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Developing a Geothermal Eco-Industrial Park: A case study of the KenGen Green Energy Park, Olkaria Geothermal field, Kenya

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ABSTRACT

Despite the huge success in electricity generation in Kenya, there are limited direct use applications of the country's vast geothermal energy potential. Studies have shown that Kenya has an installed thermal energy capacity of 22.40 MWt, annual energy use of 50.70 GWh/year with a capacity factor of 0.26 but boasts of few successful direct use applications compared to other parts of the world. The Oserian Greenhouses using the geothermal resource for the cut flower farming and the geothermal spas in Olkaria and Bogoria areas are the most successful direct use applications. Therefore, KenGen is in the process of establishing an industrial park within the Olkaria Geothermal area. The idea is to utilize available and abundant geothermal resources for industrial purposes to tap environmental, economic, and social benefits for the country. These geothermal resources include cheap electricity generated from the geothermal power plants, more than 2000 t/h of brine from several separator stations at 130°C. Other sources include steam from low to medium enthalpy wells, wells with unique characteristics e.g. cyclic wells, CO_2 or SiO_2 rich wells, and also drilled wells that are located far from the existing power plants.

The identified industrial applications within the park include textile, steel and glass manufacturing, eco-friendly fertilizer production, milk processing, and crop drying facilities. Other ongoing research opportunities include mineral extraction from brine and carbon capture for various applications. A design to promote an exchange of resources among these processes in a cascade approach will result in better resource utilisation and enhance sustainability. The use of Combined Heat and Power (CHP) technologies make more efficient use of geothermal resources. This is realised by cascading the geothermal fluid to successively lower temperature applications, thereby dramatically improving the economics of the entire system. The main aim is to assess the possibility of a stronger circular economy by optimizing the use of materials, energy, and wastes in a sustainable circular approach. Material Flow Analysis is used as the main method to optimize the flow of resources as well as identify opportunities that could arise within the cluster of companies. By promoting the industrial symbiosis innovative concept between firms, ensures the wastes of one industry become the raw materials for another industry hence, minimizing waste and enhancing resource use efficiency. These innovative technologies will upscale the planned KenGen Green Energy Park and its development guided by best practices of an Eco-Industrial Park (EIP).

1. INTRODUCTION

Kenya is endowed with a huge potential of an environmentally benign geothermal energy source that is used for electric and non-electric uses (Mangi, 2013). Studies have estimated that the geothermal resource potential in Kenya is about 7,000-10,000 MWe across the fourteen (14) high-temperature prospective resource areas in Kenya (Omenda, 2012; Ogola, 2013). With Olkaria geothermal area currently in an advanced development phase, Kenya is ranked at position eight (8) globally with an installed capacity of about 840 MWe from geothermal generation (ThinkGeoEnergy Research, 2019). Menengai, Eburru, Barrier and Paka-Silali geothermal fields are currently in different stages of development with a plan to deliver a total of 5,000 MWe by 2030. According to worldwide geothermal direct use data (Lund & Boyd, 2015), Kenya has an installed energy capacity of 22.40 MWt, annual energy use of 50.70 GWh/yr with a capacity factor of 0.26.

Unfortunately, there is limited utilization of the country's geothermal energy potential for direct use applications. However, the direct utilization of geothermal energy is continuously gaining popularity due to its economic, environmental, and energy efficiency benefits. In Kenya, a few direct use applications exist with health spas operating in Olkaria and Bogoria, crop dryers at Eburru, greenhouse heating, and carbon dioxide enrichment at Oserian flower farms and water harvesting for domestic purposes both at Eburru and Suswa geothermal areas. A demonstration centre with four direct use projects in Menengai geothermal area was set up by Geothermal Development Company (GDC) in 2015 to test the technical and economic viability of a geothermal energy cascade design. The projects include a milk pasteurizer, a heated greenhouse, heated aquaculture ponds, and a laundry unit (Nyambura, 2016).

Geothermal energy in Kenya has primarily been used for electricity generation while the separated brine is normally reinjected back into the ground while still containing huge amounts of thermal energy. Further, no other by-products of geothermal energy such as minerals or gases are extracted for useful purposes. As a result, there is inefficient utilization of the geothermal resource. It is expected that the establishment of a geothermal industrial park will address some of these deficiencies to a large extent. Also, thousands of jobs will be created for the local population and businesses through employment and provision of services to the industries within the park.

The utilization of geothermal energy depends on resource temperature. A high-temperature resource (>150°C at the surface), is mainly used for electricity generation in condensing power plants while, the low to medium temperature geothermal resources (<150°C) are utilized for direct uses or binary power plants (Mburu, 2010). The concept of a circular economy has promoted the development and optimization of Eco-Industrial Parks (EIPs) in several parts of the world. In a geothermal context, the geothermal steam, after being used for power generation, can be used for milk pasteurization, greenhouse heating, an aquaculture pond, and swimming pool heating before reinjecting it back to the reservoir as cold reinjection fluids. The innovative cascade use of geothermal heat can be an effective method to maximize the use of geothermal resources of low to medium enthalpy as shown in the Lindal diagram in Figure 1.

