Development of Energy use Profiles, Reduction Concepts, and Implementation of Renewable Energies in the Central Ugandan Pineapple Processing Chains

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By

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Declaration

I, Emmanuel Wokulira Miyingo, give assurance that I completed this dissertation independently without prohibited assistance of third parties or aids other than those identified in this dissertation. All passages that are drawn from published or unpublished writings, either word-for-word or in paraphrase, have been clearly identified as such. Third parties were not involved in the drafting of the content of this dissertation; most specifically, I did not employ the assistance of a dissertation advisor. No part of this thesis has been used in another doctoral or tenure process.

Signed   Date 9th October 2020

Emmanuel Wokulira Miyingo

Dedication

To my mother Ms. Catherine Nabukenya (RIP), my father Mr. Joseph Kaggwa (RIP), my family, and anyone out there interested in practical engineering and the "education" of Africa's child.

Acknowledgement

My heartfelt thanks and gratitude go to my supervisors: Prof. Dr. Oliver Hensel and Prof. Dr. habil. Barbara Sturm for the constructive criticisms, suggestions, guidance, tolerance, dedication, and encouragement extended to me right from the research proposal development to the point of having this research completed and documented. You have been immensely important to me during this undertaking, which involved travelling between Germany and Uganda, and you showed support whatever the circumstance.

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To all those whom I might have not mentioned; a big thank you, and I strongly believe in what Sir Isaac Newton said: “If I have seen further, it is by standing upon the shoulders of Giants”. Indeed, I had to stand on many of your shoulders in order to attain this milestone.

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List of Acronyms

AD	Anaerobic Digestion
AOAC	Association of Official Analytical Chemists
BOU	Bank of Uganda
C:N	Carbon to Nitrogen
CFLs	Compact Fluorescent Lamps
CH_4	Methane
CO_2	Carbon dioxide
CREEC	Centre for Research in Energy and Energy Conservation
DCI	Development Consultants International Limited
DFID	Department for International Development
DGIS	Netherlands Directorate-General for International Cooperation
EE	Energy Efficiency
ERA	Electricity Regulatory Authority
EU	European Union
FAO	Food and Agriculture Organization
GoU	Government of Uganda
GVEP	Global Village Energy Partnerships
IFLs	Incandescent Filament Lamps
IRR	Internal Rate of Return
LPG	Liquefied Petroleum Gas
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MC	Moisture Content
MEMD	Ministry of Energy and Mineral Development
MFPED	Ministry of Finance, Planning and Economic Development
NGOs	Non-Governmental Organizations
NH_4OH	Ammonium hydroxide solution
NPV	Net Present Value
NWSC	National Water and Sewerage Corporation
O_2	Oxygen

PBP	Simple Payback Period
RE	Renewable Energy
REA	Rural Electrification Agency
RECO	Rakai Environmental Conservation Program
RES	Renewable Energy Sources
SDGS	Sustainable Development Goals
SEC	Specific Energy Consumption
SMEs	Small and Medium Enterprises
T4T	Technology for Tomorrow
TS	Total Solids
UBOS	Uganda Bureau of Statistics
UGX	Uganda Shillings
UNIDO	United Nations Industrial Development Organization
URA	Uganda Revenue Authority
USAID	United States Agency for International Development
USD ($)	United States Dollar
USSIA	Uganda Small Scale Industries Association
VS	Volatile Solids

Abstract

Pineapples, like all fruits, are highly perishable and require either immediate consumption or preservation. To make them more stable and add value, four major processing methods are being employed in Uganda, i.e. drying, *munaanansi* (local drink), wine, and juice making. Energy is one of the main inputs required to achieve any of the processing methods. The aim of this research was to develop energy use profiles, gain insights into energy use reduction options, and to evaluate the applicability of renewable energies in Ugandan pineapple processing chains. Fifteen processing enterprises were selected from Kampala, Kayunga, and Wakiso (central Uganda) and investigated for a maximum of six days each. Measurements were conducted at three pineapple drying systems (S01 – processor one, S02 – processor two, and S03 – processor three) and five *munaanansi* makers (P01 –maker one, P02 – maker two, P03 – maker three, P04 – maker four, and P05 – maker five). Similarly, measurements at four winemakers (W01 – maker one, W02 – maker two, W03 – maker three, and W04 – maker four) and three juice makers (J01 – maker one, J02 – maker two, and J03 – maker three) were performed.

Drying is the most developed and formalized processing method in Uganda. The selected drying processors employ forced convective hybrid and traditional direct solar dryers, and results showed that the average inlet and outlet temperatures were 69.50 ^{0}C and 47.11 ^{0}C at S01, 118.26 ^{0}C and 59.20 ^{0}C at S02, and 44.79 ^{0}C and 45.62 ^{0}C at S03 respectively. The specific energy consumption (SEC) at S01 was 28.28 kWh/kg and 13.91 kWh/kg in Jan and Apr respectively, 32.28 kWh/kg at S02, and 3.22 kWh/kg at S03. The drying ratio at S01 was 17:1 (Jan) and 16:1 (Apr) while 22:1 and 16:1 at S02 and S03 respectively. Additionally, for *munaanansi*, wine, and juice making; firewood and charcoal are the main fuels used, and the three stone firewood and traditional charcoal stoves (“sigiri) are the most applied among the investigated makers. The average SEC was 1.24 kWh/l for *munaanansi*, 0.80 kWh/l for wine, and 0.66 kWh/l for juice making.

The study further indicates relatively low energy use profiles among pineapple processors, but there are opportunities for energy use improvement in terms of quantity, quality, conversion devices, and control. Moreover, energy use reduction options were identified and resource use assessment frameworks were developed and proposed for application. The use of renewable energies, especially photovoltaic and solar thermal energy for heating purposes is of particular importance, and there is also energy saving potential with regard to devices for better conversion of biomass into heat.

Kurzfassung

Ananas ist, wie das meiste andere Obst auch, hoch verderblich und muss entweder sofort verzehrt, oder konserviert werden. Zur Haltbarmachung und auch zur Wertsteigerung werden in Uganda vor allem vier Verarbeitungsmethoden angewandt: Das Trocknen, die Verarbeitung zu *Munaanansi* (ein lokales Getränk), die Wein-, und die Saftherstellung. Energie ist einer der wichtigsten Faktoren, die für jede dieser Verarbeitungsmethoden benötigt werden. Ziel dieser Forschungsarbeit war die Entwicklung von Energienutzungsprofilen, zudem Einblicke in Einsparpotentiale zu erhalten, sowie die Evaluierung der Anwendbarkeit erneuerbarer Energien in ugandischen Ananasverarbeitungsketten. Fünfzehn Verarbeitungsbetriebe aus Kampala, Kayunga und Wakiso (Zentraluganda) wurden ausgewählt und jeweils bis zu sechs Tage lang untersucht. Die Messungen wurden an drei Ananastrocknungsanlagen (S01 – S03, Verarbeiter 1 bis 3) und fünf Munaanansi Herstellern (P01 - P05 - Verarbeiter 1 bis 5) durchgeführt. In ähnlicher Weise wurden Messungen bei vier Weinherstellern (W01 – W04, Verarbeiter 1 bis 4) und drei Saftherstellern (J01 – J03, Verarbeiter 1 bis 3) vorgenommen.

Die Trocknung ist die am weitesten entwickelte und meist verbreitete Verarbeitungsmethode in Uganda. Die ausgewählten Verarbeiter verwenden hybride und traditionelle direkte Solartrockner mit Zwangskonvektion, und die Ergebnisse zeigen, dass die durchschnittlichen Einlass- und Auslasstemperaturen 69,50 °C und 47,11 °C bei S01, 118,26 °C und 59,20 °C bei S02 bzw. 44,79 °C und 45,62 °C bei S03 betrugen. Der spezifische Energieverbrauch (SEC) bei S01 betrug 28,28 kWh/kg und 13,91 kWh/kg (Januar bzw. April), 32,28 kWh/kg bei S02 und 3,22 kWh/kg bei S03. Das Trocknungsverhältnis bei S01 war 17:1 (Januar) und 16:1 (April), während es bei S02 und S03 22:1 bzw. 16:1 betrug. Darüber hinaus wurde ermittelt, dass für die Herstellung von Munaanansi, Wein und Saft hauptsächlich Brennholz und Holzkohle verwendet werden, wobei die Drei-Stein-Kocher und die traditionellen Holzkohleöfen ("Sigiri") unter den untersuchten Herstellern am häufigsten im Einsatz waren. Der durchschnittliche SEC lag bei 1,24 kWh/l für Munaanansi, 0,80 kWh/l für Wein und 0,66 kWh/l für die Saftherstellung.

