Bachelors Thesis

Topic- Use of Solar Energy in reducing food loss and waste in rural Kenya

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List of acronyms

FAO-Food and Agriculture Organization

FLW-Food Loss and Waste

FMC-Farm Milk Cooler

GDP-Gross Domestic Product

GHG-Green House Gas

HLPE- High Level Panel of Experts

KALRO- Kenya Agricultural and Livestock Research Organization

KOSAP-Kenya Off-grid Solar Access Project

PAYG-Pay As You Go

PV-Photovoltaics

SACCOs-Savings and Credit Cooperative Organization or societies

SDG- Sustainable Development Goals

UN-United Nations

UNEP-United Nations Environment Program

USAID-United States Agency for International Development

USD-United States Dollars

Kwh-Kilowatt hour.

1. Chapter 1.

1.1 Introduction

Food waste and loss are now global concerns as an alarming amount of food is lost and wasted amid the climatic, economic, and food insecurity crisis. According to the UNEP food waste index report in 2021, more than 931 million tons of food go to waste annually and are prone to occur during the post-harvest and processing stages in developing countries (Tchonkouang et al., 2023). Approximately 30-40% of post-harvest food is lost in sub-Saharan Africa (FAO, 2011), and a recent study in India, Ghana, Rwanda and Benin shows that the post-harvest losses can be as high as 80% sometimes (HLPE,2014 a) cited in (UNEP, 2016). Many food losses occur mainly in rural areas where farmers are not connected to the grid power, have inadequate food processing technologies and lack good storage facilities (Tchonkouang et al., 2023).

Most of the African population lives in rural areas, and most of their livelihoods depend on agriculture. (Karekezi, S., & Kithyoma, W., 2002, Harrington, 2016, Gustafsson, J, et al, 2013). There is a concern about exponential population growth in Africa's rural areas, projected to increase by 60% in 2050 (UNEP, 2016). The population increase has proportionately increased food production, increased energy demands, and, eventually, increased the amount of food lost and wasted (Ondraczek, 2013; Wakeford, 2017). As food is lost, food insecurity remains another big concern in Kenya and most of the sub-Saharan African countries, where some people suffer due to lack of food.

Food loss and waste mean the loss of all-natural resources, wasted energy, labour and financial investments during agricultural production, making it an environmental issue. According to UNEP (2016), the food sector accounts for almost 30% of the world's total end-use energy consumption. This consumption is mainly based on fossil fuel sources, contributing to approximately 19-29% of greenhouse gas emissions (Vermeulen et al., 2012). Conventional post-harvesting activities such as refrigeration, drying, transportation and packaging contributed to the highest number of emissions since they are energy-intensive (UNEP, 2016). Additionally, improper food loss and waste management end up in landfills and account for approximately 2.8% of anthropogenic GHG emissions (Vermeulen et al., 2012).

In 2015, the UN highlighted the SDG 12 aim to ensure "sustainable consumption and production patterns" as one of its targets (SDG 12.3), calling for halving rates of food loss and waste (FAO, 2014). According to the UN, proper production and consumption of food will go a long way toward promoting the achievement of equivalent goals such as zero hunger, reducing poverty, and climate action (Mwaniki & Nyamu, 2022). To achieve most of these goals, the food system will require a radical shift with the incorporation of sustainable approaches that include energy use in the food value chain. Some of the efforts made by countries are to employ more green, renewable energy sources, such as solar energy.

Solar energy has the potential to be used in the agricultural sector since it is more eco-friendly, clean and renewable. From a technical perspective, it is perceived that the amount of solar energy that reaches the Earth daily is sufficient to cover the world's primary energy needs (Ondraczek J, 2014). Traditionally, solar energy is used to dry food products. However, this method takes a lot of time, and the quality of food products is usually reduced or lost along the process (Adwek G et al., 2019). New solar energy technologies that are important in agricultural services have been developed as they can provide both the cooling and thermal energy required in all food chains (Chanda et al., 2023). This could be utilized for small and medium food processing and accessible to remote off-grid regions.

The Kenyan government is committed to achieving sustainable energy for all agenda in 2030 and has tried to scale up its renewable energy generation (Pueyo et al., 2016). Through its Rural Electrification Authority (REA), it has provided better feed-in tariffs and the removal of duties and taxes on solar panels to encourage more solar product consumption (Kiplagat et al., 2011). This provides Kenyan small-scale farmers living in remote areas the opportunity to access a better energy alternative than diesel.