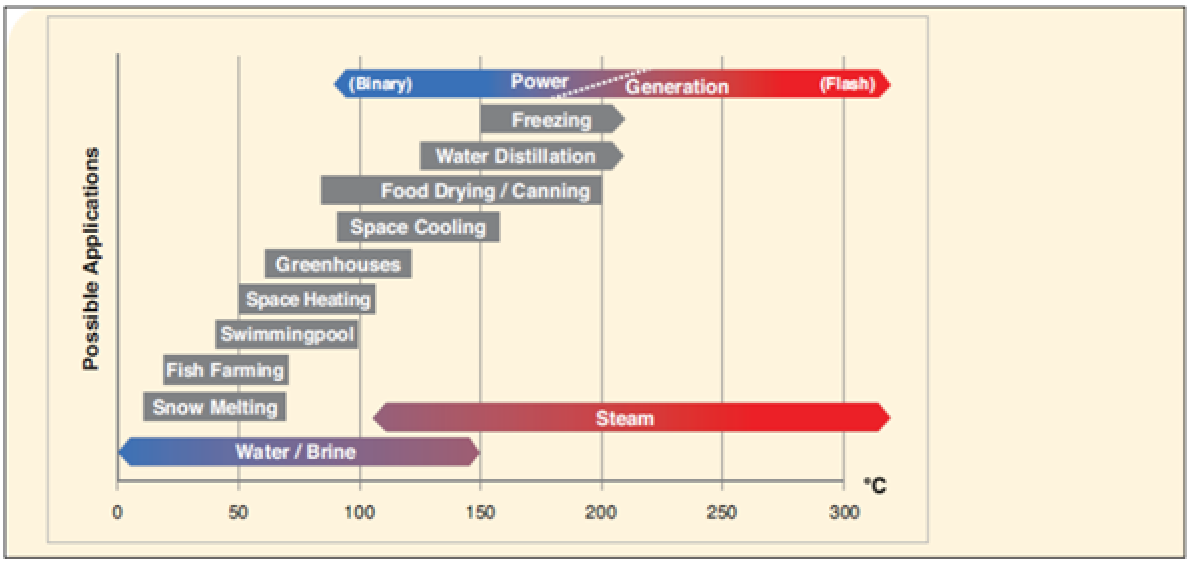

Figure 1: Modified Lindal diagram showing possible direct use of geothermal fluids

Hitherto, industrialization in Kenya has faced challenges due to the high cost of energy and its unreliability. Electricity from the grid costs about 0.1-0.12 USD/kWh during peak hours (Regulus, 2020). Due to unstable grid systems and occasional power outages, most industries install standby diesel generators and thus incur extra monthly electricity costs (VEGA, 2014). Similarly, most industries that require steam for their operations normally use industrial diesel oil or furnace oil to fire boilers. These sources are known for the emission of greenhouse gases. Besides, their prices are usually unpredictable, thus affecting costing and expected profits. Geothermal energy with a feed-in tariff of 0.088 USD/kWh, on the other hand, is cheaper, cleaner, and more reliable than the other sources of energy currently being used (Ministry of Energy, 2012). Furthermore, the direct use of geothermal energy presents an opportunity to eliminate the use of fossil fuels to generate thermal energy for industries.

Plans are, therefore, underway at the Olkaria Geothermal field to develop a green energy park that will utilize the geothermal resources therein. The facility will enable the tapping of the environmental, economic, and social benefits for KenGen and the local community. A feasibility study conducted in Olkaria (KenGen, 2016), identified the available geothermal resources to be utilized in the Park. These include cheap electricity generated from the geothermal plants and more than 2,000 t/h of brine from several separator stations at 130°C.

KenGen´s effort to attract investors and become highly competitive is largely dependent on the sale of energy directly from the power plants to the industrial park operators. The Energy and Petroleum Regulatory Authority (EPRA) in February 2020 approved a lower electricity tariff of USD 0.05/kWh, which is about half of the electricity cost from the grid (USD 0.1-0.12/kWh) at peak time (Regulus, 2020). The industrial park investors are offered a lower tariff as a selling point to cushion them from high production costs associated with the cost of energy. Similarly, the energy park offers an opportunity for a land lease at a nominal rate on a 20-year renewable lease term (KenGen, 2016). Under the lease, the manufacturing/ processing firms will be supplied with geothermal steam, brine (hot water), and raw water at the rate outlined in Table 1.

Table 1: Rate at which utilities are sold to the industrial park (KenGen, 2016; Regulus, 2020).

Resource	**Rate (USD)**
Land (ha) (annual rate)	1200
Steam (ton/hr)	4
Brine (ton/hr)	4
Raw water (m^3)	0.5
Electricity (kWh)	0.05

According to KenGen Task Force Report (2018), there are about sixteen geothermal wells that are currently not assigned to any future electricity generation project due to the aforementioned reasons. These wells have been earmarked for connection to the industrial park. The identified industrial and service applications to be developed within the park, range from mineral extraction from geothermal brine, textile, steel and glass manufacturing, eco-friendly fertilizer production, milk processing, and recreation facilities. These industries have different energy needs. It follows then that, a design to promote an exchange of resources among these processes in a cascade approach, will result in better resource utilization and sustainability. This paper will, therefore, introduce the concept of designing and developing the KenGen Green Energy Park (KGEP) as an Eco-Industrial Park (EIP), with a focus on interfirm synergies that enhance resource (including energy) exchanges, to promote efficiency and sustainable development. It incorporates industrial symbiosis and circular economy to the current energy park design and assesses the potential benefits (Figure 2).