Die Studie zeigt relativ niedrige Energieverbrauchsprofile bei den Ananasverarbeitern auf, dennoch gibt es weitere Möglichkeiten zur Verbesserung des Energieverbrauchs im Hinblick auf Quantität, Qualität, Umwandlungstechnik und Prozesskontrolle. Es wurden Optionen zur Reduzierung des Energieverbrauchs identifiziert sowie ein Bewertungsrahmen für die Ressourcennutzung erarbeitet und zur Anwendung vorgeschlagen. Eine besondere Bedeutung kommt dabei dem Einsatz erneuerbarer Energien, insbesondere der Photovoltaik und der Solarthermie für Heizzwecke zu, weiterhin bestehen Energiesparpotentiale bezüglich der besseren thermischen Nutzung von Biomasse.

1 Introduction

1.1 Background

Uganda is predominantly an agricultural country, and the agricultural sector plays a significant role in the sustainability of human life and development, and contributes substantially to Ugandan economy (UBOS, 2012). As such, the Uganda census of Agriculture 2008/09 revealed that, there were 3.95 million agricultural households with 19.3 million persons living in those households (UBOS, 2011). This was a significant proportion given the 2002 Uganda census, which reported a total population of just over 24 million persons (UBOS, 2005). Additionally, the agricultural land amounted to 61% in 1990 but 66% in 2008 of the total available usable land (World Bank, 2011) and increased by almost 4% from 2008 to 2014 (FAOSTAT, 2014). Furthermore, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) of Uganda stated a 66% employment proportion in the agricultural sector and clearly indicated that the sector contributes substantially to the Ugandan economy based on 2009/10 financial year (MAAIF, 2011b, 2014). Moreover, the 24.4% agricultural contribution to Ugandan Gross Domestic Product (GDP) emphasizes the importance and relevance of the agricultural sector to Ugandan economy (World Bank, 2016a). However, it is mainly based on smallholder farmers characterized by relatively high food losses (over 40%) (Gustavsson, Cederberg, Sonesson, van Oterdijk, & Meybeck, 2011), and such losses are more pronounced among fruits and vegetables (up to 80%) (Akaki, 2012). In addition, the sector lacks vital sectorial performance statistics due to the absence of regular surveys and well developed data collection and analytical methods (MAAIF, 2011b). There are many uncoordinated generators of agricultural data twinned with un-harmonized and inconsistent methods making the statistics vulnerable and unreliable (MAAIF, 2011b; Tröger, 2019).

In a bid to improve the sector, income, and reduce the post-harvest losses and wastage, processing and value addition to agricultural products are invoked. Processing becomes very important in the handling of perishables especially fruits and vegetables whose shelf life is relatively short because of their high moisture content (MC) of over 70% (FAO, 1987; Rwubatse, Akubor, & Mugabo, 2014). Processing such as drying extends the shelf life of the agricultural products and reduces their bulkiness leading to ease of transportation and storage (Nunes, Ribeiro, & Nunes, 2015; Sturm et al., 2018). However, to achieve processing, several inputs are required, and one of the most important ones is energy. Energy is very important, not only for processing but for almost all human activities. It is compared with food and water in sustaining human life. Therefore, energy availability, supply, and quality become relevant for processing in the agricultural sector (Anitha, Vanitha, Nivedha, & Usha Rani, 2012).

Notwithstanding the growth of the various agricultural sub-sectors (e.g. forestry, livestock, fisheries, among others), the fruits sub-sector is one of the fastest growing sub-sectors in Uganda. It is argued that, pineapples are one of the most dominant fruits grown, processed, and traded in Uganda (Bonabana-Wabbi et al., 1991). They are highly perishable (Satyanarayana, Johri, & Prakash, 2012) due to their high water content estimated to be over 80% (Orsat, Changrue, & Raghavan, 2006; Sagar & Suresh Kumar, 2010; Sharma, Chen, & Vu Lan, 2009). They therefore require immediate consumption after harvest, or processing and refrigeration for later consumption. In Uganda, there are two main pineapple harvesting seasons i.e. Dec to Feb (bumper) and June to September (meager). During such periods, a lot of pineapples are available (Ssemwanga Consulting Ltd, 2007) which leads to low prices (about UGX 500) as well as increased loss and wastage. They are normally consumed domestically, delivered to either local or international markets when they are fresh, or processed into intermediate or final products such as dried chips (MFPED, 2016; Sonko, Njue, Ssebuliba, & Jager, 2005). Delivery to the markets is sometimes done by the farmers themselves, or local traders and exporters (Ssemwanga Consulting Ltd, 2007). Some traders and exporters double as processors, and therefore transform the pineapples for value addition and shelf life extension before delivery to the markets (Sonko et al., 2005). In some cases, special direct links between processors and farmers in places such as Kayunga, Kangulumira, and Luweero have been established through schemes known as “contract farming”. This is common among organic producers where processors and exporters enter into agreement with the pineapple farmers in advance (Bolwig, 2012). However, it is common that the surplus or the unsold is left to rot hence wastage. So, processing and value addition is employed to minimize wastage and improve shelf life as is with other agricultural products (Sempiri, 2011). But as already stated, this sub-sector is not unique; there is limited information on the current performance of the various processing methods and energy use and requirement. This hinders the possibility of improving and optimizing these processes. This study was concerned with the identification of the current energy use profiles, reduction concepts, and the possibilities of integrating renewables into the processing of pineapples in central Uganda. It provides quantitative inputs with respect to outputs as well as other related parameters such as process waste, drying temperature variations, and MC of both fresh and dried pineapples.

1.2 Problem Statement

Small-scale processing is one of the cheapest and appropriate interventions being employed by individuals, small and medium enterprises (SMEs) to maximize the seasonal nature of pineapples in central Uganda, and Uganda at large (Muzaale, 2013). The main motivation is more economic rather than being a target of reducing post-harvest losses and waste although indirectly contributes to loss reduction. The economic benefit is derived based on low investment cost, use of human power (sometimes provided by family members), and limited mechanization. However, the processors face the problem of inadequate and unaffordable energy supply especially electricity (Karekezi & Kithyoma, 2002; MEMD, 2007). As a result, they experience losses and delays during processing leading to poor quality products and economic returns (Tröger, 2019).

The processors are compelled to improvise in order to keep the processes ongoing. Actually, a number of current interventions in pineapple processing and preservation in Uganda are based on solar energy (e.g. open solar drying), which is very attractive but some of equipment used for solar harvesting are too far from the ideal (Figure 1.1). Some of them are weather dependent, and in case of bad weather, the processors are likely to lose heavily because they have no any form of back up energy supply. Their performance is relatively low especially in terms of the drying rate and quality of the final products, which is attributed to lack of control of the drying process, hence prolonged drying time (Chongtham, de Neergaard, & Pillot, 2010).

Figure 1.1: Locally Fabricated Solar Dryers

Utilization of biomass (especially charcoal and firewood) as a source of energy for processing pineapples in Uganda finds a lot of application although using poor and primitive conversion devices such as the three stone cook stoves (Figure 1.2). This negatively affects not only the environment, but also leads to indoor pollution, and affects the overall cost of energy used, hence sustainability concerns (Gustavsson, Broad, Hankins, & Sosis, 2015; GVEP, 2012).

Figure 1.2: Three Stone Firewood Stove

Additionally, most of the enterprises generate a significant amount of waste dominated by pineapple peels (Figure 1.3) during processing. While there are reports of using damaged pineapples and peels for animal feeds and soil fertilization in western region of Uganda (Tröger, 2019), pineapple waste management remains a huge challenge in many parts especially in central Uganda (Zziwa et al., 2017). Those working within limited space and town locations have to incur disposal costs every time they process although the disposal by the responsible companies is still open dumping in designated central locations. Such disposal methods do not favor the environment (Ali, Pervaiz, Afzal, Hamid, & Yasmin, 2014; Ejaz, Akhtar, Nisar, & Ali Naeem, 2010). For those processing near the garden with a lot of space tend to simply dump without consideration for sanitation and environment, and flies are ever within the processing areas because they are attracted by the smell of the waste. However, the same enterprises lack reliable and sustainable energy supply for processing and cooking food at the processing sites (MEMD, 2007; Ssennoga, Ramli, Murphy, Mukhtiar, & Nsamba, 2016).