Food loss and waste are, however, defined differently by different institutes. For this literature, food loss encompasses the unintentional decline in food quality and quantity post-harvest, making them unmarketable but safe for consumption. Food waste, on the other hand, refers to the deliberate disposal of food fit for human consumption (Tchonkouang et al., 2023). In this paper, I will look into how solar energy can be used to reduce food loss and waste, considering the opportunities and potentials available in the rural areas of Kenya. In my specific objectives, I will seek to explore the environmental and socio-economic impacts of food loss and waste, explore the traditional developments in solar energy use in food processing, and determine how the price of solar energy has developed in Kenya.

Chapter 2. Methodology

This paper is a review of literature focusing on both qualitative and quantitative data. The reviewed articles were identified from books, peer-reviewed journals, reports, policy documents, and websites of agencies and organizations that address food waste and loss and the energy sector, specifically Solar energy developments. In this research, I will describe a theory, provide literature about Kenya and aligning to my objectives, share a case study and discuss the findings.

2.1 Theory

Sustainability development theory

In 1987, *sustainable development* was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Harrington, 2016). Food systems are currently unsustainable from the perspective of natural resources since they consume many fossil fuels, leading to significant natural capital degradation. Most agricultural production is done in rural areas, where fresh water is withdrawn, soil salination is high, erosion is joint, and fertility is reduced (UNEP, 2016). With the rising concern about earth capacity systems and human technology, Harrington (2016) argues that sustainability practices play a crucial role in avoiding the deprivation of raw materials in most rural areas. Reducing FLW is a vital strategy to consider in improving the use of environmental resources and ensuring an increase in total resource efficiency. The theory is desirable because it provides insights into how the social, economic and environmental dimensions can be managed without interfering with long-term conditions.

Sustainability is critical while addressing FLW and energy consumption since they directly affect social status, economy and environment. The SDG goal no. 12.3 sustainable production and consumption include reducing food loss and waste (Sheahan & Barrett, 2016). This can be interlinked with SDG no. 7, energy production and affordable and clean energy consumption, since they play a significant role in climate change(World, 2017).

Chapter 3. Literature Review

3.1 About Kenya

Kenya is a country in East Africa. Geographically, the country lies along the equator and enjoys a tropical climate with constant sunshine and an average of 22 degrees Celsius throughout the year (Kiplagat et al., 2011). According to a study done by FAO (2020), it was reported that the country's annual temperatures have increased by 1.5 degrees since 1990. The Kenyan coastal area is relatively hot and humid, with moderate equatorial climatic conditions in the country's middle and arid in the northeast and northern regions. Kenya receives an average of 5–7 peak sun hours with an average daily insolation between 4–6 kWh/m2/day. The country's yearly average is approximately 5 kWh/m2/day, equivalent to 250 million tons of oil per day (Kiplagat et al., 2011).

Most of the Kenyan land is classified as arid or semi-arid, and 18% of the land is classified as having medium to high agricultural potential, and this includes the western and eastern highlands partitioned by the Great Rift Valley (Kiplagat et al., 2011). Food production is highly dependent on rainfall and irrigation from the freshwater lakes and rivers across the country (Rampa & Dekeyser,2020). During the dry seasons, there is always a notable increase in food insecurity and during the rainy season, overproduction leads to food waste and falling food prices (Rampa & Dekeyser,2020). Some regions produce much food, but most fresh agricultural produce is lost due to infrastructural deficiencies.

The agricultural sector is among the key drivers of Kenya's economy, contributing 32% of the GDP in 2016(Wakeford, 2017). Most agricultural products are consumed locally, but tea, coffee, floricultural and horticultural crops are mainly produced for export (Rampa & Dekeyser,2020). Most of the grains, like maize and beans, are imported from neighbouring countries such as Tanzania and Uganda. Livestock products like meat and milk are also produced in significant amounts. An estimated 20-40% of the food grown in Kenya needs to be recovered. The government assessment of the food situation in 2017 showed that out of 39million bags of maize produced, 12% was estimated to have been lost in post-harvest due to high aflatoxin levels (Taurus, 2019) cited in (Mwaniki & Nyamu, 2022). In 2018, a government report highlighted that the country lost many Irish potatoes, milk, beans, bananas, sweet potatoes, tomatoes, pineapples, sorghum and millet apart from maize. Total quantitative milk losses due to spoilage are estimated to be 7.3%; however, the data does not include small unregistered dairy farmers (FAO, 2014).