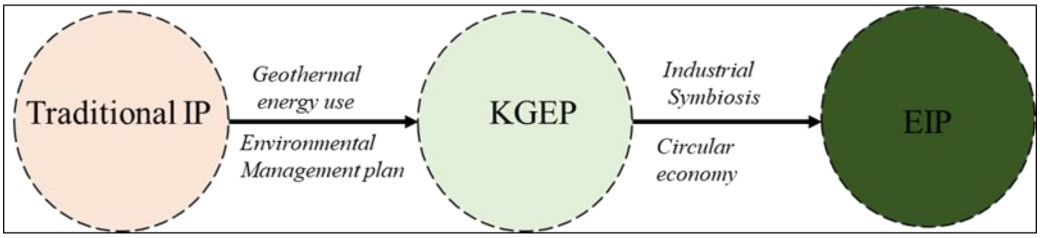

Figure 2: The proposed transition of KGEP to an EIP

1.1 Eco-Industrial Parks

The concept of energy parks within/near the geothermal resource areas is gaining momentum with Suðurnes Resource Park in Iceland as a successful example. Albertsson (2013), indicated that the geothermal energy parks are built on the following principles: a) integrated utilization of the various resources available from geothermal energy; b) sustainable development resulting in an ecological balance due to minimizing of waste through by-product sharing; c) economic prosperity due to creation of jobs in various disciplines; and d) social progress due to development of innovation, new job opportunities, and environmental awareness. Other factors include collaborations between different professions and companies resulting in the sharing of equipment, machinery, and manpower as well as increased sustainability in the utilization of geothermal resources due to increased efficiency within the resource area. All these are key drivers for developing Eco-Industrial Parks and can be customized by stakeholders in KenGen Green Energy Park. This would be in line with developing a framework for eco-efficiency evaluation, industrial process assessment, and monitoring of compliance for continuous improvement.

1.2 Industrial Symbiosis

This innovative concept is recognized as an approach towards the transition to a circular economy and its use contributes to environmental and economic benefits. It is a collaborative approach concerning the physical exchange of materials, energy, and services among different firms: accordingly, wastes produced by a given firm, are exploited as inputs by other firms (Albino & Fraccascia, 2015). In geothermal energy parks, industrial symbiosis is demonstrated by an efficient exchange of thermal energy in cascade design, to enable firms to achieve better energy utilization. The principle behind this is the fact that a single stream of hot water can meet the energy needs of several processes.

The thermal processes in the industries have been categorized into six temperature bands with each band having a temperature range of 20°C (Figure 3). The highest temperature band comprises of processes, which require more than 130°C, while the lowest temperature band processes require less than 40°C. Cold storage, milk powder processing, and deodorizing have the highest temperature requirement, while tanning processes in textile manufacture and fertilizer production, have the lowest temperature requirements. Water at the temperature of 40°C is reinjected at the periphery of the Olkaria geothermal reservoir for sustainability, forming a closed-loop system of production. As discussed by Gladek (2019), the use of renewable energy in an efficient manner is one of the pillars of a circular economy (CE). The materials required for energy generation and storage technologies are designed for recovery into the system. In CE models, thermal energy is effectively preserved and cascaded when lower amounts of energy are required for downstream processes.