Figure 1.3: Pineapple Waste Dominated by Peels

Relatedly, the extent of energy usage and requirement in small-scale pineapple processing is not well documented and unavailable to a large extent. This cripples decisions and interventions, which would lead to improved and efficient use of energy. Local capacity and innovations are insufficient and some of them are still primitively used, yet there is a high demand for appropriate solutions. Lack of information and processing statistics limit future development and modernization of such processes. Moreover, solar photovoltaic (PV) is rarely used for agricultural products processing, and mainly finds applications for lighting and powering simple devices such as cell-phone charging, watches, calculators, among others (Adeyemi & Asere, 2014; Gustavsson, Broad, Hankins, & Sosis, 2015; MEMD, 2014). Therefore, an opportunity exists to significantly improve the efficacy and reliability of pineapple processing by exploiting both solar PV and solar thermal, and other renewables. Such can be designed and planned to operate as standalone and/or hybrid energy systems (Gustavsson et al., 2015). If well developed, they present a great potential for supporting not only pineapple processing but also other agricultural products processing. However, information on the current practices and energy use profiles must be collected to inform future actions geared towards improving energy and other resource use.

1.3 Objectives

1.3.1 General objective

The main goal is to develop energy use profiles, reduction concepts, and possibilities of using renewable energies in the central Ugandan pineapple processing chains. The profiles would give the current energy usage levels and energy types being applied by small-scale pineapple processors in central Uganda. Energy efficiency (EE) and energy use reduction scenarios will be based on such, and the role and application of renewable energies in the various processing methods. This is envisaged to eventually contribute to the understanding of resource use efficiency, optimization, and sustainability in food processing.

1.3.2 Specific objectives

1. To perform real time measurements and analysis on the identified pineapple processing methods in central Uganda
2. To propose resource use assessment frameworks for small-scale food processing enterprises in low income countries – a case for Uganda
3. To suggest energy use reduction and renewable energy integration options in selected pineapple processing methods

1.4 Research Questions

To achieve the above objectives, the following research questions were formulated and pursued. They provided a guide on which information and data must be delivered at the end of this research.

Objective 1

I. How many kg of raw pineapples are input and how many kg of dried pineapple or liters of munaanansi, wine, and juice are output per processing?

II. How many kWh of energy do the selected small-scale pineapple processors consume per processing, and what is their respective specific energy consumption (SEC)?

III. What are the current energy sources used by selected small-scale pineapple processors?

Objective 2

I. Which general framework can be adopted for the assessment of resource use and improvement in small-scale food processes in low income countries?

II. Which specific framework can be adopted for energy supply-utilization assessment within small-scale food processes in low income countries?

Objective 3

I. What energy reduction constructs are relevant to small-scale pineapple processors?

II. What are the potential alternative energy sources for small-scale pineapple processors?

III. What are the possibilities of integrating renewables into small-scale pineapple processing?

1.5 Summary of the Methodology and Structure

1.5.1 Summary of the methodology

Figure 1.4 summarizes the methodology followed in this study. It started with the identification of pineapple processing methods and selecting the main ones. Some processors from each of the selected processing methods were randomly selected and real time measurements carried out. The collected data and information was analyzed and performance for the respective enterprises evaluated. This informed the development of the process evaluation and assessment frameworks. Documentation was carried out at every stage, and findings shared (reported) among the relevant stakeholders.

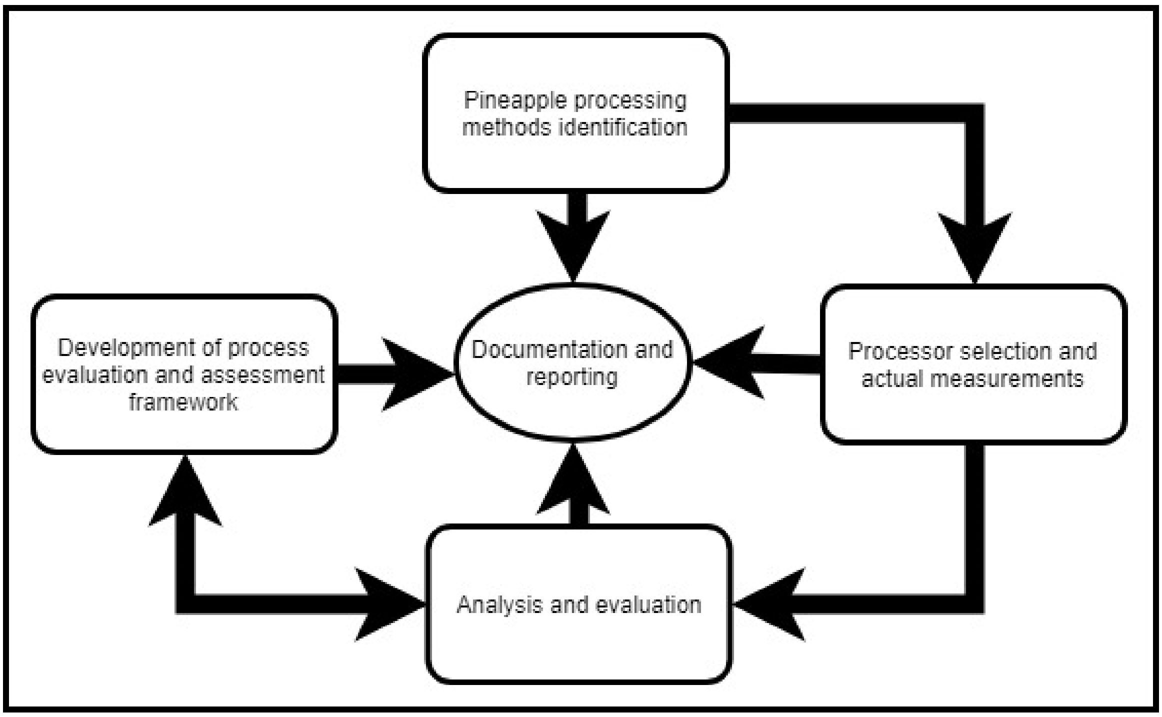


Figure 1.4: Summary of the Methodology

1.5.2 Structure of the dissertation

This dissertation is divided into six chapters beginning with the introduction, which gives the background to the study, objectives, and summary of the methodology.

Chapter 2 describes the existing body of knowledge, which is deemed relevant to the this study. This literature includes food losses and waste in general and Uganda in particular, energy requirement in food processing, pineapple processing methods in Uganda, and simulation and optimization of processes.

Chapter 3 presents the methodology used during the execution of the different activities in order to achieve the set objectives. It describes how each of the main processing methods is being employed in Uganda, and gives a systematic description of each of the procedures followed during actual measurements. It starts with the study area, selection criteria, and all the way through.

Chapter 4 gives the results while interpretations and discussions are presented in Chapter 5. Indicative illustrations, units, and measures such as percentages, degrees, tables, graphs, and photographs are used to make the presentation rich and orderly. The main resource usage levels and explanations of what they mean to the enterprises, academia, and the sub-sector as a whole are revealed. Chapter 5 further proposes process and energy evaluation and assessment frameworks derived from the literature and experience gained while interacting with pineapple processors in Uganda. It illustrates by way of giving some examples of material and energy flow diagrams coined from some of the collected data and information. It ends by describing the four most relevant energy reduction options in pineapple processing lines, which can be applicable across other processing lines.

Chapter 6 presents the summary and conclusion, summary and implications, and recommendations based on the findings and the current situation among pineapple processors in Uganda. The main limitations of the study are also pointed out, and areas for future research are suggested.

A list of references of the cited work is included as acknowledgement of other researchers' effort and contribution. Other relevant information and data not in the main document is presented in form of appendices.

2 Literature Review

2.1 Food Losses and Waste, and their Causes

2.1.1 General overview of food losses and waste, and their causes

Food loss and waste (FLW) can be defined as the edible parts of plants and animals that are produced or harvested for human consumption but that are not ultimately consumed (Lipinski et al., 2013). Food loss is generally un-intended while food waste is a result of negligence or a conscious decision to throw food away (Kiaya, 2014; Lipinski et al., 2013). Food loss and waste are a long-standing problem, which diminish the availability of essential nutrients in both developing and developed countries. In fact, they are considered some of the biggest challenges facing the Western World (Creedon, Cunningham, Hogan, & O'Leary, 2010). Several studies indicated that a significant amount of food is lost and wasted in the supply chain amounting to 1.3 billion tons annually globally (Aulakh & Regmi, 2013; Gustavsson et al., 2011). Moreover, several resources such as land, fresh water, fertilizers, labor, and energy are required for food production and post-harvest handling. Thus, food production and management is directly associated with greenhouse gas (GHG) emissions and can thus lead to environmental degradation (Buzby et al. 2014; Gustavsson 2010; Papargyropoulou et al. 2014).

