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How Direct-use Geothermal Systems Could Be Used to Meet the United Nations Sustainable Development Goals: A literature study of two Ethiopian communities

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ABSTRACT

Geothermal heat is utilized around the world for both electricity generation and direct-use applications. While the industry is expanding rapidly, the attention is mainly focused on power generation. However, shifting the focus to community-based direct-use applications could have large impacts on the developing world. Some have previously focused on this type of geothermal development.

In 2011, Ogala, Davidsdottir, and Fridliefsson discussed how the development of geothermal resources in Kenya could help the country meet the Millennium Development Goals (MDGs) in their study titled "Lighting villages at the end of the line with geothermal energy in eastern Baringo lowlands, Kenya – Steps towards reaching the Millennium Development Goals (MDGs)." In this study, the authors show that geothermal heat can be applied to alleviate many of the problems in developing nations. Though the MDGs have ended, the Sustainable Development Goals (SDGs) have picked up where the MDGs left off. The SDGs were enacted by the United Nations in 2015 and consist of 17 goals, each with their own targets. The purposes of these goals are to protect the environment, provide all peoples' basic human rights, and create international partnerships towards meeting these goals. This paper seeks to present the possibility of geothermal applications as a solution to many of the SDGs and stress the impact that smaller, creative projects can have on local communities. Using a case study of two areas in Ethiopia, the impact of geothermal heat when used for community applications is shown. The first area, the Corbetti Caldera, could implement a series of cascading geothermal applications that could help the community meet 12 of 17 of the SDGs. Tigray, the second area, could use a geothermal heat pump to regulate the temperature of a central community building. This small application could help the community meet 11 of 17 of the goals.

1. INTRODUCTION

With a new set of United Nations Sustainable Development Goals (SDGs) to meet by 2030, the world is thinking of creative ways to provide every person with basic human needs. These 17 goals include objectives such as eliminating poverty, providing clean water and sanitation for all people, and eliminating hunger worldwide (United Nations 2015). In addition, the push for green, sustainable energy and the rapidly growing world population has meant that the solutions to these problems should also be green, efficient, and sustainable. Geothermal energy has been at the forefront of the green energy boom with an increase in use of 5% per year since 2012 (Matek 2015). Geothermal heat can be employed in multiple and versatile forms; the constant temperature of the earth at a few meters below ground can regulate household temperatures throughout the year or hot geothermal fluids and steam can be pumped to generate electricity and used in direct-use systems. Direct-use systems are those that use the geothermal heat to perform tasks other than generating electricity, such as heating a greenhouse or drying crops. Though many geothermal prospects exist world-wide, some of the largest and most promising reside in Ethiopia's rift valley.

Ethiopia is located in eastern Africa on the Horn of Africa. It is a landlocked country with a population of over 80 million, of which 80% of the working aged population are employed in the agricultural sector (The Federal Democratic Republic of Ethiopia 2011). Despite the large agricultural industry, millions of people still struggle with food insecurity. Prospective geothermal resources could provide a solution to this and many other issues the country is currently experiencing. Exploration of the rift valley has identified several areas suitable for developing large power plants to provide the country with a reliable source of electricity. However, the geothermal can be used for more than generating electricity. Direct use systems could provide the area with sustainable infrastructure and steady income, as evinced by many geothermal projects around the world including the Tasman Pulp and Paper Plant in Kawerau, New Zealand (Lund 2010). In addition, shallow geothermal heat pumps, utilizing the earth's constant temperature below the surface, could be implemented in areas with marginal or nonexistent geothermal resources to regulate building temperatures, a technology that is employed in countries like Canada and Switzerland (Lund 2010). More than providing power like other renewable energy resources, geothermal provides a steady supply of heat that can be harnessed for multiple beneficial applications to bolster the local economy and provide a stable industrial platform to expand on. With these small additions to the community, the SDGs could be met. The use of geothermal to bolster a region's electrical grid, expand its economy, and improve local livelihoods to help the local communities meet the SDGs will be demonstrated through a case study of two very different areas: The Corbetti Caldera and Tigray.

1.1 Geothermal Systems

3.1 Principles of High Temperature Geothermal Reservoir Use

High temperature geothermal reservoirs, generally considered those above 100^{o}C provide a near constant, efficient source of energy. These reservoirs are hot; they often reach temperatures of hundreds of degrees Celsius. Geothermal reservoirs can be exploited in two ways: either the hot geothermal fluid is pumped directly out of the reservoir and used at the surface in an open loop system or a fluid with a low boiling point is placed in a closed loop system that sends the fluid through the heated reservoir to heat the fluid. The heated fluid is then pumped up to a heat exchanger at the surface before be pumped back into the geothermal reservoir to be reheated.

3.2 Principles of Low Temperature Geothermal Reservoir Use

Some of the most efficient heating systems with zero carbon emissions, geothermal heat pumps (GHPs) utilize the constant ground temperature of between 12^{o}C and 15^{o}C varying from a few meters to tens of meters below surface to transfer heat to the surface or send surface heat into the ground to cool a finite environment, similar to a Carnot cycle (Glassley 2015). The basic GHP system consists of a closed loop of fluid with a low boiling point that is circulated from the building into the earth and back, releasing heat either into the earth or into the building with each pass. These systems can be installed in almost any geologic and geothermal setting, however, they require electricity to run. To keep the system sustainable and carbon neutral, solar panels could be installed to provide the electricity for the heat pump.

2. STUDY AREA BACKGROUND

In 2011, Ethiopia formed a Climate Resilient Green Economy Strategy that aims to improve agricultural production, expand industry, and increase exports of the country (The Federal Democratic Republic of Ethiopia 2011). The country already has a strong renewable energy base, with eight hydro plants providing over 670 MW of intermittent power to the residents of larger towns and cities (Teklemariam and Kebede 2010). However, geothermal systems would not only provide the country with electricity, but could additionally be used in many direct-use applications. These direct-use applications will be essential to aiding the region as population grow increases the strain on the already marginal food supply and economy.

The geology and geography of the country is shaped by the Main Ethiopian Rift, a branch of the African Rift System, which cuts right through the country (Gianelli and Teklemariam 1993). Ethiopia can be divided into two geographical regions: the highlands and the rift valley. The rift system is what provides the country with its rich geothermal resources. The two study areas shown in Figure 1, Corbetti and Tigray, are representative of each of these geographical regions.