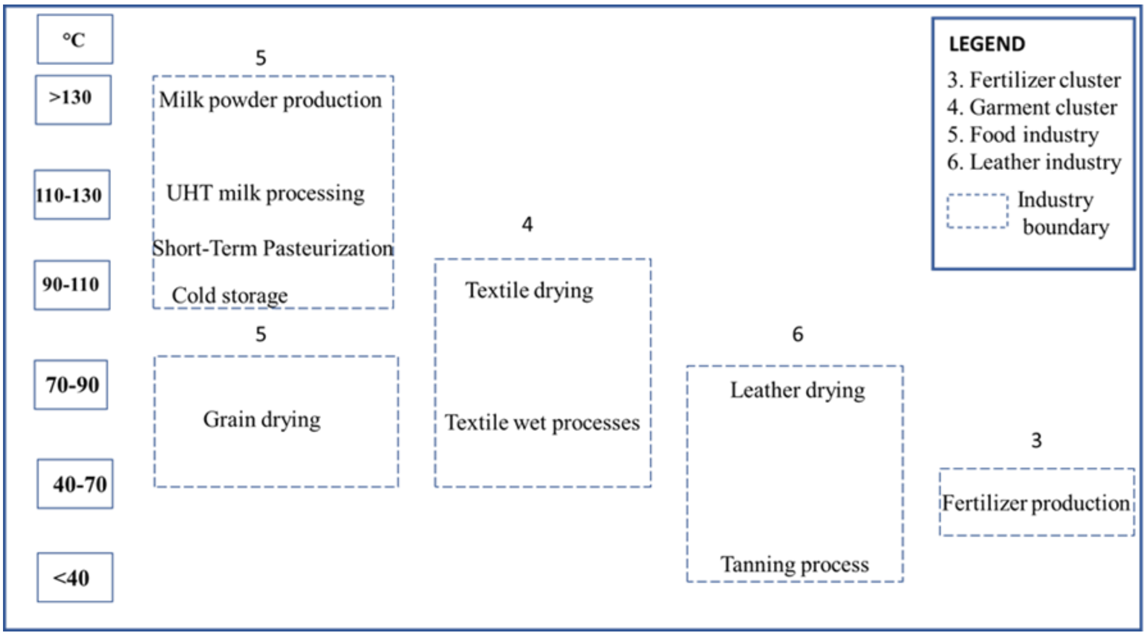

Figure 3: Energy cascade within the KenGen Green Energy Park

2. SUITABILITY OF KENGEN GREEN ENERGY PARK

2.1 New Policy Framework

Kenyan Government has identified the KenGen Green Energy Park as one of the Special Economic Zones (SEZs) to spur economic growth, by providing incentives and policies to promote and attract investment. Policies governing the Special Economic Zones in Kenya are incorporated in the draft SEZ policy and the SEZ Act No. 16 of 2015. The Act highlights integrated infrastructure facilities, access to business and economic incentives as well as the removal of trade barriers and impediments as being key benefits accorded through the SEZ regime. The major selling point of SEZs in Kenya is the tax shields offered within the confines of an SEZ (GOK, 2015). Licenced SEZ enterprises, developers, and operators benefit from various tax rebates such as exemption from excise duty, customs duty, value-added tax, and stamp duty. Further incentives include; advantageous corporate income tax rates and preferential withholding tax rates, especially concerning profit repatriation.

2.2 The Park Location

The park is located within the Olkaria Geothermal Area and is expected to tap direct energy produced within the resource area (Figure 4). The large amounts of thermal and electrical energy will be provided cheaply for utilisation by industries. The proximity of the industrial park to the Olkaria geothermal field means that energy will be transported for a short distance to the industries, hence reducing energy losses. The surrounding farming communities will also provide a source of raw materials to be processed in the park.

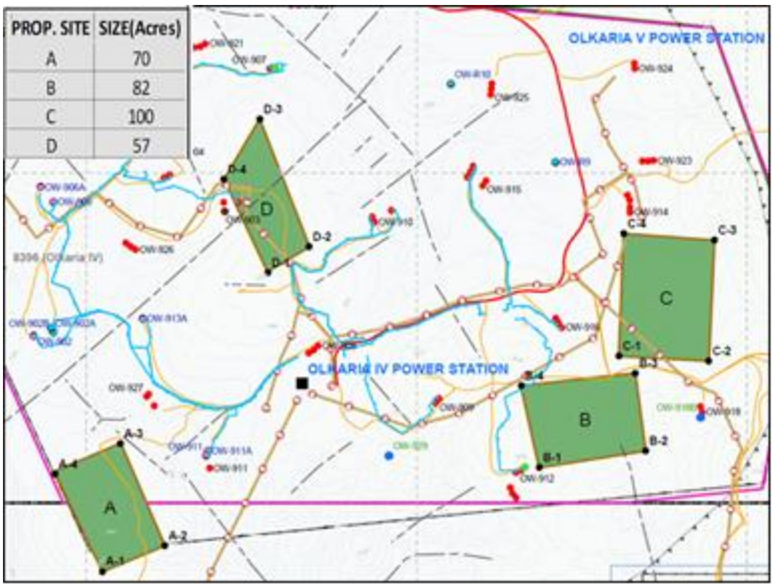

Figure 4: Proposed sites for the KenGen Green Energy Park in relation to the Olkaria IV (140 MWe) and Olkaria V (165 MWe) Power Plants

2.3 Infrastructure development

The park will be connected both by railway and road to Mombasa seaport and airports making it ideal for the transportation of raw materials and finished products to various local and foreign markets. The Standard Gauge Railway from Mombasa to Naivasha is a key major installation that connects several existing and proposed industrial parks providing a gateway into East Africa, making it a regional economic hub hence reducing time to market for the industrial products.

2.4 Geothermal Center of Excellence

The need to provide training and research on advancing technologies, the high international quality standards, the quality of the products, health, safety or environmental protection will be facilitated by the existing training centre within Olkaria. The linkages between academia and research and development institutions and other related industries will reduce technical barriers often associated with a lack of information on the changing technologies.

2.5 Water supply

Olkaria is generally a water-scarce area. However ongoing groundwater surveys within the resource area, have confirmed that the reservoir volumes are estimated at 16,964,640 m^3 and 7,121,914.8 m^3 to the East of the Olkaria Domes Field around well pad OW-922 and within the Olkaria Domes field around well pad OW-919 respectively (KenGen Hydrological Report, 2016). These viable zones have been earmarked for drilling for fresh water supply to the industrial park. Other sources of water are from the Rift Valley Water Service Board, which will connect the park with water from the Ewaso Nyiro River in Narok. Five boreholes have been drilled for this purpose.

2.6 Abundant energy resources

The energy-intensive industries will benefit from the cheap power and also thermal energy from brine and low-pressure wells in the Olkaria Domes geothermal field. Thermal energy will be harnessed from brine pipelines for use in the manufacturing zones before reinjecting it back to the geothermal reservoir. KenGen intends to supply the produced hot water to the industrial park for direct utilization. The geothermal fluid from the separator stations and steam from the low-pressure wells runs through the heat exchangers, heating up freshwater producing hot water for use at the park. After the heat extraction at the heat exchangers, the waste brine is reinjected back to the geothermal reservoir. Distribution of the hot water in the park is done in two ways: KenGen sells hot water directly to the customers or through a third-party company (private or public) which will supply to individual cluster companies as illustrated in Figure 5.