In Kenya, food processing, like cooling and drying technologies, is usually expensive and is afforded mainly by medium and big companies using conventional energies since they can access the national grid. Demand for dried food products for perishables such as fruits and vegetables, roots and tubers, and coconut, amongst other commodities, has been growing. According to the Ministry of Agriculture (2010), in 2009, "the country exported about 4000 metric tons of dried vegetables, with the highest export being experienced in 2007 when 40,000 tones of vegetables were exported" (FAO, 2014). Additionally, the companies use refrigerators and cold rooms to store their perishables and to increase shelf life. These are mostly common in urban areas and seldom in rural areas.

Most of Kenya's population lives in rural areas and earns a living by producing their food through small-scale farming. Over the past few decades, the country has recorded a high population increase, which increases pressure to produce more food to sustain the growing population (Wakeford, 2017). 74% of Kenyans live in rural areas and are often poorer compared to those who reside in urban areas since they rely on subsistence agriculture that is acutely vulnerable to climate change disasters that range from droughts and floods (Pueyo. A. et al. 2018; FAO,2014). As a result, approximately 25% of Kenya's population is reported to suffer from chronic food insecurity. The government imports food at an estimated cost of USD 1.3 billion annually to aid the affected populations. (Mwaniki& nyamu, 2022). Increased distribution and food waste and loss prevention could leverage the perennial issue.

3.2 What type of energy is available in rural Kenya?

Grid electricity is the primary source of modern energy in Kenya, which is generated from a mix of hydro, oil, thermal, geothermal and biomass that accounts for almost 80% of renewable energy in the national grid (Kiplagat et al., 2011). 92% of the Kenyans living in rural areas cannot access the grid and use kerosene for lighting and firewood for cooking (Adwek G, 2019).

To provide energy to remote rural homes, the Kenyan government introduced a rural electrification initiative in 2007, but the project's operations were implemented in 2009 (Day et al., 2018). In 2016, 50% of the Kenyan population could access electricity, a breakthrough for the government (Adwek G et al., 2019). In a study by MkOPA, a company that sells and distributes solar products, 14% of the rural population uses off-grid Solar primarily for lighting (FAO, 2020).

Regarding energy consumption, Kenya's agriculture accounts for approximately 0.2% of total final energy consumption, which relies on imported petroleum (Wakeford, J., 2017). The reliance on diesel-based energy in agriculture has increased GHG emissions and health-related complications, mainly for rural populations. A Kenyan government report in 2015 highlighted that food systems were responsible for most of the country's GHG emissions (Day et al., 2018). This prompted the country to shift to more renewable energy utilization; however, biomass is still famous, and solar PV is the second most common source of electricity in rural areas.

3.3 The environmental and socio-economic impacts of food loss and waste

The planet is assumed to produce sufficient food to feed all individuals, but it is distributed unevenly and sometimes handled poorly, resulting in losses and waste. In sub–Saharan Africa, 20% of cereals, legumes and pulses, 40% of roots and tubers and 50% of fruits and vegetables are reported to be lost and wasted annually (Daminger et al., 2016) cited in (Mwaniki & Nyamu, 2022). Most of these lost foods are common staple foods and represent their culture and livelihoods. On the flip side, there is a food insecurity problem globally, with millions of individuals enduring malnutrition and undernutrition. In 2020, for instance, 3 billion could not afford a healthy diet and up to 811 million individuals faced hunger. (Sheahans and Barret, 2016). Apart from the increase in poverty levels, food loss also robs people of their sense of identity through food.

The world population is projected to increase by more than nine billion people in 2050, meaning approximately 60% more or a minimum of 2 billion tons of food (UNEP, 2021). Population increase is seen to increase energy demand due to advancements in technologies that utilize energy (Ondraczek, 2013). Overcoming food loss and waste has been cited as a sustainable strategy for achieving zero hunger and reducing further climate change. Cutting global food waste by half will enable a 20% reduction in the food gap in 2050. Research indicates that people living in rural areas, mostly from developing countries, are more vulnerable to climatic shocks. Globally, food loss represents a waste of valuable resources such as water, energy, land, labour, agrochemicals and capital. Agriculture consumes almost 59.13% of global freshwater (World Bank, 2020). Population growth, agricultural land expansion, and increased charcoal use have decreased Kenya's forest land by 3000m2 over the last 30 years (Rampa & Dekeyser, 2020). Reliance on combustible renewable energy resources like biomass contributes to many environmental effects. The losses impact human life, the environment, and the economy, reducing the chances to achieve SDGs. In addition, it jeopardizes the livelihoods of the farmers and the producers (Tchonkouang et al., 2023).