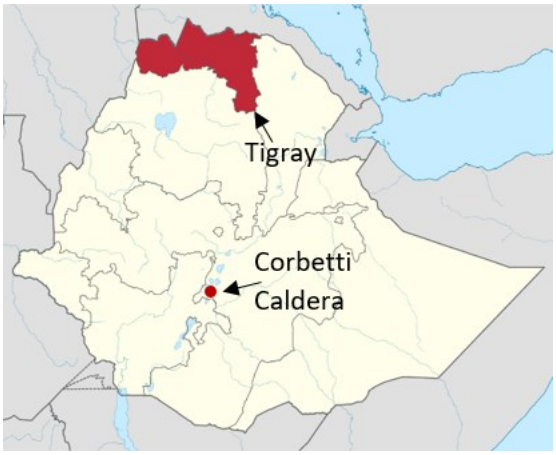

Figure 1: Map showing the Tigray and Corbetti study areas [43].

Corbetti Caldera is in the central Oromia region of Ethiopia in the rift valley. The area surrounding the Caldera is blanketed by surficial lava deposits and little vegetation grows there. The caldera provides a geothermal hot spot with the geothermal fluids estimated to be 350^{o}C in deeper reservoirs (Reykjavik Geothermal n.d.). Power plants are already being constructed by Reykjavik Geothermal, and are expected to produce over 1000 MW of electricity when they go online in 2021 (Reykjavik Geothermal n.d.). However, the geothermal heat that is prevalent here could be employed for many additional direct-use benefits to industrialize the caldera and further benefit the local people.

Tigray resides in the northernmost highlands of Ethiopia. It has average yearly temperatures between 15^{o}C and 30^{o}C (Gebremeskel, Tamir and Begna 2015). The basic buildings are built out of local stones with a roof made of wood beams and mortar (Online 2012). These houses generally do not have electricity and therefore do not have a cooling or heating system. They may be uncomfortable at times due to the hot weather in Tigray. The region is ruled by small governmental bodies called kebeles who are the primary governmental contacts for citizens (Yilmaz and Venugopal 2008). Tigray does not currently have any explored geothermal resources but a shallow geothermal heat pump could be installed to regulate the temperature of a town hall and community center building.

3. GEOTHERMAL UTILIZATION TO MEET THE SDGS IN ETHIOPIA

3.1 Corbetti Caldera

Corbetti Caldera is a highly explored geothermal resource located in the Ethiopian Rift Valley in the central Oromia region. It is located 200 km south of Addis Ababa. The Caldera produces geothermal fluids between 250-350°C that could be utilized for multiple direct-use applications beyond electricity generation (Gislason, et al. 2015). Direct-use applications of the geothermal heat in the caldera would not only ensure sustainable use of the geothermal resource, but would also improve the local economy and ultimately help the region meet the UN SDGs. The direct-use system would be built as an industrial and tourist area around the caldera and would include processes such as speeding up compost production, heating a greenhouse, drying and preserving crops, leather processing, and heating a hot spring.

3.1.1 Geothermal Resource Use

A shallow, closed loop, cascading geothermal system would be added to the power plant to deliver the heat to the direct-use applications. A schematic is shown in Figure 2. The system, after generating electricity, would be cooled to between 150°C and 170°C using a cooling tower to bring it to a workable temperature for direct-use applications. The heat would be transported throughout the system using water, which has a sufficiently high heat capacity and can be more easily obtained than other fluids. In addition, water does not contaminate the groundwater if it were ever to escape the system. The heat would be transferred using heat exchangers. The system would be buried only a few meters below the surface and would run from building to building. It is assumed that as the heat is transferred to and used by the different processes, the geothermal system will lose heat energy at a rate of 15% until it is at 25°C, then the fluid is pumped underground to repeat the process (Glassley 2015).

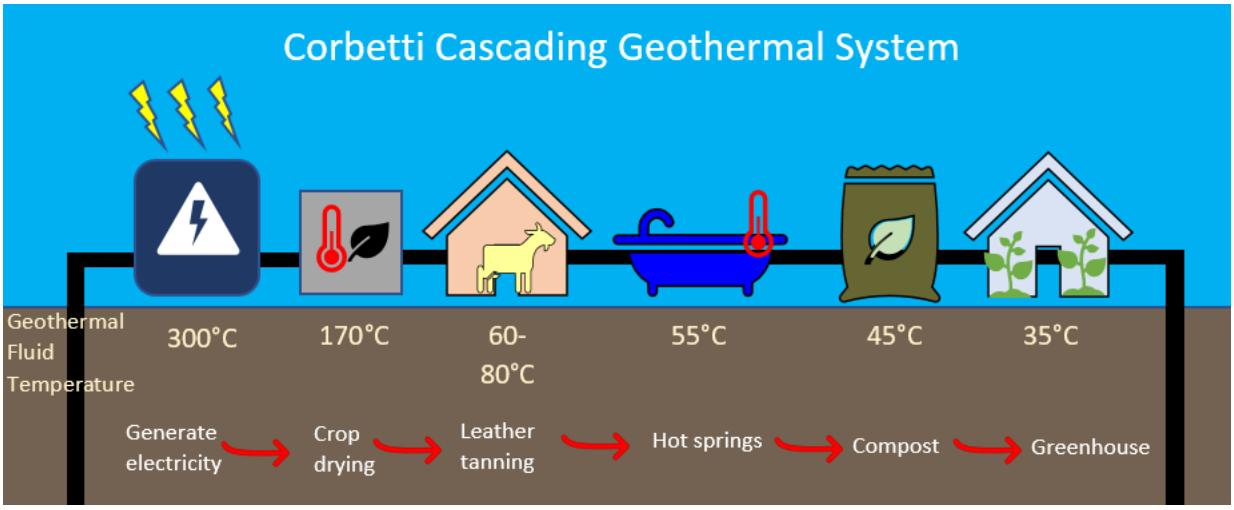

Figure 2: Schematic showing the proposed closed-loop, cascading geothermal system.