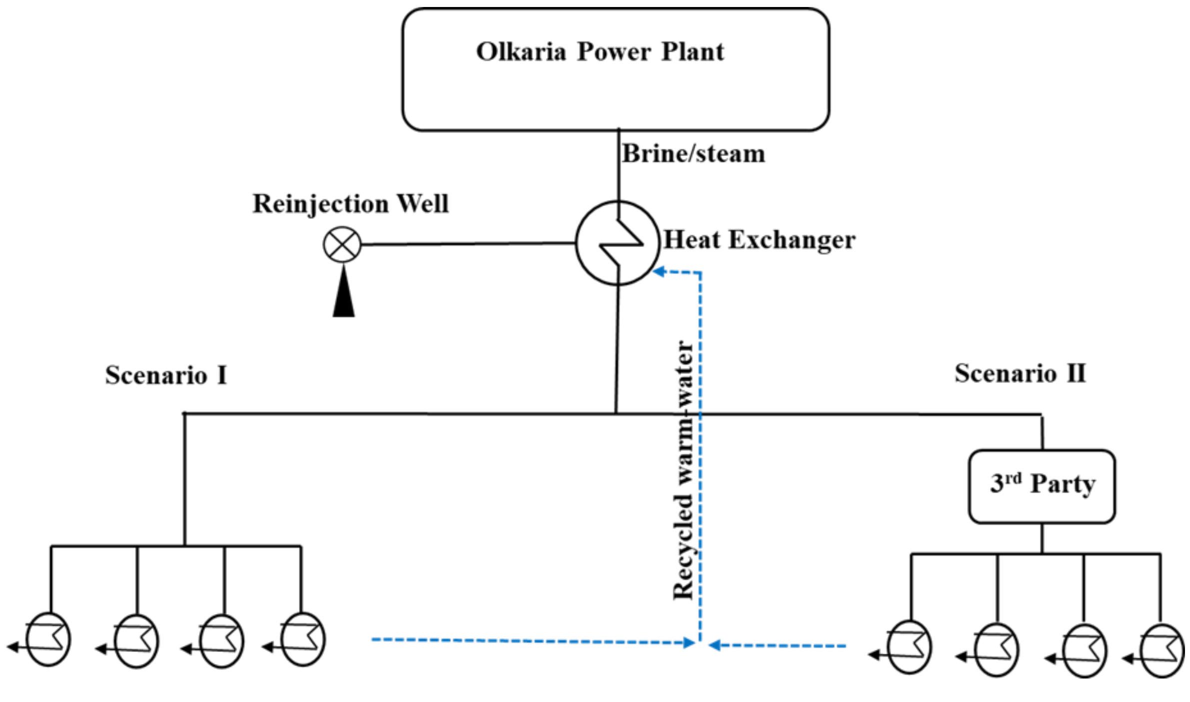

Figure 5: Possible scenarios for the sale and supply of hot water

The distribution of hot water to the proposed sites is discussed using two possible scenarios:

Scenario I; KenGen is the sole producer and distributor of hot water and will collaborate with individual companies during infrastructural development. KenGen´s technical team and park management are responsible for the maintenance of the hot and cold-water systems. The main advantage in this scenario is that KenGen gets a higher revenue from its sale of hot water.

Scenario II; The third-party company buys hot water from KenGen at the heat exchanger and distributes it to end consumers. The third-party company assumed to be a privately-owned company will be responsible for the technical aspects including detailed design of the distribution, development of the infrastructure as well as maintenance. In this scenario, KenGen transfers most risks (economic, environmental, technical, and social) to the private company.

3. MATERIAL FLOW THROUGH THE PARK

To develop an EIP within the KenGen Green Energy Park, resource efficiency and waste monitoring need to be effective. This could be optimized using a material flow analysis to show the contribution of industrial symbiosis to the circular economy approach. This is mainly to determine the possibility of symbiotic relationships between industries and possible future incorporation of spin-off companies, to utilize the remaining by-products and wastes.

Geographical proximity is necessary for industrial symbiosis and cascade designs as it offers a greater opportunity for co-located firms to develop better synergies. Eco-industrial clusters are geographic concentrations of interconnected industries in a specialized field and, essentially consist of clusters that operate with a higher degree of eco-efficiency. This inevitably leads to improved environmental quality, economic gains, and equitable enhancement of human resources for both the business and local community.

Cluster zonation needs to be included in the master planning and detailed design of the park to enable infrastructural layout that facilitates resource sharing. To cluster the resident firms in the KGEP, factors to consider will include the industry requirements (water, steam, and electricity) and the potential environmental pollution that the industries will cause. The key approach is to determine industry characteristics in terms of raw materials, products, co-products, energy, water, waste materials, and CO_2 emissions within the park. The proposed cluster is outlined in Table 2.

Table 2: Proposed industrial cluster

Polluting firms	Cluster	Allocated site
High	Steel, Glass	A
Medium	Textile, Leather	D
Low	-Food processing: milk & grain -Eco-fertilizer production	B/C

The Steel-glass cluster comprises of the steel manufacturer and the glass production plants (Figure 6). This cluster is considered an energy-intensive cluster with a considerable amount of CO_2 emission to the atmosphere. Both manufacturing plants required heating to about 1500-1600°C and emit high amounts of waste heat as a by-product. New by-products (e.g. waste steam), can be harnessed and utilized as raw materials for other companies or processes. The main geothermal resources required in this cluster is electricity from the power plants or the grid.