In terms of food type, perishables such as fruits, tubers, and vegetables suffer the most with about 50% loss (Green & Schwarz, 2001), which is mainly attributed to the fact that they are characterised by a high water content (over 70%) (FAO, 1987; Rwubatse et al., 2014) and decay rapidly just after harvest (Kitinoja & Kader, 2015). It is emphasized that food losses and waste occur at every stage in the food supply chain right from the field or garden, processing, transportation, storage, distribution, and consumption (Betz et al. 2015; Gustavsson 2010; Gustavsson et al. 2011; Kitinoja et al. 2011; Parfitt et al. 2010b). However, the severity of loss and waste at various stages differs mainly depending on either more developed or least developed country. In more developed countries (MDCs) for example, the loss is highest at the distribution and consumption stages while highest after harvesting and before the market or distribution stage in least developed countries (LDCs) (Aulakh and Regmi 2013; Gustavsson et al. 2011).

Similarly, the causes of food loss and waste differ depending on whether more developed or least developed country. Thus, in MDCs, food loss and waste is caused by but not limited to personal preferences, consumer behavior, uncoordinated purchases and consumptions, and portions beyond one's ability to consume. However, in LDCs, some of the causes are poor harvesting methods, inadequate food handling infrastructures, inadequate energy supply, over-production, and limited processing technology (Aulakh and Regmi 2013; FAO 2012a; Gustavsson et al. 2011). So, any food loss and waste reduction intervention and effort might have to be stage and country specific.

2.1.2 Food losses and waste, and their causes in Uganda

In Uganda like many developing countries, food losses and waste are not well documented. However, there are clear indicators and highlights to illustrate the extent of this problem in Uganda (AGRA, 2013; HLPE, 2014; Ruhunda, 2012). It is reported that losses in fruits especially mangoes, pineapples, and pawpaw can be as high as 80% in Uganda (Akaki, 2012). The losses are mainly due to inadequate knowledge, well-established infrastructures, advanced food preservation and handling methods, electricity supply, as well as the perishable nature of some crops (Brockamp, 2016; Gustavsson et al., 2011; Kiaya, 2014; Themen, 2014). The need to store agricultural products by farmers for future use and sale at better market prices is another factor leading to losses and wastage. Usually, agricultural product prices are low when everyone is harvesting, so some actors e.g. resellers choose to store as they wait for better prices. However, due to factors such as perishability, poor storage facilities, and poor harvests, they end up losing their produce to pests, molds, and rotting. Those who choose to sell immediately after harvest; they sell at low prices, only to buy it back at higher prices after a few months (Tefera et al., 2011). Eventually losses and waste, and low prices lead to adverse economic consequences to the government, private sector, farmers, food sellers and buyers. So, food losses and waste are a real threat to food security and interventions to reduce them must be sought globally and locally (country level), and much more focus should be on perishables where the losses are quite alarming. Local products such as pineapple wine, banana ketchup, and mushroom powder developed by Makerere University researchers in collaboration with farmer groups in Uganda through the RELOAD Project (RELOAD, 2017) sound very interesting and applicable. They are scalable and easy to adopt to the other regions especially those bearing similar characteristics. Such interventions add value to food products, reduce the level of post-harvest losses and waste, and improve the incomes of food value chain actors.

2.2 Food Loss and Waste Reduction

2.2.1 General overview of food losses and waste reduction

Food loss and waste reduction involves systematic actions undertaken to minimize food loss and waste. These actions must consider the entire food chain right from the field and pre-harvest through harvest, post-harvest, transportation, processing, storage, and marketing while involving every stakeholder (Gustavsson et al. 2011; Kiaya 2014; Parfitt et al. 2010b). When food loss and waste is reduced, more food becomes available for human consumption, thus contributing to food security. In effect, food loss and waste reduction contributes to Sustainable Development Goal (SDG) #02, which aims at “No Hunger” by 2030. The goal challenges everyone to rethink on how they grow, share, and consume food (UNDP, 2016). In short, the goal points at ensuring efficiency of the entire food value chain from the garden to fork.

Food loss and waste reduction approaches range from infrastructural and technical improvements to awareness campaigns and more research on food loss and waste. Of course, the approaches will differ depending on the food product, region, and stage in the food supply chain (Brockamp, 2016; Canali et al., 2016). For instance, in MDCs, consumer awareness campaigns might have a greater impact than in LDCs where infrastructural and technical development are likely to have a more significant impact (Hodges, Buzby, & Bennett, 2011). Appendix A gives some examples of post-harvest loss and waste reduction interventions that have been employed so far with respective achievements. The examples are cited within UK and Africa. The reported loss and waste reductions are quite impressive, and would contribute greatly to food availability if adopted and spread widely. Therefore, a reduction in food losses can go a long way in reducing the burden on food production (Kiaya, 2014; Vijayavenkataraman, Iniyan, & Goic, 2012). This means, several factors influence food loss and waste reduction efforts, and this should be remembered whenever actions are being taken. Affected stakeholders e.g. farmers, food processors and transporters must be the center of the proposed interventions. In other words, interventions should be stakeholder centered since some of them might require voluntary actions.

2.2.2 Reduction of food losses and wastage in Uganda

In Uganda, a number of strategies and efforts towards food loss and waste reduction are underway. Several policies and strategies by the Government of Uganda (GoU) through the Ministry of Agriculture, Animal Industry and Fisheries such as the National Agriculture Policy (NAP) (MAAIF, 2011a) have been put in place. However, most studies and efforts on post-harvest technology and loss reduction have so far concentrated on grains and other durable products, which are stored dry and a substantial technology has been developed to deal with them. Contrary, less work has been undertaken on the perishable food crops such as fruits, yet they are of great importance in the food mix of Uganda and the world at large (Atanda, Pessu, Agoda, Isong, & Ikotun, 2011).

Moreover, most of the current technologies and mechanisms for food products processing and preservation in Uganda such as open sun drying are still primitive (Ruhunda, 2012), and advanced ones are still insufficient because most of them are imported and relatively expensive. This is usually coupled with inadequate and unreliable energy supply, rendering most advanced processing and loss reduction mechanisms unsustainable. Thus a knowledge gap, and in the case of breakdown, there is no adequate local capacity to repair and service imported equipment (Abass et al., 2014; Akaki, 2012). Several data gaps on the quantification and characterization of post-harvest losses and wastes still exist (MAAIF, 2011b; Parfitt, Barthel, & Macnaughton, 2010b). Such situations tend to hinder most of the efforts meant to reduce food losses and waste in Uganda. Government and Non-government organizations (NGOs) in Uganda continue to promote food storage using silos and granaries to meet future food demands and reduce losses and wastage. However, the uptake is still slow given that some of the food products are perishable, and pests usually attack cereals during storage (Lipinski et al., 2013).

Locally developed and innovated solutions for reducing food losses and waste especially those involving renewable energies must be encouraged and should find support by all stakeholders. They should be developed together with local communities to establish local human capacity. The research outputs must be disseminated to the targeted beneficiaries, and technology development must be linked to technology transfer if these efforts must have long lasting impact to reducing food loss and waste and improving the actors' incomes in Uganda. Essentially, local knowledge e.g. on maturity indicators based on color and size changes can be integrated since it is already very useful in determining the most appropriate harvesting times to avoid premature harvests (Okiror et al., 2017). Such indicators are mainly based on local experiences and relatively cheaper to adopt and propagate. However, there is need for assimilation and synchronization with modern maturity indicators in order to optimize harvesting and consumer acceptability especially among fruits and vegetables in Uganda. In fact, some users of local maturity indicators in Uganda so far consider them unreliable and inaccurate (Okiror et al., 2017).