The first direct-use application would be to dry produce. The crop processing facility would use geothermal resources with temperatures between 110°C and 170°C (Glassley 2015). Heat would be exchanged from hot fluids into hot air in an oven to dry crop products. The dried crops would have a longer shelf-life than fresh crops and would, therefore, provide the locals with a more stable preservation mechanism for their crops. Currently, crop drying is not a widely-used practice and is often done using solar radiation, which takes several weeks to months (Wakjira 2010). As a result, there is only one season per year when the locals can eat fruits and vegetables. At the end of this season, because of the produce's short shelf-life, up to 30% of the fruits decay and are wasted (Wakjira 2010). However, by providing a local mechanism to dry the fruits and vegetables for preservation, the region would be taking a large step towards eliminating hunger. Furthermore, as the population grows, a larger and more secure food supply would be needed. Since the dried commodities could be saved for longer periods of time, it could be stored and eaten during droughts and other food shortages. In addition, during these shortages the dried produce could be more easily transported to other regions who may need it. Having a longer shelf-life would allow the crops to be sold more readily and easily, improving the local economy.

The second direct use application will be for leather tanning. The hides and skins industry makes up at least 14-16% of Ethiopia's export business (Tesfaye, Dubie and Terefe 2015). However, there are only 27 tanneries in the country that process these commodities (Urgessa 2013). Currently, the locals in Shashemene have no facilities to process their own hides and skins. The collection centers are far away, making it difficult and expensive for the locals to do business with them. As a result, they sell 82% of their hides and skins to middlemen, who transport them and sell them to collection centers. The other 18% of their hides and skins are sold directly to collection centers for more money (Tesfaye, Dubie and Terefe 2015). These collection centers process the hides and skins and either sell them domestically or export them. However, using the geothermal resource to build a tannery close to these communities would enable the locals to sell their hides and skins directly to the tannery for a better price, eliminating the middlemen, and therefore would increase the region's export market. The tanning process requires temperatures up to 65°C to process and preserve the skins and hides (U.S. Environmental Protection Agency: Office of Air Quality and Pollution Standards 1995). The geothermal system will provide the required heat to the tanning facility. Creating a facility where the surrounding community could process their own hides and skins

instead of having to sell them to a third party would allow the community to be more financially independent with additional job opportunities.

Geothermal heat would also be used in this facility to sanitize the fluids resulting from the slaughter of the animals. Currently, larger slaughterhouses in Ethiopia discharge some of the animal fluids to the wastewater, which flows into directly or indirectly rivers and rural slaughtering practices involve throwing the animal fluids directly into the rivers. Some large slaughterhouses treat the water first while others do not. The practice of throwing untreated animal fluids into the rivers introduces pathogens in the water, which others use as potable water (Mulu and Ayenew 2015). To combat this effect, the fluids from the animals could be collected and heated in large vats, using the geothermal heat, to temperatures between 70^{o}C and 80^{o}C to kill the salmonella bacteria (Doyle and Mazzotta 2000). It is assumed that other pathogens will also be killed at this temperature. After it is sanitized, the fluid byproducts can be disposed of into the rivers with little to no risk of introducing pathogens. This geothermal direct-use would help to prevent epidemics of sicknesses downstream from the slaughter facility.

Next, the geothermal fluid will need to be cooled to 55^{o}C so that it could be employed to heat hot springs. The hot springs will deliver two benefits: exploiting the tourism industry to benefit the local economy and to provide a location for the natives to relax. In 2015, the tourism industry only contributed 4.1% to the national GDP of Ethiopia (World Travel and Tourism Council 2015). Bolstering this industry in the region would create more jobs and enable the locals to sell the goods they produce using the geothermal direct-use system (i.e., leather, dried crops, etc.). The springs would be attached to a hotel to create a resort that would attract tourists to the area. It would consist of several pools that would be kept at temperatures between 35^{o}C and 46^{o}C. The geothermal system would be piped under the pools to exchange heat with heat exchangers that would warm the water. Having tourists to contribute to the local economy would provide more money for the communities to use for other infrastructure, such as irrigation or schools. Additionally, the locals would benefit from the hot springs, providing them with a place to relax and socialize. One of the challenges of this application would be adequate water supplies for the hot spring during a drought but perhaps a water purification process similar to that in use by the tannery might sufficiently purify the water and allow for its recycling and reuse.

The soil in the region is degraded, with a low nutrient level and soil structure (Ouedraogo 2001). This degradation has been tied to Ethiopia's declining food per capita value (Haileslassie, et al. 2005). However, compost has been shown to double harvest yield in the Ethiopian highlands by increasing the nutrition level of the soil. The same technique could be applied to the Corbetti area. Compost use would not only double the harvest, but it would also expand the farmable area (Edwards, et al. 2007). Being able to increase the harvest yield using the same amount of land would be essential to providing food for the region's growing population. However, the compost could also be employed to expand the farmable acreage on previously unsuitable soils. A compost production plant could be created using the geothermal heat at 45^{o}C as a source to speed the production of the compost as well as to kill weed seeds and pathogens in the compost that may hinder crop growth (Trautmann 1996). Currently, compost takes several months to produce but using the geothermal heat will reduce production time down to several weeks. The compost would consist of solid and livestock organic waste. The compost material would be collected from the local communities and other facilities within the geothermal system, such as the unusable material from the tannery and crop drying facilities as well as the crop material that is left after a harvest in the greenhouse. The compost would be kept and processed in cylindrical holes in the ground. A mechanized stirring system would be installed to turn the compost over periodically. The geothermal heat would be exchanged to hot air, which would be pumped underneath the compost pile. This arrangement would allow for optimal oxygenation of the compost and would keep the compost at temperatures between 50^{o}C and 60^{o}C, which is the ideal temperature for faster compost production. The use of solid waste to create the compost would help keep the local region cleaner, thus reducing disease and groundwater contamination. The compost could be used in greenhouses and on fields in the area. The increased production of food would help eliminate food shortages and eliminate boom and bust production as drought and climatic conditions fluctuate, providing a sustainable food base for the growing population.