3.4 Solar energy use in food processing

Traditionally, many rural farmers used direct sun drying to increase shelf life and reduce microbial developments that degrade the products that would force farmers and traders to throw them. However, this has numerous limitations, such as high crop losses ensuing from inadequate drying, fungal attacks, insects, birds and rodent encroachment, unexpected downpours of rain and other weathering effects (Ndirangu et al.,2018). Direct sun drying is commonly done to preserve and dry meat, some fruits, cereals, fish and vegetables. Among the Mijikenda, a community that lives along the coastal part of Kenya, post-harvest preservation of maize was achieved by storing the grain along with neem tree leaves, which repels insects; others did underground pits and guards for storing food. (Mwaniki & nyamu, 2022). Smoking, using ashes to preserve food, and salt, among other practices, are also daily in most of Kenya's rural areas, but still, much food is lost.

3.4.1 Developments

The Rural electrification program established in 2009 opened up a pathway for more opportunities for solar energy in rural, remote areas through off-grid solar options. In the Agricultural sector, Solar technologies are famously used for water pumping. Recent developments to provide cooling and drying services have been piloted mainly through private entities and foreign donors (Kiplagat et al., 2011). Some of these projects include; "Soko Fresh" and "Solar Freeze", which provide rentable cold storage facilities near farmers and fields. Solar Freeze is a micro-finance business that provides digital options for farmers to locate and manage cold storage units (Mwaniki & Nyamu, 2022). They also provide solar-powered milk cooling tanks with a capacity to cool over 500 litres, a solar ice maker able to supply 5 kg ice blocks to local fishermen on Lake Victoria (Alliance for Rural Electrification, 2022). The projects are still being developed, are barely five years old, and target a few farmers in different regions of Kenya.

The Kenya Agricultural and Livestock Research (KALRO) in Njooro Nakuru has fabricated six solar dryers with different air flow modalities and solar use. The available types of dryers include Easy dry capacity of 495kg, greenhouse 180kg capacity, multipurpose 90kg capacity, the POD 90kg capacity, Dhytray 7kg capacity and hybrid 5kg capacities. (De Groote et al, 2023). In their study, De Groote and the team found that all the dryers were efficient in drying maize, and the easy dryer was the fastest (2023). Some farmers in Kenya's eastern and central parts practically use greenhouse solar dryer designs that consume direct solar energy. The drying rates varied per crop, although it was faster than direct solar drying, and its performance reportedly reduced levels of food losses (Ndirangu et al., 2018). Other farmers in rural Kenya use Inflatable solar dryers. This is more common and used in many other countries like Uganda and Benin, where they use it to dry vegetables and grains.

Most private companies exporting products from Kenya have installed solar power plants to supplement their power supply and reduce annual electricity costs. Most of these companies deal with tea, flowers, and coffee and utilize solar energy to supplement the power supply to their factories and farms. William Som Tea, the Changoi tea factory in Rift Valley, and the Uhuru flower farm, among others, were reported to have saved electricity costs by 30% after installing the solar power plants (Mburugu et al., 2019). Some plants have batteries to store solar power, while other farms consume direct solar energy. Here, they use a variety of dryers, mostly indirect solar dryers that utilize direct and solar-powered concentrators or hybrid dryers that consume energy from both solar and other sources(Udomkun, P,2020). An indirect solar collector is capable of preserving vitamins and colour.

Compared to Sub-Saharan Africa, Asian countries like China, the Philippines, Thailand and India have upgraded to newer models of solar drying products for commercial and small-scale farmers. Since 2000, China is reported to have installed more than 200 solar drying systems that cover a total area of about 20,000m2. China aimed to have more than 50% of grain drying utilize solar drying systems by 2020 (Udomkun et al., 2020). In Thailand, for example, a parabolic greenhouse dryer using solar drying systems is widely used to dry large quantities of products equivalent to 2 tonnes. According to research, the drying times of paddy rice are reduced from 5-7 days to 3-4 days, with the food loss and waste reduced by 10% using solar dryers (Chanda et al., 2023). In general, economic returns of solar dryer technologies valued at market prices and without considering possible positive environmental effects are much higher than those of traditional drying technologies.

Solar drying processes can be broadly classified based on their mode of operation, active or passive (Chanda et al., 2023). The active mode has a pump or blower that directly forces heated air into the drying chamber. In contrast, the passive mode depends on the natural movement of hot air heated by the solar flows to the density of indifferent air (Verma et al., 2022, cited in Chanda et al., 2023). Solar dryers vary in heat interactions; they can be direct, indirect or through mixed modes. (Prakash and Kumar, 2013, cited in Chanda et al 2023). Direct dryers use greenhouse effects, indirect dryers are connected to a solar collector that acts like heating equipment, and mixed dryers incorporate both direct and indirect or are connected to another energy source. (Chanda et al, 2023).