Both companies use a high amount of energy and release enough amount of waste heat which can be channeled to other small and medium scale enterprises that utilize thermal energy for their production. A large amount of wastewater is gathered and treated in the shared water treatment plant. The treated water is recycled and reused in the production cycle or reinjected back to the reservoir to recharge the geothermal system.

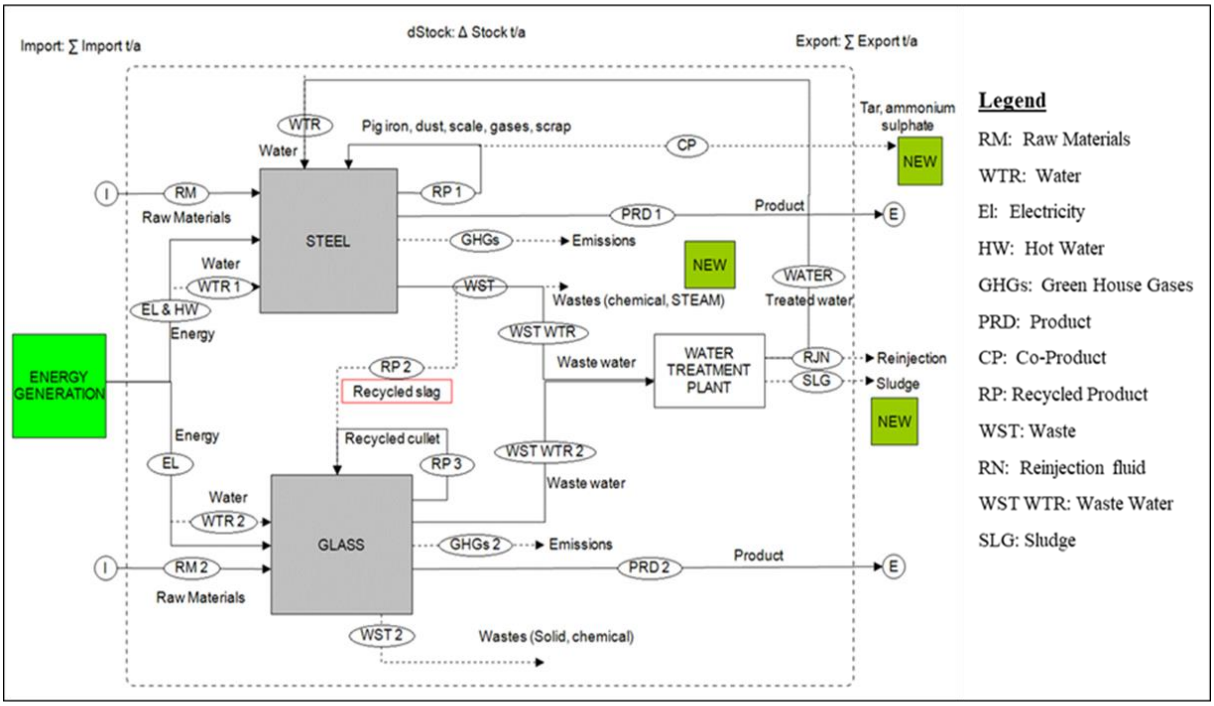

Figure 6: The material flow in the steel-glass cluster.

The design should ensure the sharing of resources and infrastructure such as power, water, and steam lines, roads, waste collection system, and water treatment plants. The two companies should have mutual trust and share data about resource utilization and ensure efficient exchanges.

The Food-fertilizer cluster comprises of food processing plants (milk pasteurizer and grain driers) and the organic fertilizer manufacturing plant (Figure 7). Key raw materials for this cluster are milk and cereals, majorly from, the neighboring farming community of the Narok and Nakuru Counties. The desired products from these processes are packaged and transported to the various markets in the country. Energy (electricity and steam) and water are provided by KenGen. A cascade design, in this case, can be useful as it ensures waste hot fluid from milk processing is run through the grain driers to provide heat for dehydration. Organic fertilizer plant uses low heat and can utilize thermal energy from the warm wastewater from the food driers before disposing into reinjection wells.

Some of the marketable by-products of milk processing include buttermilk which can be used to make beverages and sports drinks. Ghee and skim-milk can be valuable raw materials in the production of cheese, sweets, and chocolates. The sludge from the water treatment plant in this zone is treated and used to produce organic fertilizer pellets and powder. Other solid and chemical wastes are treated and transported for use outside the industrial park. Emissions from the production of fertilizer include carbon dioxide and methane which can be sufficiently harnessed for biogas production.

