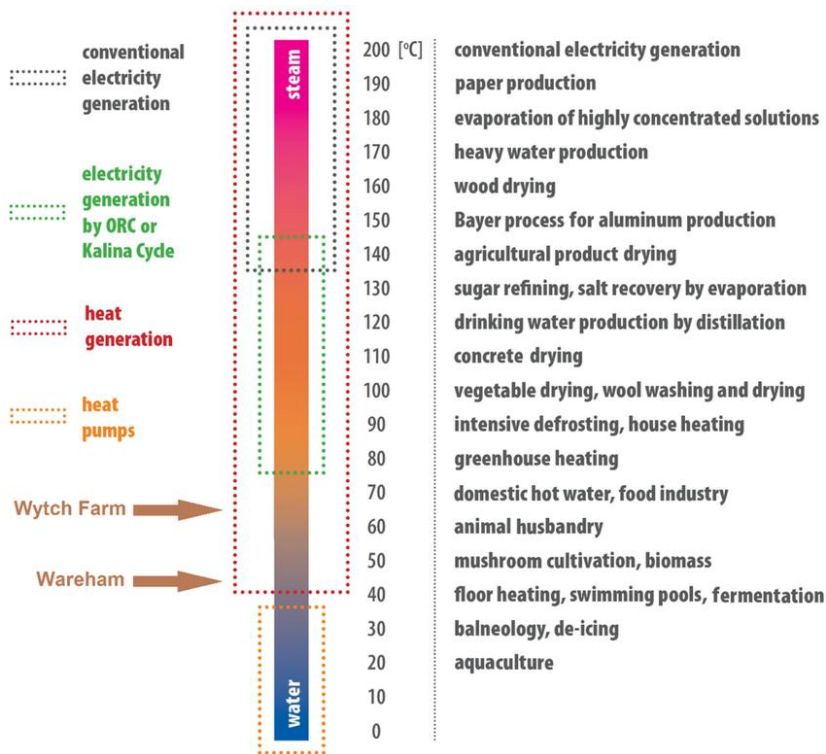
## **3 Literature Review**

This study is focus on the direct use of geothermal energy for agroindustry, namely:

### **3.1 Drying agricultural products and making palm sugar in PLTP Lahendong, North Sulawesi**

#### **3.1.1 Background**

The direct utilization of geothermal energy in Indonesia, as referred to in Law No. 27 of 2003 on Geothermal Energy, is believed to significantly contribute to energy diversification and conservation, fuel substitution, and the improvement of community welfare. The direct use of geothermal energy has been rapidly developing and is increasingly applied, particularly in the agricultural and agroindustrial sectors, especially for processes involving heating, drying, sterilization, and pasteurization. Several examples of direct geothermal energy applications can be seen in the Lindal diagram (1973), which illustrates the various uses of geothermal energy based on temperature. Based on the Lindal diagram, geothermal energy with a temperature of 140°C can be utilized in the drying process of agricultural products (Figure 1).



**Figure 1** Lindal Diagram (1973), as cited in Sveinbjornsson (2016).

In 2012, the North Sulawesi region had developed several geothermal production and injection wells, enabling the potential utilization of residual heat (waste heat) for food processing and agricultural product treatment around the geothermal site. Lahendong geothermal power plant is one of the commissioned geothermal power plants of Indonesia, and currently produces a total of 120 MWe to meet the energy demand in North Sulawesi. Moreover, the Kotamobagu geothermal working area (WKP) has been assigned to Pertamina Geothermal Energy for its development [3]

Lahendong Geothermal is one area in North Sulawesi are used for power generation to supply electrical energy in North Sulawesi. Lahendong geothermal technology produces steam waste heat energy (waste heat) is large and returned to injection cycle (reinjection). Abundant steam waste heat through the exhaust pipes have been drained to palm sugar processing unit and 1 unit of agricultural product drying equipment, mainly for drying grain. Especially for drying grain has been cultivated for drying grain and corn. From the observation of surprisingly large waste heat energy for agricultural products processing applications.

Direct use of geothermal activity should be regulated by the government so that its implementation can work well and be able to make a significant contribution to the diversification and energy saving, fuel substitution, and increasing the standard of living of the communities [4]. In addition to technological aspects, community acceptance is also a key factor in the successful implementation of geothermal power plants. When local communities directly benefit from the project, resistance to the presence of geothermal power plants (PLTP) tends to decrease. Therefore, studies are needed to assess public response regarding the presence, benefits, and impacts of geothermal power plants, as well as the implementation of geothermal-based agricultural drying technologies.