The other intervention targeting loss reduction among perishable crops in Uganda is the Presidential Initiative on Banana Industrial Development (PIBID). Banana is a very important food crop in Uganda whose production increased from 0.45 million tons in 2009 to around 0.49 million tons in 2011 (UBOS, 2012) and about 0.44 million tons in 2013 to 0.46 million tons in 2015 (UBOS, 2016) with about 75% of Ugandan farmers involved in banana growing activities

(PAEPARD, 2012). With such in mind, a set up by the GoU aimed at helping the banana sector in Uganda through banana value addition was established in 2005 (Ariho, Makindara, Tumwesigye, & Sikira, 2016). This was intended to reduce persistent banana losses that were being experienced in the banana value chain. The set up focuses on banana value addition, quality control, and marketing by providing access to tested technology and experienced professionals to banana farmers, processors, and traders. As a result, banana products such as instant tooke flour, raw tooke flour, cakes, and tooke flakes are being made and traded in Uganda (Ariho et al., 2016; Newvision, 2013; PIBID, n.d.; State House of Uganda, n.d.). These are interesting examples, which can go a long way in guiding further actions towards food loss and waste reduction not only in Uganda, but also in many other developing countries with similar challenges. There must be coordination and integration given the various variables and inputs required especially energy supply. This contributes to achieving SDG #09, which focuses on "Industries, Innovation and Infrastructure" development. The goal calls for investment into improving transport, irrigation, energy, and information and communication technology (UNDP, 2016). It further asserts that, "…Without technology and innovation, industrialization will not happen, and without industrialization, development will not happen…" (UNDP, 2016). Therefore, everyone engaged in reducing food losses and waste must keep reflecting on the bigger picture taking into perspective the global needs and concerns. Indeed, we are tackling global issues even when our solutions seem local and particular.

2.3 Energy Requirement in Food Processing

2.3.1 General background on energy and its role in food processing

Energy is considered a driver for all human and economic activities. It plays a key role in sustainability of human life, economic and social development, poverty alleviation, food production and security, human health, and climate and ecosystem. Thus a prime commodity for modern human civilization, and has become a measure of human standard of living and industrialization based on per capita energy consumption, the higher the per capita energy consumption, the higher the standard of living (GEA, 2012; Goldenberg, Johansson, & Anderson, 2004; Li, 2011; Turyareeba, 2001). However, the per capita energy consumption does not show the level of energy distribution although important in illustrating the inequalities among groups of countries basing on how much energy is consumed per person (Goldenberg et al. 2004). Indeed, it is reported that in 2001, industrialized countries consumed 4.7 tonnes of oil equivalent (toe) per capita, compared to only 0.8 toe per capita used by developing countries, when the world average was 1.7 toe per capita. Similarly, the per capita energy use in the Sub-Saharan region was only 0.6 toe (Goldenberg et al. 2004). Actually, the per capita energy consumption is a very informative indicator especially where it is derived based on commercial energy consumption. It reveals the extent to which a country's energy is involved in commercial activities, and its contribution to the economy. It can also disclose the wastefulness or effectiveness of energy utilization especially in the production processes by comparing with figures from other countries or regions, different periods, and between the same or similar processes (Belward et al., 2011; FAO, 2012).

Due to the importance of energy, the framers of Sustainable Development Goals (SDGs) dedicated a special goal (SDG #07) of ensuring "Affordable and Clean Energy" by 2030 (UNDP, 2016). They clearly state that energy is central to almost all major challenges and opportunities the world is facing today such as jobs, food production, security, to mention but a few. This goal actually interlinks with almost all the other goals since energy is paramount in nearly every human activity (UNDP, 2016). Therefore, energy availability, quality, sustainability, and affordability is very pertinent to human survival. Moreover, pursuit of SDGs is rendered ineffective without sustainable energy supply.

This important resource (energy) is grouped into two categories, i.e. conventional or non-renewable and non-conventional or renewable energy (RE). Conventional or non-renewable energy sources such as coal, oil, nuclear, and natural gas are finite and will eventually be depleted. They are associated with several adverse effects to the environment such as huge emission of greenhouse gases leading to climate change and environmental degradation, and conceived as unsustainable (Twidell & Weir, 2006).

Non-conventional or renewable energy sources (RES) exist on a recurring basis. Solar, biomass, wind, geothermal, hydro, tidal, and wave energy are examples of these energy sources. They are associated with several advantages such as being clean (limited or no emissions), modular, silent, and the world can rely on them for sustainable energy supply. The current global trend is to promote the use of RE for sustainability (Twidell & Weir, 2006). It is anticipated that renewables will provide 30 - 80% of the total global energy consumption by the year 2100 (Fridleifsson, 2001; Nguyen, Arason, Gissurarson, & Pálsson, 2015), and by 2015, renewable energies had already provided an estimated 19.3% of the global final energy consumption (REN 21, 2017). They are found in most parts of the world and more so, in Sub-Saharan Africa (SSA) where by coincidence, conventional energy supply is still a big challenge. Most countries or regions, especially in SSA, will have at least two of the RES readily available with solar and biomass being the most common ones. Therefore, Sub-Saharan region is a suitable candidate for the utilization of RE not only in food processing, but even in other day-to-day energy requiring human activities.

In the context of food processing, transportation, preservation, storage, and distribution, energy is identified as one of the major inputs. Lack of or poor quality energy supply contributes and intensifies food loss and waste. The resulting negative impact is more pronounced in developing countries where energy supply especially electricity is very scarce (FAO, 2012). Moreover, agricultural activities consume a significant amount of energy and energy supply is still associated with some challenges and problems especially inadequacies, cost, and sustainability issues.

Energy loss and waste

One of the concerns for energy use sustainability relates to energy losses and waste. Energy loss and waste can sometimes be significant leading to increased energy bills and reducing the profit margin of the chain actors plus the negative environmental impact (Bundschuh & Chen, 2014). Energy losses and waste are due to several factors such as human behavior, negligence, poor equipment, to mention a few. These losses and wastage can be alleviated by employing EE and energy conservation, awareness campaigns, energy management programs, among others (Wang, 2014). However, many processors and energy users never carry out regular energy assessments to establish periodical performance levels yet such evaluations are needed in order to come up with suitable measures to increase energy use efficiency (Bundschuh & Chen, 2014; Wang, 2014). In the end, limited information is available about energy utilization, losses, and wastage especially among small-scale processors.

In line with energy loss and waste reduction and energy use sustainability, EE such as the use of more efficient devices and machines is usually emphasized in most sectors especially industrial and agricultural sectors in order to reduce the overall energy consumption (Kluczek & Olszewski, 2016). This is considered as one way of ensuring sustainable economic growth and development (Kebede, Kagochi, & Jolly, 2010). In fact, RE and EE are seen as “twin pillars” such that they have to be adopted together in order to stabilize and reduce greenhouse gases especially carbon dioxide (Fatona, 2011; Meyers, Schmitt, Chester-Jones, & Sturm, 2016). Such approach would ensure clean energy utilization and slow the demand (Fatona, 2011). This is in line with SDG #12, which requires “Responsible Consumption and Production”. This goal emphasizes promotion of "resource and EE, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all" (UNDP, 2016). Therefore, energy supply and utilization must always take into account sustainability by considering measures such as EE and energy conservation. It is also implied that RE is only sustainable if used sustainably.

2.3.2 Renewable energy in food processing

Currently (2020), solar energy is one of the most developed and used RES globally. It is commonly applied in drying agricultural products using solar dryers (solar thermal) although open sun drying is also still a common practice especially in Africa. However, open sun drying is associated with several disadvantages such as degradation of the products due to wind-blown debris and dust, lack of protection from rain and dew, insect infestation, attacks by rodents and birds, over or under drying, and slow drying. These greatly affect the quality of the final product despite open sun drying being cheap and straightforward (Chaudhari & Salve, 2014; Murthy, 2009; Nunes et al., 2015; Rahman, 2007; Tiris & Dincer, 1995). Solar PV is particularly used in forced convective dryers for powering direct current (DC) fans or motors, which circulate warm air within the dryers replacing the fossil fuel based electricity (Kiggundu et al., 2016). It is also used as auxiliary power supply for powering electronics and control circuits in food processing systems especially drying where monitoring and control of particular parameters such as humidity and temperature is required (Román & Hensel, 2018).

Biomass is also widely available with a high potential for energy supply although different studies have arrived at different conclusions regarding the future biomass availability as an energy source (Berndes, Hoogwijk, & Van Den Broek, 2003; Heinimö & Junginger, 2009). Some researchers identified biomass as a suitable substitute for the current fossil fuels and as an important energy source in the fight against increased greenhouse gas emissions (Heinimö & Junginger, 2009). In fact, it is indicated as already supplying over two-thirds of energy for cooking and heating (during food processing) in developing countries (Heinimö & Junginger, 2009). But it is associated with deforestation, environmental degradation, as well as causing health hazards due to air pollution (Cerutti et al., 2015; Menya, Alokore, & Ebangu, 2013; WHO, 2014). These are key concerns, which require follow up especially by engaging researchers from those regions and countries where such problems are most prevalent.