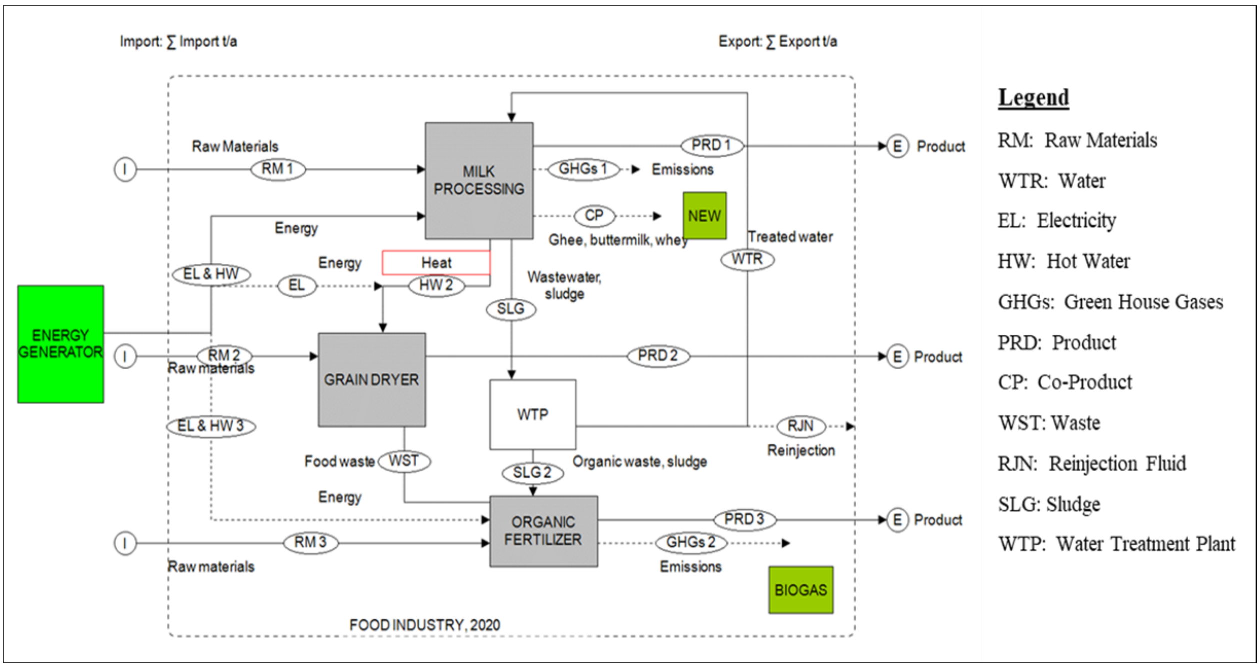

Figure 7: Material flow in the food industry-organic fertilizer cluster.

The Textile-leather cluster comprises of the garment and leather processing industries. The cluster uses high amounts of chemicals, steam, and water. The two are clustered together to enhance resource efficiency and advanced pollution control measures to curb environmental degradation in this zone.

High amounts of thermal energy required in this cluster and can be harnessed from the abundant geothermal brine or steam. A cascade design allows the steam exchange between the high-temperature utilization in the textile plant to the lower temperature leather processing units. Some of the recoverable wastes from this zone include garment off-cuts, chemical, and organic wastes from the textile industry (Figure 8).

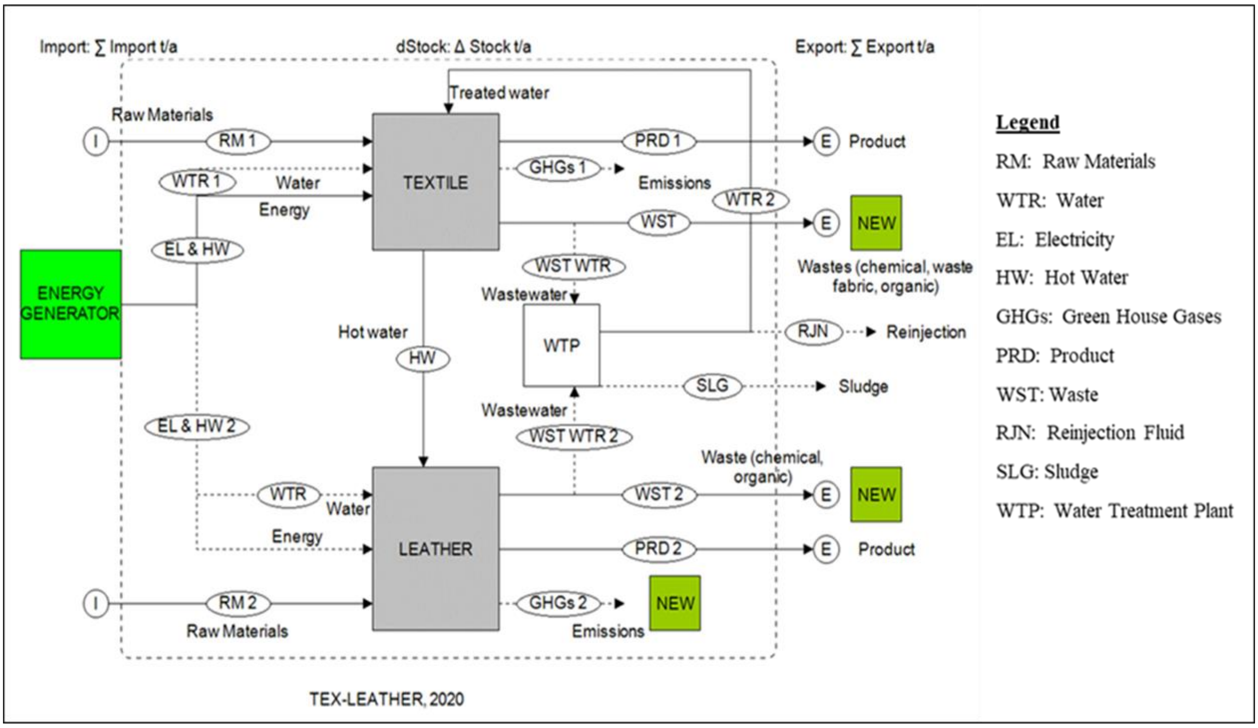

Figure 81: Material flow in the textile-leather cluster.