The final geothermal direct-use would be to heat a series of greenhouses. Currently the staple crops in the region are maize, cereals, and haricot beans (Biazin and Sterk 2013). The lack of water limits what can be grown in the Corbetti area and the lack of nutrients in the soils makes it difficult to grow most crops. Only some fruits and vegetables, such as tomatoes, green beans, oranges and papaya, are grown during the short rainy season from July through September (Wiersinga and de Jager 2009). However, a series of greenhouses would provide a resource for the locals to grow these crops year-round. The condensation that would form in the greenhouse could provide a humid atmosphere and water for the crops. The greenhouses would be kept at 30^{o}C using the geothermal heat system, at 35^{o}C, to provide the right climate for these fruits and vegetables. In addition to the fields, the compost could be used in the greenhouses to increase the crop yield. This geothermal system would provide a more sustainable and reliable way to grow fruits and vegetables, which will be needed as the population grows. A year-round source of these fruits and vegetables would improve the overall health of the locals and the local economy. In addition, these fruits and vegetables could be dried using the geothermal system so they could be preserved and stored longer, as described above.

The remaining geothermal heat would be cooled to a temperature around 25^{o}C when the system is pumped back underground to begin the system again.

3.1.2 Meeting the Sustainable Development Goals

The UN SDGs outline 17 goals for the world to meet by 2030. These goals and how a direct-use geothermal system in Corbetti would help to meet them are outlined below.

1. End poverty

The targets for this goal are centered around reducing the number of people living in poverty worldwide (United Nations 2015). There are many ways to achieve this, however, it has been shown that expanding Ethiopia's agricultural industry reduces poverty by 4% per year (The World Bank Group 2015). However, the poverty rate is still 42% for rural regions and 37% for urban regions (Tafere 2012). The proposed Corbetti direct-use system focuses on the agriculture industry in the region to help reduce poverty. The ability to grow, process, preserve, and sell produce locally would be essential towards building the local economy and would help the locals be more self-sufficient and less reliant on changing market prices.

One of the larger causes of poverty in the area is the high price for food and goods during the dry season when crops are not being produced (Asha, et al. 2006). During these times, prices can double or even triple, meaning that the impoverished locals are perpetually under the poverty line since they have to spend more money for the same goods. However, the use of geothermal heat for crop drying to preserve the produce would allow the locals to save their food to eat during the dry season, thus reducing the amount of goods they would have to buy at peak prices. Also, speeding up the compost production using geothermal heat would allow for larger harvest yields, thus increasing the amount of goods available, lowering prices during the dry season. Lastly, a local geothermally-heated greenhouse would reduce the amount of fruits and vegetables that would have to be imported during the dry season since crops could be grown year-round.

A larger harvest yield will also allow for more food to be used to feed livestock, thus allowing locals to expand their herds. The increase in animals would also increase meats and animal byproducts available for local consumption and export.

In addition to agricultural benefits, other benefits to the region would also help in ending poverty in the area surrounding Corbetti. Being able to process hides and skins locally would eliminate the middleman and provide the Corbetti area with an exportable product. The hot springs would bring in tourists providing a market for these commodities. Also, many jobs will be created through this system. Workers will be needed to maintain the system, cultivate farm and greenhouse crops, run the compost production facility, tan hides and skins, work the crop drying facility, and staff the hot springs and resort.

2. Eliminate hunger

Targets for this goal include eliminating hunger and malnutrition as well as doubling agricultural productivity and creating sustainable food production systems (United Nations 2015). The proposed geothermal system could help meet these goals by providing compost to double the harvest yield, greenhouses to grow crops year-round, and crop drying to preserve the crops so they can be stored.

An empirical study done in Shashemene suggests that 36% of households are food insecure and that two of the leading causes of this insecurity is a shortage of cultivatable land and shrinking harvest yields (Mitiku, Fufa and Tadese 2012). The use of geothermal heat to speed the production of compost would allow the community to expand their farms and increase crop production. Since the compost would be produced faster, it could be applied several times a year, possibly allowing for another growing season (if water is available). Currently, the harvest yield of those who have food insecurity is estimated to be only 83,000 hectacres compared with 186,000 hectacres for those with a secure food supply (Mitiku, Fufa and Tadese 2012). Since compost use was found to double harvest yield, it could be expected that the food insecure would produce 166,000 hectacres of crops on the land they already cultivate, not including the possibility of expanding their cultivation areas. An expansion of farmable area would require, however, a larger water supply. This amount is much more comparable to the harvest of someone with a secure food supply in the region and would make giant strides towards eliminating hunger in the region. In addition, the double in harvest would allow for more livestock to be taken in since there would be more food to feed them with. This increase in livestock production would provide meat and dairy products to the locals, further increasing their food supply.

As discussed above, during the dry season the prices for produce and goods can double or triple (Mitiku, Fufa and Tadese 2012). This price increase means that the locals cannot buy as much food at a time, causing them to eat less. A greenhouse heated year-round using geothermal would be invaluable to this region. The greenhouse would allow for year-round production of fruits and vegetables that the locals could obtain at much lower prices than imported fruits and vegetables during the dry season providing a more stable, less expensive food supply.

The geothermal crop drying facility would also be very important for meeting this goal in the Corbetti region. Being able to dry and preserve the crops that are grown would provide a food source during droughts and other food shortages.

3. Ensure health and promote well-being

People living in the Corbetti region experience many health issues from a lack of fruits and vegetables in the dry season. More importantly, children in the region suffer from growth stunting due to prolonged hunger and women often suffer from malnutrition [30, 31]. One of the targets of this goal is to reduce the number a child deaths and the number of neonatal deaths (United Nations 2015). While there are many causes of child and neonatal deaths, malnutrition accounts for 472,000 deaths in the region annually (Fentaw, Bogale and Abebaw 2013). The geothermal system proposed for the region would be able to substantially mitigate these issues. The greenhouse will allow for year-round cultivation of fresh fruits and vegetables while the crop drying system would allow for preservation of these goods. The ability to grow fruits and vegetables year-round and to dry the commodities the locals produce will increase the availability of fruits and vegetables that the locals can consume during the dry season since they can be saved for longer periods of time. This would improve the diet of the locals during the dry season.