### **3.1.2 Result**

The process of utilizing geothermal energy for the production of crystal palm sugar begins with the extraction of geothermal fluid through a production well in the Lahendong area. This fluid is a mixture of two phases, namely steam and hot water (brine), which is then channeled to a separator to be separated. The steam produced is partly used for electricity generation, while the other part is channeled directly to the palm sugar processing plant as a source of thermal energy.

This hot steam is first directed to be processed in a juice heater, where the sap from the palm tree is heated to deactivate microorganisms and prepare it for the evaporation process. Furthermore, the sap is processed in an evaporator to reduce the water content and increase the sugar concentration. After that, the concentrated liquid from the evaporation is channeled to a vacuum pan, which is a low-pressure concentration chamber, where further evaporation takes place at a lower temperature. This allows the crystallization process to run efficiently without damaging the quality of the sap.

In the production process of crystal palm sugar, the juice heater plays a role as the initial stage of heating the sap. At this stage, hot steam from the geothermal system is used to raise the temperature of the sap so that it is more sterile and ready to be processed to the next stage. This initial heating also serves to reduce the viscosity of the sap and speed up the evaporation process in the next stage. After being heated, the sap is flowed into the evaporator. This is where most of the water in the sap is evaporated. The evaporator uses the heat from the geothermal steam to increase the sugar concentration by significantly reducing the water content, resulting in a more concentrated sugar syrup liquid. This stage is very important for the efficiency of the crystallization process later. Next, the concentrated liquid from the evaporator enters the vacuum pan, which is a concentration chamber that works at low pressure (vacuum). Because the pressure is lowered, the boiling point of the liquid also drops, so that the evaporation process can take place at a lower temperature without damaging the

quality of the sugar. This is where the crystallization process occurs in a controlled manner, producing high-quality crystal palm sugar that is ready to be molded and packaged.

## **3.2 Coffee drying in PLTP Wayang Windu, West Java**

### **3.2.1 Background**

West Java Province hosts 20% of the total potential, which approximately, as much as 5311 MW that is spread across several areas such as Kamojang (200 MW), Darajat (255 MW), Wayang Windu (227 MW), Mount Salak (375 MW), and Karaha (30 MW) with total installed capacity of 1087 MW for Java-Bali grid. Wayang Windu Power Plant is located in Maga Mukti Village, Pangalengan District, 40 km from Bandung City. In Pangalengan, the production of coffee cherries in 2014 reached approximately 6,499.04 tons with the majority types of coffee crops grown is Arabica. The coffee industry in this area has traditionally depended on fossil fuels and solar energy for processing which known to release carbon dioxide and are not environmentally sustainable, while the performance of solar thermal systems is often affected by unpredictable weather. Therefore, the potential of using geothermal fluids as an alternative and more stable heat source for the coffee drying process is very considered.

In the processing of coffee, there are 3 types of processing method which have their own respective advantages; dry, full washed, and semi-washed. The difference between wet and semi-wet process in Arabica coffee processing is at the elimination of fermentation process in semi-wet process. Among the processes, arabica coffee is best processed using semi-washed method. The semi-washed coffee product has lower acidity level and stronger body than coffee processed by full-washed method. Another reason of using semi-washed method is that the coffee processed has a good quality, shorter time required, and efficient water usage.

Generally, after the coffee fruits are manually harvested and sorted to obtain seed with defect value according to SNI 01-2907-2008, it soaked by the water to separate good quality fruits from poor quality fruits, where good quality fruits will sink and poor-quality fruits will float. Dirt such as leaves, twigs, soil, and gravel should be removed, as it can cause damage to the peeling machine and fruit peeler (pulper). Removal of mucus residue on the skin surface of the horn (demucilaging) was performed mechanically with a demucilager tool without using water. There are two stages of drying of coffee seeds, first is drying up until the water content reaches  $\pm 40\%$  and then the seed is peeled until it is obtained

rice coffee beans. The second drying is done until the beans moisture content reaches  $\pm 12.5\%$  [2]

### 3.2.2 Result

Geothermal energy located beneath the surface of the earth comes from volcanic activity and the natural heat of the earth that flows to the surface through underground reservoirs. Through production wells, geothermal fluid in the form of a mixture of steam and hot water (brine) is taken and flowed to a separator to separate the steam and brine. Brine which still has a high temperature is flowed to the first heat exchanger (Heat Exchanger 1) to heat water as a working fluid with a temperature of  $80^{\circ}\text{C}$ . Then, the hot water is flowed in a closed circulation system to the second heat exchanger (Heat Exchanger 2) to heat the air that will be used in the coffee drying process. Hot air with a temperature of around  $50^{\circ}\text{C}$  is blown into the drying chamber using a fan to help the coffee bean drying process. After that, the fluid will release its heat in Heat Exchanger 2, then the fluid is returned to the circulation system to be reheated in Heat Exchanger 1. Meanwhile, the brine that has lost heat is discharged through the injection well to be re-injected into the earth's surface. Thus, geothermal energy is utilized indirectly and efficiently for post-harvest processes of agricultural products.