3.5 How has the price of solar energy developed?

The solar market in Kenya has been increasing since the 1980s. The initial solar panels in Kenya were affordable but physically big and had low power ratings. As the prices dropped, the power rating increased, and the physical size reduced (Adwek, G. et al. 2019). Between 2008 and 2009, there were remarkable technological changes in solar energy, and the market dynamics changed rapidly, leading to an approximately 50% decrease in price for solar energy products (Adwek G et al. 2019). A preliminary survey in 2005 established that the annual market demand for photovoltaic (PV) panels was at a 500-kilowatt peak, projected to grow at 15% annually. (Adwek G et al 2019.) The private sector drives the high demand, which takes advantage of the rural non-electrification. The Kenyan private sector has pioneered innovative business models to reach more customers by rolling out a technological application that enables customers to pay as they go (PAYG system) (World Bank, 2017).

The costs of mini-grids have been cross-subsidized by the incorporation of many partners in the energy ministry. Currently, the county has 25 hybrid mini-grids and 151 mini-grids are being developed by Kenya's grid solar access project (KOSAP), supported by the World Bank. (Kurdziel et al, 2019). Many companies run private mini-grids for business consumption or sell energy to rural communities. According to one of the companies, the cost of setting up the rural off-grid solar PV decreased by almost 50%. In 2014, it cost USD 1430 per connection; in 2017, it was USD 1000 and progressed to USD 856 per connection (Kurdziel et al., 2019). Kenyans in rural areas receiving off-grid solar access pay an equivalent of Ksh. 700 ($7) per month proves that the mini-grids are cost-effective and more efficient for the rural population.

Solar PV markets in Kenya are dominated mainly by solar home systems and small-scale commercial and off-grid community systems utilized in schools, telecommunications, and tourism—more information about the cost of solar energy in East Africa (Ondraczek J., 2014). The cost of solar PV energy varies and is influenced by the installed capacity, technology applied, and the year of manufacture. In 2010, using the Levelized Cost of Electricity (LCOE), the price of solar energy was USD/Kwh 1.63-0.175; other data shows that under good African weather conditions, the cost can range from USD /Kwh 0.24- 0.37. A recent study trying to challenge outdated data found that solar energy costs had reduced in Kenya and went to

USD/Kwh 0.165-0.30 (Ondraczek J., 2014). This makes it more competitive than other forms of energy.

The price of diesel-based fossil fuel generation in Kenya ranges from 26-42 US/Kwh, while geothermal is considered low as 5.4US/Kwh can be 4.7 when measured using the LCOE. The average cost of electricity in Kenya is 17 USD/kWh (2015), while for subsistence, monthly costs are US$ 5 (Pueyo et al., 2016). The better feed-in tariff in Kenya makes solar energy economically effective compared to fossil fuel sources. However, geothermal is currently more cost-effective in Kenya. Pueyo et al. (2016) argued that compared to all other energy mixes in Kenya, solar energy is not financially viable for profit-oriented investors; geothermal energy will instead be used since it is currently more cost-effective.

Many food industries with commercial products employ state-of-the-art drying equipment such as Freeze, spray, drum, and steam dryers. The prices of such dryers are high, and only commercial companies generating substantial revenues can afford them. Drying with fossil fuels or grid electricity is expensive. It has been estimated through calculations at US$ 0.02-0.03/kg of raw produce to be dried or about US$ 0.20-0.30/kg for dried fruits or vegetables (Ndirangu et al., 2018). Therefore, because of the high initial capital costs, most small-scale companies and farmers cannot afford the price of such dryers, although they produce high-quality products. The Kenya Agricultural and Livestock Research Organization and universities have developed customized dryers. As of 2023, the Easy dry capacity of 495kg cost $850, the greenhouse 180kg capacity costs$330, the multipurpose 90kg capacity costs $300, the POD 90kg capacity costs $150, Dhytray 7kg capacity cost $60, and the hybrid 5kg capacities costs $170. (De groote et al, 2023). These are affordable to small-scale farmers, although one can only access them from the research centre.

3.6 Case study: Existing solar energy uses and its technologies in agriculture.

Most published solar-powered dryers and freezers are sponsored by foreign donors and institutions. Many projects are still piloting, while others are still under study. In most regions, livestock products like milk are perishable and could easily get spoiled within 2-3 hours due to warmer temperatures. Refrigeration is energy-intensive and almost unavailable in rural areas (Sonja L et al. 2012). Of over 850,000 smallholder dairy farmers in Kenya, 85% do not access the national electric power grid. A typical dairy farmer has about 3-5 cows that produce an average of 8 litres per day per cow. Since 40% of milk produced is processed nationally, the rest of the small-scale farmers would traditionally boil the milk to increase shelf life, consume by force, sell cheaply or lose their milk due to lack of on-farm refrigeration (Foster R et al., 2015).