Additionally, the compost would increase harvest yields. An increase in harvest yields would allow for an increased livestock capacity since the extra harvest could be used to feed the animals. The extra livestock would provide an increase in meat and animal products, like dairy products, which the impoverished often cannot afford and thus do not consume even though they are essential to the human diet. However, providing the locals with more meat and animal products will benefit the diet of the region and thus improve the health of not only children and pregnant women, but of all the locals.

The use of geothermal to perform these activities also may improve the local air quality. If fossil fuels or biomass are used to complete these tasks, more carbon dioxide and smoke would be released into the atmosphere. Therefore, utilizing geothermal for direct uses in this community would keep the local air quality at the current level or even improve it.

Another target aims to improve the overall health and wellbeing of individuals around the world (United Nations 2015). The geothermally heated hot springs would promote health and improve general wellbeing. Hot springs have been proven to increase blood flow, reduce stress, relieve pain, and help combat numerous medical conditions. By providing the locals with a place to relax, the geothermally heated hot springs will promote the community's wellbeing. In addition, the locals would have a reduction of muscle pain and stress.

Lastly, the use of geothermal heat to sanitize the animal fluids produced by the butchering and tanning processes would help prevent disease outbreaks in the region. The targets for this goal include a target that aims to reduce the number of deaths and illnesses caused by contaminated water (United Nations 2015). The proposed direct-use system would help prevent water contamination by sanitizing the fluids before they are released.

4. Quality education

Target 4.7 of this goal strives to teach students about sustainable development and give them the skills to develop and promote sustainable development (United Nations 2015). The geothermal development at Corbetti Caldera could provide an example of a sustainable project that students could learn about and explore. Corbetti Caldera is located within the proximity of the Awasa College of Agriculture, which is 16 kilometers away. Since the direct-use system would be built to focus on bolstering the agricultural industry in the area, it would be an invaluable location for the students of the college to visit and study. A hands-on, real-world application of what they have learned during their education will further their learning.

Another target aims to educate the locals in vocational and technical applications that they could use for employment. Since there is a shortage in technicians who can repair geothermal systems, the colleges could implement a geothermal major that incorporates both the sustainable applications of geothermal and the technical aspects such as the creation, maintenance, or repair of the different systems. Those who go through the program could find jobs locally working on the geothermal system and developing others.

Furthermore, the entire geothermal system would provide an excellent way to educate the local people about geothermal energy and sustainable systems. The local people could learn more about the UN SDGs, which may inspire some to make small changes in their own lives towards meeting the goals.

5. Gender equality

Currently, women in Ethiopia are largely seen as unequal to men in education, jobs, and politics but they are slowly gaining equality through programs such as the Ministry of Women, Children, and Youth Affairs and the National Policy on Women (United Nations Development Programme 2014). A geothermal direct-use system at Corbetti could help these programs to eliminate gender inequality in the surrounding area. If more women are involved in building and maintaining geothermal plants and processes at Corbetti, they may take more personal ownership over it, thus improving their status in the community. Also, this geothermal project could be used as a method to integrate more women into the workforce since women could be hired to work the different components of the system such as the greenhouse, tanning, or hot springs facilities and resorts. With an increase of women working in the public sector, integration into the political sector would soon follow.

Additionally, since gender inequality is often closely linked with poverty, addressing poverty as described above would make large strides in eliminating gender inequality (United Nations Development Programme 2014). Women entrepreneurs could start small trading or commercial businesses that would sell the geothermally-produced products such as the dried fruits and vegetables or the hides and skins. This would give women more economic power and fight poverty in the area.

6. Clean water and sanitation

Most of the targets for this goal focus on keeping the local water sources clean and free of pollutants (United Nations 2015). The geothermal system would make large strides towards keeping the drinking water around Corbetti Caldera free of pollutants. Currently, in rural areas solid and animal waste is often dumped along roadsides and in open fields since there are no collection systems in place or the ones in place are inadequate for the amount of trash that accumulates (Tadesse, Ruijs and Hagos 2008). This litter is often comprised of debris ranging from glass and plastic to organic waste. If an adequate waste collection system were put in place that could not only collect the waste but could also separate the organic waste, the geothermal system would help keep solid and organic wastes out of the river systems since the compost facility would use these wastes to make compost. Therefore, less wastes would be dumped into the water sources, keeping pathogens and other pollutants out.

Additionally, animal wastes produced during the butchering process are often discharged into the river without any treatment, thus contaminating the water supply for others who live downstream (Mulu and Ayenew 2015). However, the geothermal system could be

used to utilize a lot of the waste in the compost system and to sanitize unusable waste by heating it between 70oC and 80oC, killing pathogens in the fluids, before it is discharged, thus helping to keep the rivers clean and pathogen-free.

7. Affordable clean energy

This goal aims to increase the diversity, efficiency, and access to sustainable energy sources (United Nations 2015). The geothermal system that would be implemented in Corbetti will meet all of these targets. First, the planned geothermal system that is to be put in the Corbetti Caldera will generate 1000 MW of electricity that can be used to power Ethiopia's cities and towns (Reykjavik Geothermal n.d.). The extra electricity could also be exported to other countries, providing them with a clean, affordable energy source. In addition, Ethiopia currently relies on hydropower for 86% of its energy (What Power Africa Means For Ethiopia 2015). Ethiopia's shift from relying almost exclusively on hydropower to generating geothermal energy will provide a more reliable electricity source since unpredictable rainy seasons render the hydro-plants unreliable and inadequate. Also, utilizing geothermal energy instead of other renewable energy sources creates added benefits such as the ability to use the heat in direct-use applications and zero carbon emissions. Furthermore, using the geothermal heat in direct-uses such as crop drying and heating a hot springs eliminates the energy draw-down that would be caused if these systems had to be powered using electricity. Lastly, geothermal power plants are more efficient than fossil fuels or other renewable energy since the system generates more energy with less input. Therefore, a geothermal system at Corbetti will help the region produce affordable, reliable, clean energy.