Related to biomass, biogas is the gaseous form of biomass, derived directly from living matter by anaerobic digestion (AD). The biogas composition is methane (50 – 70%), carbon dioxide (50 -

30%), water, and other traces of gases (Rupf, Bahri, De Boer, & McHenry, 2015; Subramani & Kumar, 2016). Most of the biodegradable materials such as agro-waste, food crops, faecal sludge, and municipal waste are suitable for AD although animal manure has so far been extensively employed (Subramani & Kumar, 2016). Some of the factors that influence the yield and quality of biogas are the nature of the substrate, microorganisms involved, MC and pH of the substrate, loading rate (LR), operating temperature, digester type and size, toxicity, carbon to nitrogen (C:N) ratio, retention time (RT), Total Solid (TS) and Volatile Solids (VS). Additionally, finely ground waste products generate more biogas due to large surface area of contact with bacteria. Therefore, some of these factors can be investigated by anyone interested in assessing the suitability of a particular feedstock for biogas generation. Some conditioning of the substrate might be required so that the above factors are adjusted to suitable ranges for optimal biogas yield e.g. 6.5 - 7.5 pH and 35 – 45 ^{0}C mesophilic temperature (Nga & Trang, 2015). Similarly C:N (20:1 to 30:1) (Nga & Trang, 2015; Subramani & Kumar, 2016), MC (94 - 91%), and TS (6 - 9%) (Sorathia, Rathod, & Sorathiya, 2012; Subramani & Kumar, 2016) might all require adjustment. Despite of the challenges associated with biogas, it is still viewed as a promising energy resource on global scale especially in developing countries where energy shortages are still rampant. However, there is still limited funding and dissemination of biogas use, rendering it to remain on small-scale majorly for cooking and lighting in developing countries. So far, it is Europe and USA where large-scale biogas based power is being popularized (Scarlat, Dallemand, & Fahl, 2018; Stuckey, 1986). The idea of biogas utilization sounds more relevant to developing countries where cooking and lighting are some of the main energy needs.

2.3.3 Energy in food processing in Uganda

Background

There is limited information on energy utilization in food processing and the agricultural sector in general in Uganda, although energy remains a central factor in both. Currently, the emphasis by most of the stakeholders especially the government and NGOs is on RE promotion, and some enabling policies such as “the renewable energy policy for Uganda” have been put in place (MEMD, 2007). Such efforts have resulted into increased installed capacity for renewables e.g., the 10 - 100 kW small-scale institutional and domestic solar systems, which have been installed (by both private and public sector), promotion of more efficient cooking stoves, and the establishment of the Uganda Energy Credit Capitalization Company (UECCC) for the provision of funding to RE projects (MEMD, 2017). However, solar PV is not yet extensively exploited in food processing apart from a few cases cited when DC fans are used for circulating drying air in solar dryers and some fruit exporting companies in Uganda exploring the combination of hydropower with solar PV on a small-scale (Kiggundu et al., 2016; Kwikiriza, Mugisha, Kledal, Karatininis, & Namuwooza, 2016). Relatedly, most of the current engineering solutions in food processing need sufficient and reliable energy supplies. Therefore, issues of energy demand, supply, and utilization greatly influence the nature and impact of the engineering solution(s) in the agricultural sector and food processing in particular.

Conventional electrical energy in Uganda

The conventional electricity is not readily available and used in the agricultural sector in Uganda (Karekezi & Kithyoma, 2002; Ojok, 2012; UBOS, 2010). It is mainly from hydropower plants but considered unaffordable to most Ugandans. Moreover, some studies indicated that less than 13% in urban areas and less than 5% in the countryside (where over 80% of agricultural producers are found) have access to electricity in Uganda (MEMD, 2007; Ojok, 2012; Ssennoga et al., 2016). Even then, a very small proportion of electricity is utilized for agricultural products processing in Uganda (Mukuve & Fenner, 2015). Therefore, alternative energy sources are required to bridge this gap, and non-conventional energy sources have been cited as having a great potential in Uganda, and it remains to be seen how much energy they can contribute in reality (Mukuve & Fenner, 2015). Here, biomass and biogas, which are closely related energy sources, are further elaborated.

Biomass

It is noted that biomass (mainly charcoal and firewood) is currently the dominant energy resource in Uganda with over 90% energy requirements being satisfied by use of biomass (MEMD, 2007; Ssennoga et al., 2016; Turyareeba, 2001). The current challenge with the utilization of biomass is that the conversion devices and methods (e.g. three stone firewood stoves) are still primitive and unattractive with respect to the desired life styles and sustainability requirements (Ssewanyana, Matovu, & Twimukye, 2011). Biomass is majorly directly combusted to provide thermal energy in Uganda for heating and cooking food, but there are also other thermo-chemical conversion methods such as gasification and pyrolysis, which result into fuels of higher heating values (Gumisiriza, Hawumba, Okure, & Hensel, 2017; Panwar, Kothari, & Tyagi, 2012). The other biomass conversion methods are biochemical that lead to products such as ethanol and biogas

(Gumisiriza et al., 2017). Electricity can also be generated from biomass through various conversion stages although this option is not yet common especially in developing countries (Dimpl, 2011). Therefore, appropriate possibilities should be explored to make biomass more user friendly, clean, and ensure sustainable utilization. Artificial forests, agricultural waste, and improved cook stoves can significantly improve biomass availability and limit deforestation. In fact, biomass is considered carbon-neutral since the carbon dioxide generated during its combustion is captured during the biomass growth. This creates a closed cycle, and to some extent makes it a low-carbon energy source since the net carbon emission in its life time is negligible (Dimpl, 2011; Panwar et al., 2012).

Biogas

Biogas is another RE which is becoming more important in the energy mix for Uganda (Gomez, 2013; Lutaaya, 2013). Appendix B summarizes biogas utilization with related challenges and potential approaches to biogas successful dissemination. The studies mainly focused on SSA, but Uganda is of interest in this dissertation. Most of the studies indicated a current low uptake and unsuccessful experience, but they paint a good picture on the future potential of biogas as an alternative energy source especially for cooking and lighting domestically. Additionally, the bio-slurry from the biogas plants is used as a fertilizer to enhance soil fertility and improve crop yields (Karekezi & Kithyoma, 2002). Similarly, some success stories are being told on the benefits and achievements biogas utilization has brought to some Ugandans most of which are about access to clean cooking and lighting energy as well as improved agricultural outputs (Kansiime, 2017; Nieuwenhuizen, 2016). However, there are still some challenges facing biogas in Uganda e.g. limited financial capacity, awareness, local technical capacity, and high maintenance costs (Tumwesige, Joanne, & Avery, 2011). There are some possible solutions (Appendix B) to those challenges ranging from creating awareness and education to providing microfinance support and involving all the stakeholders. With its associated benefits (social, monetary, and environmental), biogas should be promoted and blessed to meet some of the current energy needs in Uganda. Thermal and lighting applications should be emphasized, and techno-economic analysis be further done in line with the current Ugandan economic situation to provide the financial viability scenarios.

In the end, all the other renewable energies can be brought into the complete picture, but emphasis on those that have already showed great potential especially solar and biomass. There is need to coordinate and find a good balance between them. Indeed, they can be utilized in combination, e.g., using solar PV, solar thermal, and biogas as one hybrid energy system. In doing so, the most influential factors such as the technical, economic, and social must be critically considered to ensure that the target groups adopt the systems. Such an approach is likely to yield better and more sustainable results in terms of energy supply for food processing and preservation in Uganda. Therefore, further research needs to be done in order to evaluate the performance of the various hybrid combinations based on resource availability, cost, and environmental impact in relation to Uganda's situation. The research should focus on developing hybrid evaluation packages where RE is utilized as thermal energy. The current traditional evaluation software and packages tend to emphasize electrical energy e.g. biomass, biogas, and solar to electricity, and usually include the grid. This leaves a gap in those scenarios where only small-scale thermal energy is required e.g. for heating and pasteurization, and need to be evaluated. Such small-scale thermal energy combinations seem to be more relevant to developing countries like Uganda since most of those renewables exist although not yet full tapped (Fashina et al., 2018).