One project, "Sustainable Milk for Africa through PV Smart Refrigeration Technology", sponsored by USAID, provided on-farm solar milk refrigeration for off-grid small dairy farmers in Kenya. The project started in 2014 and collaborated with the Department of Dairy and Food Science and Technology at Egerton University and the county governments of Baringo and Nakuru. The PV innovative project developed an affordable solar-powered farm milk cooler (FMC) to enhance the value of milk from remote producers. In addition to preserving up to 40 litres of milk, the cooler can preserve other perishable farm produce such as eggs, meat, fruits and vegetables. Energy from the Solar was directly connected to the cooler, which could preserve the milk at 4 degrees Celsius.

Due to the high capital needed to purchase the solar power system, the project steered and collaborated with financial service associations such as savings and credit cooperative societies (SACCOs) ready to work with dairy cooperatives. Through these, farmers were able to access credit on reasonable terms. The estimated return on investment on the Smart for dairy farmers is 1-3 years, considering solar products have lower operating costs. The project attracted small-scale dairy farmers due to the economic benefits of gross incremental income gains per farmer that ranged from US$23 to $650 per month. In 2015, 40 pilot units were deployed to the dairy cooperatives and Egerton University (Foster R et al., 2015). As opposed to previous encounters where the warmer temperatures were dreadful to the farmers, it was reported that the hotter climates became better as far as payback for the farmers.

In 2020, another project by Allgåu-based solar company and ARE member Phaesun supported the commission of three solar-powered cooling systems for three regions in Kenya. The regions targeted were central, western and along the Lake Victoria region. Solar-powered cooling systems are used to cool various food products, such as milk, fish, vegetables, and herbs, which are popular in the regions. The project involved engineering students from the University of Hohenheim and Kenya's Strathmore University and established a solar centre (Alliance Rural Electrification, 2022).

The innovative technology of this solar-powered cooling system is reported to have been initiated in 2013, and the development of the self-chill system was optimally made to adapt to the tropical climate. The self-chill main components are composed of cooling units powered by solar modules to generate cold, which could be stored as frozen water in ice storage units. (Alliance Rural Electrification, 2022). The project is attractive since it was made to meet the needs of small-scale farmers prone to losing most of their perishable foods due to a lack of cold storage. The ability to contain over 500 litres of milk from the farmers economically promotes the dairy farmers' livelihoods that could have been wasted. This project and others implemented in other regions of Kenya significantly reduce food loss and waste in these hard-to-reach areas. Sustainability is promised in the two projects since local students were involved in the design and commissioning of the projects.

Chapter 4. Discussion

4.1 The environmental and socio-economic impacts of food waste in rural Kenya

People living in rural areas are often part of the resource-dependent socioenvironmental systems such as agriculture and energy. Socio-economic factors related to increased population growth, changes in global food prices, and technological advancement have shaped and influenced food systems and equivalent GHG emissions (UNEP, 2016). Additionally, conventional agricultural systems utilize fossil fuel energy and flow throughout the food chain. Cumulatively, agricultural production contributes to the highest GHG emissions, and post-harvesting practices are the second. Food processing practices such as drying, refrigeration, and storage contribute to more emissions in the post-harvest phase.

According to the review, food loss and waste occur in different magnitudes in developed and developing countries. FLW occurs more at the consumption level in developed countries, while in developing countries, FLW is mainly during the post-harvest levels. Fruits and vegetables account for the highest amount, averaging 50% of losses across almost all developing countries, and then grains come second. From the review, we see that insufficient energy supply, poor infrastructures in terms of storage, and poor handling contribute to high FLW in developing countries. This is contributed by the consistent use of traditional food processing practices such as open sun drying, which is time-consuming and also results in some food loss.

Food waste and loss threaten sustainability since they affect social, economic and environmental facets. Socially, although high amounts of food loss and waste are reported in Kenya, there have been concurrent perennial food insecurity and hunger problems. Poverty levels are increasing among farmers living in rural areas since they cannot gain as much as they are supposed to. Food loss and waste translate to financial losses that have psychologically affected some farmers in countries like India. Some farmers are reported to have committed suicide due to post-harvest losses (UNEP, 2019). Population growth has been found to influence high food production and eventual food loss and waste. Considering that Africa's population is projected to double by 2050 and the rural population is expected to increase by around 60%, investing in food waste and loss prevention strategies will be imperative.