8. Sustainable employment and economic growth

The targets of this goal include increasing the national GDP by 7% each year, diversifying the markets, and increasing the number of youth working (United Nations 2015). This geothermal direct-use system would create several jobs, which include maintenance workers to maintain the geothermal system and employees for the tannery, hot springs, compost, and crop drying facilities. Women and youth could be employed to work in some of these jobs, thus increasing the number of youths working and decreasing gender inequalities. In addition, they could be trained in different agricultural practices or geothermal system maintenance, skills which they may use throughout their lives. The addition of the hot springs and the crop drying facilities would add new markets in the Corbetti area, diversifying the economic inputs into the community which would provide a more stable economic foundation. Currently, economic inputs include agricultural products, such as livestock and grain, and crafts, such as pottery and clothing (Asha, et al. 2006). Lastly, while this system would not single-handedly increase the national GDP by 7% each year, it would help to increase the GDP towards meeting that goal by expanding the local markets and creating more goods for the locals to sell. Additionally, creating a tourist area with the hot springs will bring in additional income to the community. Thus, the GDP of the Corbetti area would be largely improved.

9. Industry, infrastructure, and innovation

The first two targets of this goal are to provide sustainable infrastructure that improves the local economy and the locals' wellbeing, and to provide more industrial processes to raise employment and the local GDP (United Nations 2015). Providing the locals of Corbetti with the infrastructure to utilize this geothermal resource would create an industrial area around the Corbetti Caldera where the locals can go to grow and process their own goods. These resultant goods would provide the locals with a larger, more stable and more diverse food supply which would improve local diets, thus improving local well-being. The system would also create a larger local economy with the addition of produced goods such as dried crops and fruits and vegetables from the greenhouse. Furthermore, the hot springs will provide another element of wellbeing to the locals since hot springs provide an area to relax.

The geothermal direct-uses would provide many jobs for the surrounding communities such as maintenance workers and employees to manage the geothermal compost heating system. Lastly, while geothermal has been used in direct-use applications for hundreds of years, it is still underutilized. A geothermal system at Corbetti could meet several of the UN SDGs through innovative applications when compared to the traditional ideals of focusing on only one goal at a time.

11. Sustainable cities and communities

The targets for this goal include protecting cultural and national heritage, reducing environmental impacts of cities, and improving regional development planning (United Nations 2015). By seeking to increase the yield from local traditional agricultural practices, the geothermal system proposed for the Corbetti Caldera would seek to protect and enhance the local cultural traditions. An example is the local process of leather tanning. The geothermal system would not change any aspects of the process but would instead remove the need for fossil fuel or biomass energy to complete the process by using the residual geothermal heat.

In addition, the use of geothermal to perform all of these processes has several positive environmental impacts. By replacing the traditional use of fossil fuels to achieve these processes, the area would have better air quality than other areas and would produce no carbon dioxide emissions, unlike fossil fuels. At this time, the use of biomass and fossil fuels in the area causes the area to be polluted with smoke (Asha, et al. 2006). Also, the use of geothermally-produced compost would improve local soil quality and reduce the amount of contaminants in local water systems by removing organic and solid waste to use for compost. The leather tanning process, which produces animal fluids, would also be made more environmentally friendly since these fluids would be disinfected before being discharged into the environment.

Lastly, as the population of Ethiopia grows by 2.6% per year, more sustainable industries will be needed to provide food for the increased population (Wines 2006). This geothermal system would increase the amount of food and would provide a model for other communities to develop a system to increase their harvest yields. Compost use would likely double the agricultural output per harvest

and the extra harvest could be used to raise more livestock (Edwards, et al. 2007). Creating access to crops year-round through the use of crop drying and a geothermally-heated greenhouse would also ensure adequate food for the growing population.

12. Responsible consumption and production

This goal has targets aiming to reduce the amount of food waste that an area produces and to reduce the amount of chemicals and biohazards that are released to the air or water of a community (United Nations 2015). The geothermal system proposed for Corbetti offers several responsible consumption practices including use of spoiled food and unused crop components to make the compost. The system creates a cycle that begins with the production of compost which is then used to increase the harvest yield. The unused portions of the crops from the harvest are in turn put back into the system to create more compost. In addition, the crops that are produced can be dried to reduce the amount of waste since the dried crops can be stored longer.

Furthermore, the geothermal heat would be able to kill pathogens in the animal fluids that are produced during butchering and skinning of the animals. These fluids are currently a biohazard to those who use the river as a potable water source since they are often discharged into the river without being processed (Mulu and Ayenew 2015). The geothermal heat would limit the amount of biohazards that are discharged into the rivers of the Corbetti area by disinfecting the fluids before they are discharged.

15. Life on land

One of the targets of this goal is to preserve and protect freshwater resources on land (United Nations 2015). However, the current practice of dumping animal fluids produced during the butchering and skinning of animals into the rivers of Ethiopia causes contamination and degradation of the drinking sources, especially rivers (Mulu and Ayenew 2015). To combat this effect, the geothermal system could be used to eliminate the harmful bacteria by heating the fluids before they are released, killing potential pathogens.

Another target focuses on restoring degraded land and soil (United Nations 2015). In Ethiopia, especially the highlands, soil erosion and nutrient depletion are common problems that deplete the harvest yields (Amsalu and de Graaff 2007). However, the use of geothermal to speed up compost production in the Corbetti area would enable more compost to be put on the fields, thus restoring the degraded soil and improving harvest yields.

4.2 Tigray

Tigray is the northernmost region in Ethiopia. It relies heavily on agriculture, with 65% of the land being cultivated (Beyene, Gibbon and Haile 2001). The population of the region is dispersed, with most of the population living in rural areas. Currently, the government of Tigray is divided into smaller sub-governments that answer to the higher governmental bodies. The smallest of these bodies in Tigray is the kebele which is in charge of the local community or of a specific neighborhood. They act as the first point of contact for citizens and are responsible as a liason for the community to the higher governmental bodies who approve local policies (Yilmaz and Venugopal 2008). Being composed of several legislative bodies such as a cabinet, an assembly, and an elected council, these kebeles also have many community committees such as women committees and youth committees.