2.4 The Role of the Fruits Sub-Sector and Related Challenges in Uganda

The fruits sub-sector is one of the agricultural sub-sectors, which greatly contribute to Uganda's food supply and non-traditional agricultural exports. Some of the major fruits produced include pineapples, mangoes, passion fruits, jackfruit, citrus, avocado, guava, and watermelon (Ssemwanga Consulting Ltd, 2007). However, the sub-sector is still in the hands of smallholder farmers scattered all over the country. This cripples the improvements, development, and commercialization of the sub-sector, and as such, its export contribution has remained low e.g. less than 1% for five years (2011 – 2015) (UBOS, 2016). The fruits are consumed fresh especially domestically, but also traded locally and internationally for income generation. Processing of the fruits is invoked in order to stabilize and extend their shelf life for marketability.

Among the above fruits, pineapples are by far the most grown and widely spread in Uganda, and gaining popularity in the local and international market. They are currently attracting a significant number of actors such as farmers, processors, and traders although on a small-scale (Tröger, 2019). Their production quantities have kept increasing e.g. there was about 14.5% growth in production from 2012 to 2014 (FAOSTAT, 2016). The concept of organic farming in the production of pineapples is taking roots, and many farmers are now officially categorized under organic farmers as well as their land being classified as organic land (Kwikiriza et al., 2016; Namuwoza &

Tushemerirwe, 2011; NOGAMU, 2010; Willer & Lernoud, 2016). This aims at further penetrating the international market where organic products attract higher prices.

However, like in the rest of the agricultural sub-sectors (e.g. livestock, agro-forestry, fishing and aquaculture), actors in the fruits sub-sector experience inadequate human capacity, inadequate supply of clean and safe water, insufficient and unaffordable energy (especially electricity), limited advanced technology and equipment (i.e. agricultural mechanization machinery), among others (Namuwoza & Tushemerirwe, 2011; NOGAMU, 2010; Van Melle & Buschmann, 2013). The other major challenges to the fruits sub-sector are the limited access to markets, finances, existence of poor infrastructure, and limited value addition (MFPED, 2016; Sonko et al., 2005). These challenges are closely linked e.g. poor infrastructures such as roads, power and communication networks lead to limited access to markets and therefore inability to deliver commodities to intended markets. Similarly, value addition becomes untenable because of the inadequate input supplies especially energy. Without value addition, the fruits cannot access the high value markets where probably better prices can be enjoyed (MFPED 2016; Sonko et al. 2005). These challenges place the sub-sector in a very difficult situation, which influence its long-term performance and therefore necessary to devise and implement consistent and sustainable solutions.

To overcome some of those challenges, many smallholder farmers and traders have come together to form companies and clusters. Currently (2020), there are several micro and small fruit processors and dealers such as the Luweero Fruit Processing Cluster (LFPC) located in Luweero and dealing in pineapples, mangoes, and passion fruits, (Ecuru, Trojer, Lating, & Ziraba, 2013). The intention is to add value and stabilize fruit products through processing such as drying, juicing, and winemaking. Processing and value addition boost the competitiveness of the products in the local and international market, which can eventually improve the local and export value of the Ugandan fruits (Sonko et al. 2005). The GoU has put in place some enabling policies such as the liberalization of the economy and opening markets to private and business people to allow free business interactions and engagements. This attracts both local and foreign investors, which is very relevant in attempting to improve the performance of the various sub-sectors including the fruits sub-sector. The government has also attempted to improve the infrastructural network especially the roads in order to improve access to markets (MFPED 2016; Sonko et al. 2005).

Therefore, considering the post-harvest management of these commodities such as processing, energy requirements, transportation, and storage is essential to reducing losses and wastage among these products. This is because the processed products are more stable and can be stored for a significant period of time and can also command higher market prices. Therefore, this research focused on the processing of pineapples in central Uganda although the methodologies and findings can be applied across the whole of Uganda and many developing nations as well as other processed commodities especially fruits.

2.5 Pineapple Processing Methods in Central Uganda

Several pineapple processing methods exist; they include but are not limited to drying, munaanansi (local drink), wine, jam, and juice making (Tröger, 2019). Figure 2.1 illustrates the pineapple processing activity chain, focusing on value addition and shelf life extension. The route where raw pineapples without any value addition are transported and sold directly to consumers or delivered to markets from where consumers eventually buy them is not explored because of its limited engagements. There are a number of participants who influence the processing ranging from farmers to the final consumers (Sonko et al., 2005; Ssemwanga Consulting Ltd, 2007) but this study did not focus on the chain actors but rather on the main processing methods. Processing intends to add value and extend shelf life so that pineapples can be kept longer, and probably attract better market prices (Sempiri, 2011). There is also a possibility that they can be available all year round including off seasons.

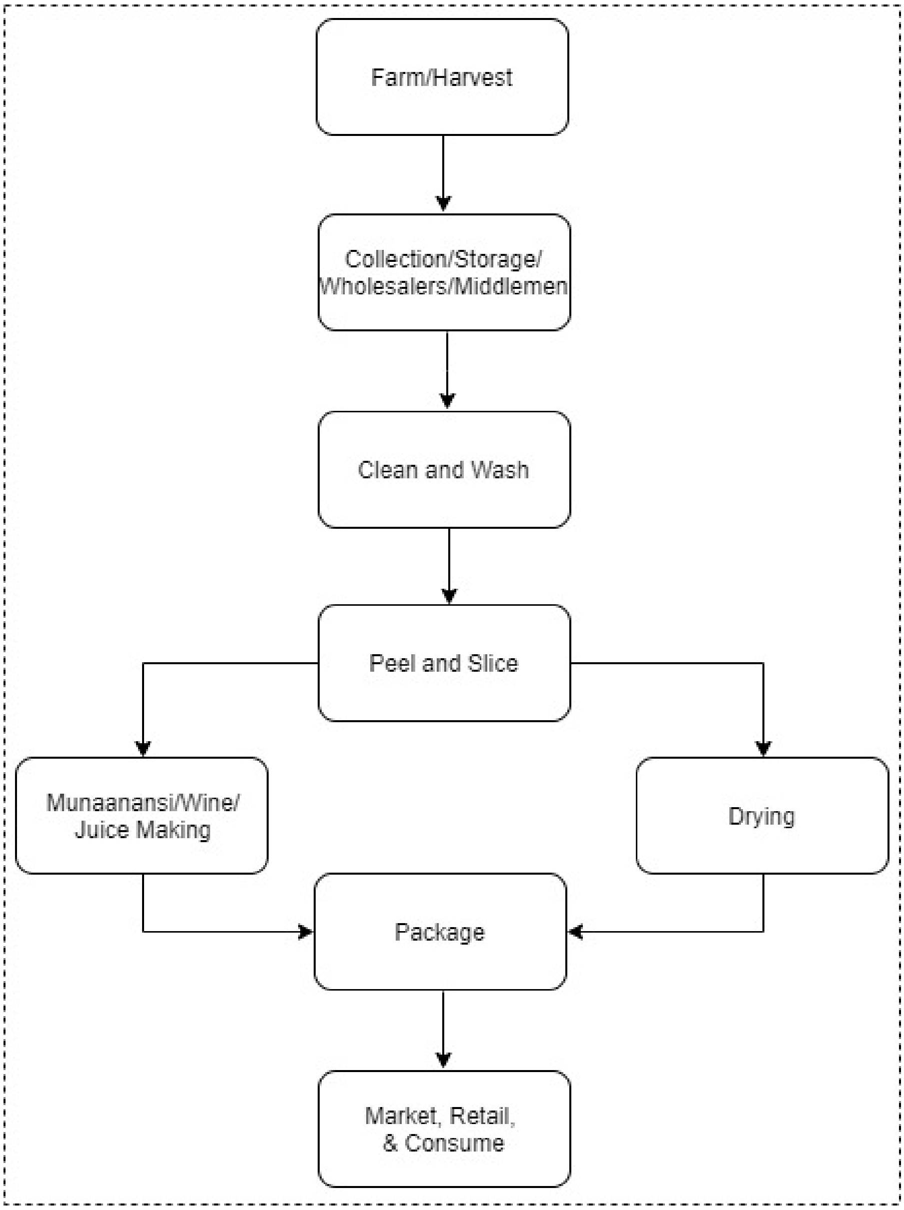


Figure 2.1: Pineapple Processing Activity Chain in Uganda

Each of the processes is further described in sub-sections 2.5.1 – 2.5.4 to give more background information and related details.