Additionally, the current food systems are perceived to affect the environment due to land and soil degradation, overuse of freshwater reservoirs and general pollution. Food loss and waste contribute to the further loss of these natural resources, causing sustainability problems. Reliance on fossil fuels in food systems and biomass as energy sources has increased GHG emissions, which is detrimental to the environment (Mohammed et al., 2013). The combustion of biomass releases carbon and encourages deforestation, which is not beneficial to the environment. Kenya and most of Sub-Saharan Africa are already vulnerable, having arid, semi-arid and desert areas, and dependence on biomass could be more damaging.

Kenya is a member and participated in the Malabo Declaration adopted by the African Union in 2014. The declaration directed Africa's countries to transform their agricultural sector from 2015 to 2025. The member states were expected to reduce food loss by at least 50% by 2025 (Mwaniki & Nyamu, 2022). However, Kenya is far away from achieving the target. Since there is already a suitable environment for solar product markets in Kenya, the government, through the Ministry of Agriculture and Energy, needs to encourage rural farmers to adopt these solar-based resources to prevent further food loss and waste.

4.2 solar energy use in food processing in rural Kenya

Traditional direct solar drying is widespread in rural Kenya and even across many developing countries since it is cost-effective. However, a significant amount of food is lost and wasted due to contamination and quality concerns. Over the past decades, significant developments and technologies have occurred, and Solar energy using photovoltaic PV is getting more attention in most regions in the sub-Sahara and even Kenya. Although not successfully used to its potential, solar PV systems have been embraced more by private individuals for solar home systems or commercial purposes. Compared to open sun drying, solar-powered dryers accelerate drying by 30-40%, improving the quality of the product and reducing the time (Chanda et al., 2023). It is encouraging to find out that there have been a lot of technological developments using solar energy, mainly in Asian countries, to mitigate the food loss and waste problem.

The solar cooling and drying options provide better economic benefits than conventional fossil fuel or biomass energy sources. First, an incentive to develop solar energy systems is due to the exhaustion of some of the hydroelectric power potentials due to perennial drought and reduced rainfall in the country (Wakeford J et al., 2017). Secondly, since conventional energies are expensive, most poor farmers in rural regions need help to afford them. However, Solar powered drying systems are not famous yet; from the literature, we see that for both Kenya and India, privately owned companies preferred to use solar cooling or drying technologies for commercial products such as tea, coffee and flowers compared to cabbages and tomatoes (Udomkun et al, 2020).

Remarkable food loss and waste have been prevented by solar drying and cooling systems. Solar heating systems improve the quality of products that would have been wasted or destroyed using traditional fuels. For instance, under the solar freeze project, farmers reported over 90% reduction in post-harvest loss after using cold storage solar equipment (The Borgen project, 2020). The great demand for dried products in Kenya and globally indicates the possibility of reducing food loss and waste in the future. Drying has enormous potential to preserve perishable crops, including fruits and vegetables, and reduce losses estimated at 11% and 7% for fruits and vegetables, respectively (Chanda et al., 2023).

In Kenya, most solar products are used for lighting and powering TVs, phone charging, vaccine refrigeration, water pumping, and water purification. Solar drying and cooling systems are a relatively new concept, only partially utilized in the agricultural sector. From the review, it is evident that the agricultural sector in the rural areas still has a low consumption of this modern energy. This indicates that agriculture needs to get more attention or that the interaction with the energy sector is fragile, yet they must interact closely. The ongoing research in KALRO is hoped to bear fruits in the future. Borrowing from India, their country's agricultural sector has increased the market value of food products and decreased conventional energy consumption by using solar dryers. Solar dryers decreased conventional energy consumption in India by 27-80%. Combining solar and other energy sources enables one to save up to 20-40% of energy (Udomkun et al., 2020).

Otherwise, it is noted that the solar energy food processing mechanisms only partially prevent food loss and waste. The type of solar dryer, solar radiation and monitoring are consequently necessary. Some studies recommended merging solar and biomass heaters to speed up the drying process and increase heat supply during rainy seasons (Musembi et al., 2016). Technological applications have been developed for cooling systems that allow farmers to track and monitor their solar cooling systems (The Borgen Project, 2020).