4. DISCUSSION AND CONCLUSION

KenGen Green Energy Park has been identified as one of the revenue streams complementing the electricity generation within the Olkaria Geothermal Resource Area. The park will utilize cheap electricity from the geothermal power plants and thermal energy harnessed from separated brine and steam from low pressure / low enthalpy wells within the geothermal field. Two scenarios for thermal energy distribution in the park have been discussed. In Scenario I, KenGen will develop infrastructure and distribute the hot water to the industrial park. KenGen wholly assumes all the risks and the revenues accruing from the sale of the hot water. Potential risks are technical, economic, environmental, and social related. For higher energy efficiency, KenGen should design a cascade-use set up in the master plan. The design will provide for an infrastructural layout that least results in losses of energy in distribution. In Scenario II, KenGen sells hot water at the heat exchanger terminal and the private company distributes it to the park. The costs of installation and piping the hot water, are absorbed by the private company. Lower revenue will be realized by KenGen in scenario II compared to the scenario I.

Through the application of the Lindal concept, it is evident that it is possible to enhance the feasibility of geothermal projects with cascading and combined uses. The possible utilization depends on the resource temperatures, available flow rate, the chemistry of the geothermal fluid, and the type of application. Additionally, innovative concepts like for Combined Heat and Power – CHP production will be viable as the energy park is surrounded by many hotels and facilities that are interested in hot water for their daily domestic use.

By incorporating industrial symbiosis technology in the Green Energy Park, linkages between companies will be realized. Two major exchanges are envisaged; utility and infrastructure, and resources (wastes and by-products). Clear cooperation between the tenant companies will encourage symbiotic relationships and also promote the emergence of other SMEs and start-up companies that will benefit from opportunities arising from industrial symbiosis.

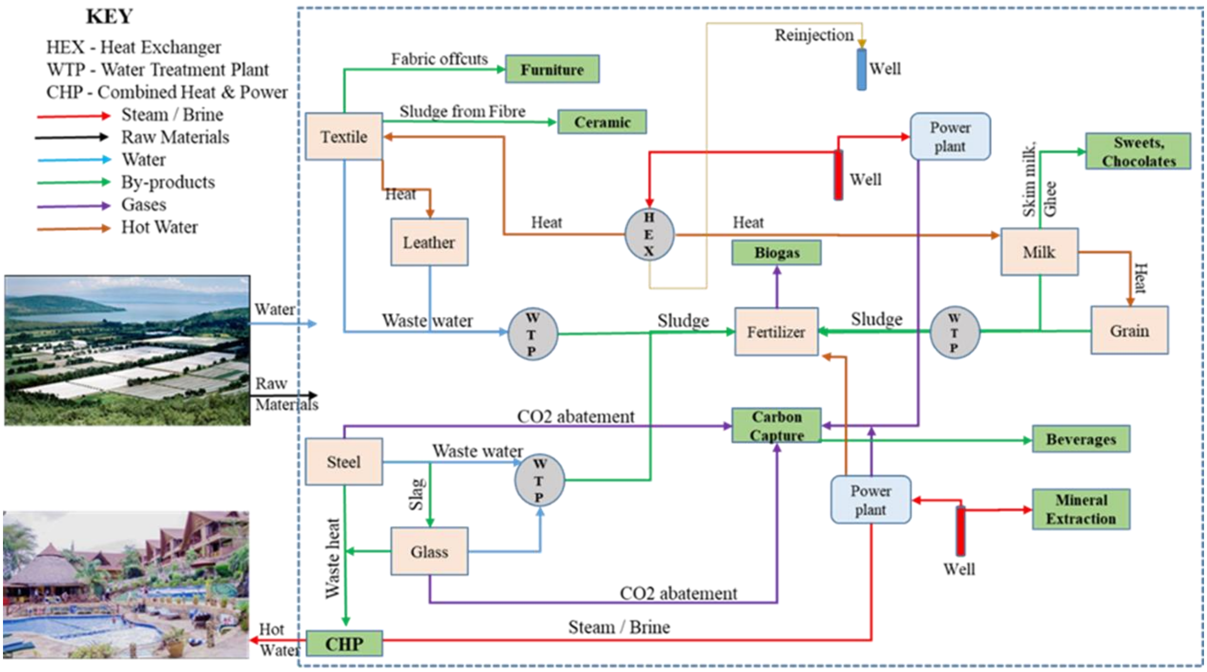

Figure 9: Industrial Symbiosis opportunities for KGEP

The opportunities arising from resource efficiency include the manufacture of beverages sports drinks, chocolates, cheese, and sweets from dairy by-products. Fabric waste can be used to produce bags, furniture covers, diapers, and wipes among others. Food wastes and all biodegradable wastes are raw materials for organic fertilizer production (Figure 9). The community farms around Lake Naivasha provide part of the raw (food) materials to be processed e.g. grains, vegetables, and fish from the lake. Other projects that are currently being evaluated for viability are mineral extraction from geothermal brine. Silica and Lithium mining is one of the projects that will drive the circular economy in the green energy park. Also, the collection of gases for methane production and CO_2 for use in beverage production is under evaluation. Carbon Capture and Storage or Utilization is an innovative technology that will be used to harness up to 90% of the CO_2 and promote a carbon-negative environment both in electricity generation and the industrial processes at the park.

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