In coffee drying process whether stage 1 and stage 2, total energy required can be calculated by equations below.

$$Q = mC_p\Delta T \quad [1]$$

Total energy required for evaporate the water content in coffee beans at each stage can be calculated using equation 1. Where  $m$  is mass flow rate (kg/s),  $C_p$  is specific heat capacity (kJ/kg $^{\circ}\text{C}$ ), and  $\Delta T$  is the temperature difference ( $^{\circ}\text{C}$ ).

$$Q = U_{HE} A_{HE} \Delta T_{lm} \quad [2]$$

The illustration of heat exchanger designs are based on equations 2. It can be used to determine the size and efficiency of the heat exchanger system used in stage 1 and stage 2.  $U_{HE}$  is overall heat exchanger coefficient (W/m $^2$ .K),  $A_{HE}$  is heat exchanger area (m $^2$ ), and  $\Delta T_{lm}$  is logarithm mean temperature difference (K).

$$Q = \frac{\Delta T L}{\frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k} + \frac{\ln\left(\frac{r_i}{r_2}\right)}{2\pi k}} \quad [3]$$

In the process of heat transfer through pipes, some energy will be lost due to conduction and installing fluid flow. Heat loss is calculated using Fournier (for layered cylindrical walls) (equation 3). In Fournier’s Equation, L is length of the pipe (m), ΔT is temperature difference (°C of K), r is pipe radius (m), k is pipe thermal conductivity (W/m°C or W/mK).

$$M_a = M \left( \frac{Q_1 - Q_2}{1 - Q_2} \right) \tag{4}$$

To find out the amount of released water from the fruits, so it might have dryness level as targeted before, we can use equation 4. M in initial coffee mass (kg), Q1 is initial coffee water content (%), dan Q2 is desired final water content (%).

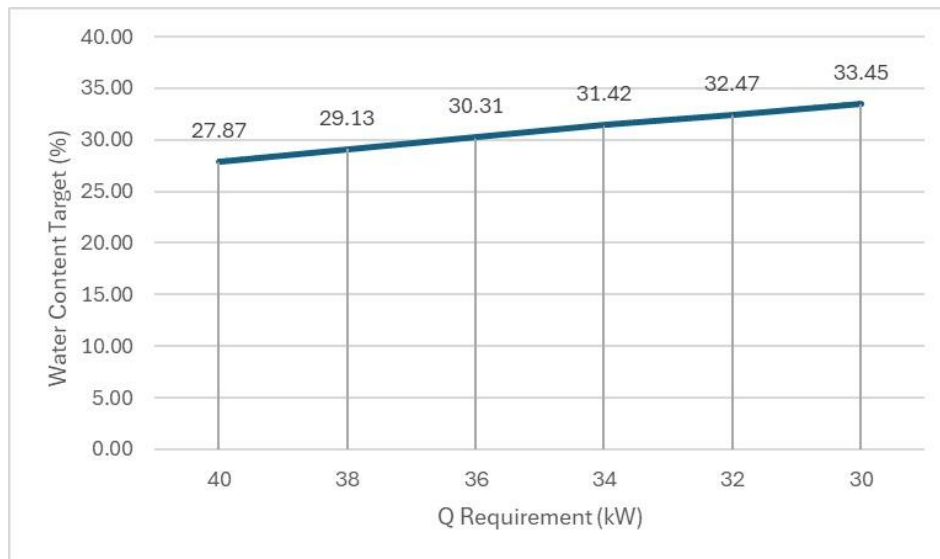
**Stage 1: Initial Coffee Drying**

In the first stage, the drying process is carried out by reducing the water content by 60%. This initial drying stage is carried out before the advanced drying stage. Calculation of energy requirements is carried out to produce coffee beans with water content of 40%, 38%, 36%, 34%, 32%, and 30%. At each initial water content target, the calculation of heat energy requirements (Q) is carried out based on the amount of water released by the coffee beans. The results showed that the lower water content is produced, the more heat energy is required (Table 1).