4.3 How the cost of solar energy has developed in Kenya

Kenya is considered among the largest consumers of Solar energy products in Africa. The climax of consumption is assumed to have increased drastically in 2008 and 2009 due to tax exceptions, affordable tariffs, and generally encouraging policies from the government (Ondraczek J, 2013). This encouraged many investors who promoted the development of off-grid solar systems in the most remote areas in Kenya. A constant decrease to an equivalent of USD 856 per off-grid connection indicates excellent progress for the government of Kenya and its donors towards providing affordable and clean energy in rural regions (Day et al., 2018). The technological developments that allow people to pay as they go, through partial payments, have motivated more consumption of these Solar products.

Ondraczek J (2014) criticizes the government of Kenya and most of the sub–Saharan African countries. According to him, there is much potential for countries to utilize solar energy, considering the geographical location and climatic conditions. However, he argues that solar energy has not yet been considered for the country's long-term energy systems plans, yet it is competitive like other conventional energy sources. According to him, solar energy costs have changed over time, making it more competitive. However, most African countries, even Kenya, are still accustomed to old data that indicate that solar energy installation is costly. Based on research, he found out that the cost of solar energy dropped from USD 3.5-4.5/watt peak in 2008 to USD 0.16 /wp with the introduction of thin film technologies (Ondraczek J, 2014). I agree with him since the Kenyan government did not prioritize solar energy development in its 2011-2031 long-term power system plan.

The pursuit of sustainability implies that the goal is to maintain and improve beneficial conditions that are desirable over the long term. In another review, beyond the perceived economic unattractiveness of the solar energy installation, development actors in the energy and agricultural field are encouraged to look at the cost-benefit analysis of solar energy concerning its low carbon emissions and efficiency in rural populations. Solar products are said to have short investment returns since they have meagre operational costs. This makes it the most appropriate form of energy for Kenya and Sub-Saharan countries to thrive and adapt to the hotter climatic conditions

4.4 Limitations

From this research, there is a notable data gap in terms of food loss and waste in Kenya. According to Sheahan and Barrett (2016), most of the available data are based on assumptions and tend to be used yearly. More food could be lost, while some food products miss the classification. In another study, solar PV was identified as an attractive renewable option, and almost all the sub-Saharan countries are reported to have used their PV but have yet to use it to its potential. According to Karekezi, S., & Kithyoma, W. (2002), other factors, such as sociocultural issues, can inhibit the use. Sociocultural issues can affect ownership and, therefore, maintenance of the systems; proper dissemination needs to be done.

Generally, solar PV systems have tradeoffs in terms of lifespan and flexibility with technological innovations. The life span of solar PV is from 20-30 years, and it has yet to be developed if the solar panels can be recycled, posing an environmental waste challenge. Solar systems have had remarkable technological innovation, but some scholars question their flexibility in the dynamic technological world. However, these limitations can be overcome. First, a cost-benefit analysis of solar systems indicates that solar systems have short investment returns. By the time 20 years elapsed, the farmers would have benefited.

Conclusion

In the food waste hierarchy, prevention is the best option to prevent food loss and waste. A lot of the food loss waste reported in Sub-Saharan Africa and Kenya due to poor infrastructures can be avoided if key strategies are implemented to support the farmers. First, the government must increase funding to encourage more research on solar energy technologies, mainly cooling and drying. Just as the trend was seen in the solar home systems, the demand and consumption increased once the government reduced taxes and introduced subsidies. If the same is applied to agriculture, more dryers and cooling systems will be available to rural farmers, reducing post-harvest loss and waste.

Second, it is evident that energy systems are closely linked with food systems. The Kenyan Ministry of Energy and Agriculture needs to work closely and inspire research and developments from which both can benefit. Food waste can be valorized to generate electricity when prevention is complex. There is generally scanty information on food loss and waste in Kenya, meaning FLW needs to be measured. Farmers and traders need to be informed on how to keep track of food losses and waste since what is measured can be managed.

Thirdly, awareness creation needs to be done on cost-effective and appropriate solar dryers and coolers. Since some of them can be constructed using locally available materials, farmers and traders need to be informed and guided through financial assistance avenues. With the ongoing knowledge gap, business will be as usual: more food production, food loss and eventually, no progress. The review noted that it is easy to help farmers who are already registered or part of a cooperative. Farmers in rural areas can organize themselves in groups so that information will reach them easily.

In summary, solar-powered dryers and cooling systems present a good opportunity for farmers in rural Kenya to increase their food shelf life and agricultural gains. Reducing food loss will go a long way to improving food security, reducing GHG emissions, reducing degradation, and ensuring the achievement of SDGs 7 and 12.3. in the long run, the ongoing climate change and low water levels interfere with hydroelectric potentials. Rural farmers have more incentives to develop and utilize solar-powered food processing.

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