The assembly is composed of all the community members and they meet as needed, but often these meetings do not represent the community's voices since they are run by the kebele administration's agendas. Additionally, attendance at these meetings is generally low unless attendance is forced by the kebele leaders in an effort by the government to increase community participation (Vaughan and Tronvoll 2003, United Nations Development Programme 2014, Albin-Lackey 2005). The low attendance reduces the accountability of the community members which may contribute to the corruption that Ethiopia's government is often plagued by. Forced attendance results in frustrated community members and causes a distrust of the local government, with only 28% of Ethiopians proclaiming trust in their government (Rheault 2008). Women often serve on the council but they are usually not involved in decision making and their voices are not heard (Yilmaz and Venugopal 2008). Smaller villages in the Tigray region generally only have one kebele responsible for handling all the community's affairs but its size varies based on the population of the area with one kebele being assigned for every five hundred households (Vaughan and Tronvoll 2003).

Tigray does not currently have any explored high temperature geothermal resources. However, a heat pump could still be installed to utilize the low temperature geothermal resource that exists at a few tens of meters below the surface. The geothermal heat pump could be used to maintain a constant, comfortable temperature in a town hall and community center facility with the goal to increase the public's attendance of governmental meetings due to the comfortable atmosphere of the building. In addition, the building could be used for community events that would benefit the locals and foster a sense of comradery. These events could include cultural festivals and celebrations or adult classes in other languages, trades, or technical skills.

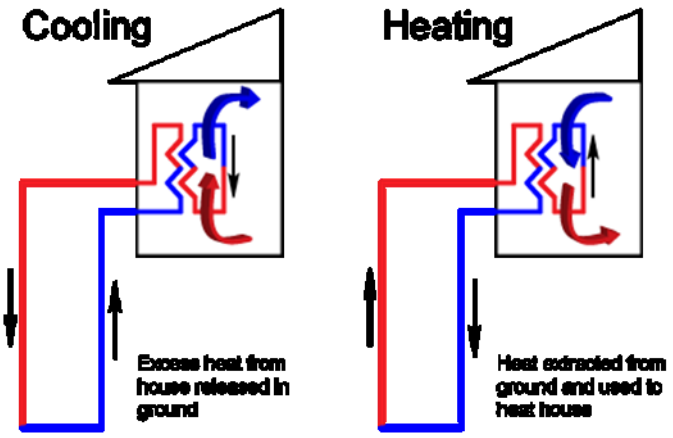

Figure 3: A Geothermal Heat Pump (GHP) system works like a Carnot cycle (Geothermal Heat Pump n.d.).

4.2.1 Geothermal Heat Pump System Use

The geothermal heat pump system will be comprised of a closed loop system that begins by pumping a fluid with a low boiling point from underground, where it picks up the latent heat (assumed to be 15°C in this region) to the heat pump on the surface as shown in Figure 3. Then, a compressor raises the temperature of the fluid to 30°C so that when the heat is lost during the exchange, the temperature of the air to heat the room will be comfortable, around 20°C. This fluid passes over a heat exchange coil that heats or cools the air in the building. Air ducts would be used to move the air around the building. Several heat pumps would need to be installed to efficiently heat or cool the entire complex (Glassley 2015). Solar panels could be used to provide the electricity that the heat pumps require.

Providing a space for the locals to congregate during the day would help to bring the community closer. They could use the space for community festivals or celebrations. Furthermore, using the city hall space as the meeting area for the kebele and making it comfortable would make the community members want to go be a part of the meetings. This close-proximity to the policy makers of the community could help to reduce corruption and hold the kebele members accountable. In addition, the locals would be more apt to voice their opinions and make their needs known. During these congregations, the community members could be educated about politics and receive an introduction to the SDGs, geothermal systems, and climate change. By learning about these topics, the community may decide to implement policies that would help the area meet the goals and combat climate change. Lastly, having a stable and central political organization in the rural regions of Tigray would allow for more funding by outside organizations since they will be more likely to donate money to an organized area that could be used for community-driven improvements.

4.2.2 Meeting the Sustainable Development Goals

An overview of how a GHP in a rural region of Tigray could help the local community meet the SDGs is presented below.

4. Quality education

Targets of this goal include providing early childhood education and teaching adults skills that they could use in everyday life (United Nations 2015). As it is, Ethiopia is making progress towards creating more opportunities for early childhood education as shown by the National Policy Framework for Early Childhood Care and Education. However, there is still a shortage of education facilities, especially in rural regions (Orkin, Yadete and Woodhead 2012). Having a geothermally heated community center could provide the local community with a space where community members could bring their young children to be taught, similar to a preschool. In addition to an early childhood education facility, the community could use the building to hold adult technical classes, such as accounting, language, entrepreneurial, or agricultural classes that could increase the knowledge and skills of the community members.

5. Gender equality

One of the targets of this goal is to ensure that women have equal participation in political, social, and economic life (United Nations 2015). Women in Ethiopia are becoming more active in the political sector, however, only 10% of governmental ministers are women and only 16% of women hold legislative or managerial positions (United Nations Development Programme 2014). If more women are present at the kebele meetings due to the comfortable atmosphere, women may have a larger voice in the political, social, and economic sectors in the rural regions of Tigray. They could hold women's meetings in the community center that could be used to collectively voice women's needs and build comradery between the women of the community.

Also, women in Ethiopia are usually responsible for collecting wood for fuel which can be time consuming (Vaughan and Tronvoll 2003). Because the building would be heated using the ambient underground temperature, no fuel-wood would need to be collected, thus not adding to the women's work.

6. Clean water and sanitation

The targets of this goal focus on providing all people with a reliable source of clean water (United Nations 2015). Though the geothermal heat pump would not directly create water for the local community, it would not take away from their water resources. One of the benefits of geothermal heat pumps is that they do not use any water. Also, by keeping the inside temperature of the town hall/community center building cool during the hot summers, community members could cool off there which may reduce the amount of water that the locals would need to drink.

7. Affordable clean energy

Hydropower is currently the largest generator of electricity in Ethiopia and biomass is often utilized for heat and cooking (What Power Africa Means For Ethiopia 2015). However, the hydropower is unreliable due to droughts and the biomass pollutes the air. The targets for this goal concentrate on generating reliable, sustainable, and clean energy. The use of a geothermal heat pump to regulate the building's temperature by keeping it warm in the winter and cool in the summer eliminates carbon dioxide and smoke emissions that would otherwise be produced if fossil fuels or biomass has been used to achieve the same results. The heat pump is not dependent on the nature of the area like solar, wind, and hydro power are. Therefore, it is much more reliable and sustainable than these sources.