**Table 1** Heat energy requirement (Q) for initial coffee drying at various moisture content targets.

No.	Water content target (%)	Q requirements (kW)
1	40	27.87
2	38	29.13
3	36	30.13
4	34	31.42
5	32	32.47
6	30	33.45

These results indicate a direct correlation between the decreasing of water content and energy requirements, where the higher level of dryness in coffee beans also need the higher energy to be supplied. To produce 30-40% initial water content at the first stage, 27.87 to 33.45 kW is required (Figure 2).



**Figure 2** Heat energy requirements (Q) for initial coffee drying at various moisture content target.

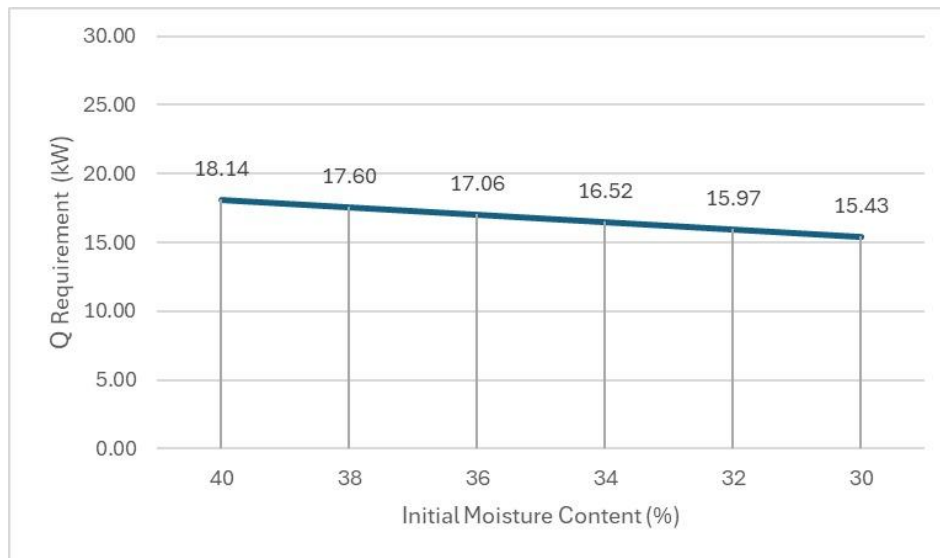
### **Stage 2: Advanced Coffee Drying**

After the first stage of drying and the peeling process [5], the coffee beans required second drying stage to reducing water content to 12.5%. The simulation in the second stage of drying starts from different initial water contents, namely 40%, 38%, 36%, 34%, 32%, and 30% to the same final target of 12.5%. For each condition, the heat energy requirement (Q) is calculated based on the amount of water that still needs to be evaporated. The results showed that the lower initial water content of coffee beans, the smaller energy is required to reach final water content of 12.5% (Table 2).

**Table 2** Heat energy requirement (Q) for final coffee drying (12.5% water content).

No.	Initial water content (%)	Q requirements (kW)
1	40	18.40
2	38	17.60
3	36	17.06
4	34	16.52
5	32	15.97
6	30	15.43

These data showed that coffee beans which have been dried earlier will require less energy to reach the final water content at 12.5%. Based on the calculation above, the amount of  $Q$  decreases as the initial water content decreases, with energy requirements ranging from 18.40 to 15.43 kW (Figure 3). Therefore, optimization of the first stage of drying is greatly affects the required energy efficiency in the next stage.



**Figure 3** Heat energy requirements ( $Q$ ) for advanced coffee drying with final water content at 12.5%.

The results of both stage of coffee drying show a direct relationship between the water content level and the heat energy requirements. The more water that needs to be released, the more heat energy is required. Therefore, drying process gradually can help optimize energy consumption and design an efficient geothermal direct utilization system for coffee drying.

#### 4 Conclusions

This study highlights the considerable potential of direct geothermal energy use in enhancing agricultural productivity and improving the livelihoods of surrounding communities. Case studies in Lahendong and Wayang Windu confirm that residual heat sources such as brine and waste heat from power plants can be efficiently utilized through heat exchanger systems for agro-industrial applications.

In Wayang Windu, the coffee drying system with 32.65 kW of energy successfully reduced moisture content to 12.5%. Meanwhile, in Lahendong, palm sugar production reached 12 tons per day with a drying efficiency of 51.10%. The integration of direct geothermal utilization into geothermal work area planning is essential to support energy diversification, community empowerment, and the enhancement of local economic development.

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