8. Sustainable employment and economic growth

One target of this goal is to create policies that encourage entrepreneurship and job creation (United Nations 2015). Collaboration is needed to determine which policies will benefit the community the most. Without community and kebele leader interactions, the policies enacted may be useless. Having a space for the community members to meet and interact with the leaders could enable policy making that benefits both stakeholders and is unique to every small community based on their needs. These policies could be focused on local resources that could be sold in entrepreneurial pursuits such as lumber, honey, or grains. Additionally, job creation could be attained because community members in need of help could advertise their jobs during these gatherings.

10. Reduce inequalities

One of the targets of this goal is to promote and empower the political, social, and economic inclusion of all people (United Nations 2015). Currently, women, those in occupational minorities, and those in perceived "lesser" ethnic groups are largely excluded from the political sector (Vaughan and Tronvoll 2003). Since the kebele is responsible for making all community decisions, a greater attendance at kebele meetings would be invaluable in decreasing the inequality of these various groups. However, these groups may find more inclusion in the local kebele if a building was created that was geothermally maintained at a comfortable temperature. This would encourage the attendance of these groups as they seek to rest and converse out of the heat or cold of Ethiopia. An increased attendance could allow for more inclusion of these groups, their ideas, and their needs in community decisions.

11. Sustainable cities and communities

Target 11.4 of this goal focuses on preserving the cultural traditions of local communities (United Nations 2015). Ethiopia is a country with many different ethnic groups and cultures. The cultural traditions of many of the groups in Tigray include festivals and celebrations throughout the year, such as Ashenda, a festival in August (Olorunnisomo 2013). The geothermally-heated community center could be used as a place for the community to hold and pass on cultural traditions like the Ashenda festival. This could preserve the local culture as well as promote a greater sense of community and unity throughout the region. If different cultures held festivals and ceremonies at the community center, it would also provide an opportunity for the locals to teach others about their cultures and traditions.

12. Responsible consumption and production

Target 12.8 of this goal aims to provide everyone with information about sustainable development and environmentally responsible systems (United Nations 2015). The geothermal heat pump could provide an opportunity for the community to learn about renewable energy and utilizing it to combat climate change. Also, meetings could be held in the center that provide information about these topics including a class about geothermal heat pump systems.

13. Climate action

One of the targets for this goal is to educate people about climate change (United Nations 2015). Classes could be held to educate the community about climate change and how geothermal could combat it. Additionally, the use of the geothermal heat pump to maintain the temperature of the building ensures that no further emissions will be released to pollute the air like if biomass or fossil fuels were used to heat and cool the building. This not only makes a small step towards reducing carbon emissions and thus combating climate change, it could also be used as an example to the locals that they may decide to implement in their homes, thus further reducing emissions and combating climate change.

16. Peace, justice, and strong institutions

Targets for this goal include creating greater accountability and transparency of governmental institutions while reducing corruption and bribery. Other targets focus on increasing community involvement in governmental decision-making and to make information available to the public (United Nations 2015). Currently, there are mechanisms in place to increase governmental accountability. However, these mechanisms are often focused on service-based goals and do almost nothing to increase governmental accountability (Yilmaz and Venugopal 2008). By creating a comfortable space for community members to meet with each other and with government officials, greater attendance at kebele meetings could be obtained. Since the kebele is responsible for making community decisions, greater community attendance would be invaluable to meeting all of these targets. If more community members are present, the government

officials would be watched more closely by a wider group of individuals. This could promote more transparency and reduce the corruption of the local government. Additionally, some groups who are currently marginalized could be brought into focus because of their presence at meetings. Government officials, seeing the groups' obvious concern and interest in their community, may be more apt to involve them in policy making decisions. Thus, providing a geothermally heated and cooled town hall and community center area in a small community would be helpful in meeting this goal.

17. Partnership for the Goals

This goal is centered around bringing groups of people, both nationally and internationally, together to work together to meet the UN SDGs (United Nations 2015). By bringing the local community together with a shared space, they can meet in and hold political meetings in, the community could become united and driven to meet the UN SDGs in their own community. Though it may be a small group of people, they could serve as an example for other nearby communities to learn from. They could teach these other communities about the SDGs and how they may be able to take steps to meet them. In addition, having a centralized government building may make political organizations and businesses from other countries or areas more apt to partner with this area to help them meet the goals.

5. CONCLUSION

Based on the case study of the Corbetti Caldera and Tigray areas, it can be shown that geothermal, in its different forms, can be utilized to make small changes to the local communities. These small changes are instrumental in allowing the communities to meet the United Nations Sustainable Development Goals. A closed-loop geothermal system using the spent heat from generating geothermal electricity can be implemented to complete many direct-use applications. However, geothermal heat must be present to create such a system. Another geothermal system is a geothermal heat pump, which utilizes the near-constant temperature of the ground a few meters below the surface to regulate a building's temperature. This system can be applied in almost any setting.

In Corbetti, the spent heat from generating electricity would be utilized to complete several processes including drying produce, tanning leather and sanitizing the animal's fluids, heating a hot springs, speeding up the production of compost, and heating a greenhouse. The processes used would provide larger harvests, a mechanism for preserving crops, and a tourist market that could benefit the local community. These results would have major impacts on the surrounding community's progress towards the UN SDGs, helping the community to meet 12 of the 17 goals. These goals include ending poverty, ensuring health and promoting well-being, and building sustainable cities and communities.

In the Tigray region, a town hall and community center building could be built that would use a geothermal heat pump to keep the building a constant, comfortable temperature year-round. This small system could greatly improve the local community's political, social, and economic systems. The comfortable atmosphere of the building in the winter and summer could improve the local attendance of the kebele meetings. In addition, the space could be utilized to host festivals, celebrations, ceremonies, and classes for the locals. These benefits could help the community meet ten of the UN SDGs including attaining gender equality, reducing overall inequalities, and creating a partnership for the goals.

Some of the next steps towards implementing these systems include soliciting involvement of the communities, designing the systems, and conducting surveys to see which processes would benefit the communities the most. However, it is clear to see that geothermal energy can be used for more than generating electricity; it can be used to help communities grow and meet the United Nations Sustainable Development Goals by 2030.

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