2.5.1. Drying

Drying involves the reduction of water content of the products under consideration thus lowering their weight leading to easy transportation, packaging, handling, storage, and extended shelf life (Nunes et al., 2015; Sturm et al., 2018). It is one of the oldest and most widely spread means of food preservation (Sturm, Nunez Vega, & Hofacker, 2014), and it is as old as mankind although some researchers argue that it could have started in about 20,000 BC (Hayashi, 1989). It began as a natural open sun drying process and transformed into the current mechanical and advanced drying systems (Hayashi, 1989). However, open sun drying did not cease and is still employed in the present day drying practices because it is simple and cheap (Barret, Somogyi, & Ramaswamy, 2005; Nunes et al., 2015). In fact, it is one of the common pineapple preservation methods in Uganda although associated with several inefficiencies. In the drive to have more control and guarantee quality, several advanced dryers were and continue to be innovated and developed. There are currently several drying equipment ranging from microwaves to solar dryers as well as variations in the drying methods such as freeze, spray, and continuous drying (Hayashi, 1989; Mujumdar, 2007). However, the advanced drying methods are energy intensive processes (Agrawal & Methekar, 2017; Darvishi, Zarein, & Farhudi, 2016; Sreekumar, 2010; Visavale, 2012) and to some extent still affect the sensory and nutritional value of the dried products (Sturm & Hensel, 2017; Sturm et al., 2018; Vega, Sturm, & Hofacker, 2016). In fact, some researchers have reported 15 – 25% of the total industrial energy demand as going to drying processes across all sectors, and indicated that some dryers have very low thermal efficiencies which can be as low as 10% (Crichton, Shrestha, Hurlbert, & Sturm, 2017; Mujumdar, 2007). Moreover, they use a range of energy sources and forms such as electricity, oil, gas, biomass, and solar. But in Uganda, electricity is not readily available and is considered unaffordable. So, solar energy dominates drying, and although there are several solar dryers including the ones that are thought to be more advanced, a number of them are still inefficient and unaffordable (Kiggundu et al., 2016). In addition to being energy intensive, drying involves extensive use of water. However, water requirement is not unique to drying, but considered as one of the most important inputs in any food processing line not only in Uganda but everywhere in the world (Klemeš, Smith, & Kim, 2008; Mavrov & Bélières, 2000). It is needed for blanching, washing raw materials such as fruits and vegetables, handling utensils, equipment, and working floors. For drying in particular, water is needed for cleaning trays, drying chambers, peeling and cutting tables, and scrubbing working areas. Therefore, a significant amount of water is needed for most of the processes. It is thus reported that 1.5 – 5.0 m^3/ton of finished product as water being used in the processing of vegetables although most of it (about 90%) being used for washing and rinsing the vegetables (Lehto, Sipilä, Alakukku, & Kymäläinen, 2014). Further, it is argued that clean and safe water is a scarce commodity globally (Arthey & Ashurst, 1996), and research has indicated that only 2.5% of the total global water resources is freshwater although only 0.3% of it is accessible to human beings (Oelmez, 2014). This suggests that water must be used consciously and where possible re-use should be considered (Oelmez, 2014).

Drying of pineapples is currently at the center of pineapple processing in Uganda partly because solar energy (considered free energy source) can be extensively utilized. Furthermore, there are local companies such as Fruits of the Nile, FLONA Commodities Ltd, and AMFRI Farms Ltd ready to absorb all quality dried pineapples, and export to the international markets (Ssemwanga Consulting Ltd, 2007). However, it is not yet clear when commercial drying started in Uganda, but known that open sun drying has been in existence since time immemorial. This could explain the early description of solar drying as being an "elaboration of sun drying" (Zaman & Bala, 1989). So drying was one of the processes considered in this study.

2.5.2 Munaanansi making

Munaanansi is a local drink made out of pineapples or the peels as the main raw material. The other ingredients are tea leaves, sugar, and ginger (RECO, 2016). Fresh pineapples or pineapple peels are usually crushed and then mixed with water and crushed ginger in a suitable cooking pan. The mixture is then placed on the cooking stove, and tea leaves added towards boiling. Filtering is done, and the product left to naturally cool. Sugar is added in right proportions (based on maker experience); packaging (in small (less than 30 microns) white polythene bags locally known "kaveera" or "buveera"), distribution, and retailing follow. Munaanansi making is an informal business usually run by local makers (i.e. individuals or families). It is sold in retail shops as a soft drink, and while locally consumed, many Ugandans earn a living out of its making and selling. However, there is no clear information to indicate that practical studies have been done before on its making, which makes this study one of the first ones. Additionally, there is limited documentation to trace its origin although common opinions seem to suggest that it has been in existence for many centuries (Mwakikagile, 2009; Pouw, 2008) and started as a family or community drink (Baganda, 1999). There is also a notable variation in spelling its name (munaanansi, munanasi, and munanansi) (Bitzan, Tröger, Lelea, & Kaufmann, 2016; Mwakikagile, 2009; Pouw, 2008; Tröger, 2019), which can be attributed to pronunciation and language background e.g. Kiswahili. Additionally, Luganda is where many people tend to error with spellings since many never learn the Luganda writing guidelines and basics. The emphasis in this research however, was about resource utilization in its making.

2.5.3 Winemaking

Winemaking is one of the world's oldest industries whose antiquity can be traced beyond 5,000 BC (Satyanarayana et al., 2012), notwithstanding the suggestion that wine (alcoholic beverage) discovery might have been accidental (Joshi, Panesar, Rana, & Kaur, 2017). Wine is considered healthy and medicinal with several curative and remedial benefits such as reducing the risk of diabetes, enhancing longevity, and reducing cardiovascular diseases (Joshi et al., 2017; Satyanarayana et al., 2012). Traditionally, wine is made from grapes (Pretorius, 2000; Reddy & Reddy, 2005) and the making process follows almost the same steps across the world (Satyanarayana et al., 2012). However, there are slight variations in the making process depending on the type of wine being made (Pretorius, 2000), and wine can be categorized into natural or fortified. Those categories are further broken down into e.g. red, white, sparkling, sweet, to mention but a few. Similarly, wine can be made from a variety of other fruits e.g. pineapples, mangoes, banana, passion fruits, and apples through the fermentation process in combination with yeast (Hossain & Bepary, 2015; Jagtap & Bapat, 2015). It is a common practice to name a wine after the fruit from which it is made e.g. pineapple wine (wine made from pineapples), and most of them have alcohol content of 5 – 21% (Idise, 2012; Swami, Thakor, & Divate, 2014). In Uganda, the most popular fruit for winemaking is the pineapple, and the demand for wine keeps increasing especially in urban areas although generally considered a luxury and for the "rich" and "high" status group (Alsos, Hytti, & Ljunggren, 2016; UNIDO, 2004).

As it is in the rest of world, it is not yet known exactly where, by who, and when winemaking started in Uganda. Nevertheless, there are some traces of vine planting by a French monk although its usage and reason for cultivation does not clearly point towards winemaking, not until 2005 when the GoU in the person of President Yoweri Kaguta Museveni sponsored some nuns from Mbarara to acquire the art of winemaking from Weltevrede in South Africa (Weltevrede, 2013). Additionally, there are indications that the first organic wine is said to have been made as early as 2002 with the name Bella Wines. There are other related reports about winemaking and usage e.g. the use of banana wine by Ugandan healers in cesarean section to semi-intoxicate a woman, sanitize hands, equipment, and abdomen, which was witnessed by a British traveler (R.W. Felkin) in 1879 (U.S National Library of Medicine, 2013). Furthermore, most small-scale winemaking in

Uganda and many other parts of the world arises as a result of having surplus fruit supply e.g. banana, passion fruits, tomatoes, and pineapples during bumper harvests (Jagtap & Bapat, 2015; Muzaale, 2013; Ssali, 2017). That means, winemaking in Uganda is quite seasonal, and can be considered as one of the interventions that largely intend to counter the seasonal nature of fruits in Uganda (Muzaale, 2013). This research work focused on pineapple winemaking in central Uganda.

2.5.4 Fruit juice making

A number of stages are involved during juice making right from reception of the fruits to packaging of the final product. It is either a ready-to-drink juice or one which is used little by little and usually after dilution (Kaaya, 2000; UNIDO, 2004). The juice can be classified as organic or non-organic, and the main preservation methods are pasteurization and refrigeration.

There is an increasing demand for fruit juices (Elepu, Nabisubi, & Sserunkuuma, 2016) especially in the urban areas of Uganda with pineapple and passion fruit juices being the most popular ones. However, there are several others whose production and consumption is on the rise e.g. banana, orange, hibiscus, among others, and sometimes made as a mixture of fruits (cocktail) (Kalungi, 2012). Further, the fruit juice makers are threatened by the competition from those who import concentrated fruit flavors, which they dilute to come up with the so-called “fruit drinks” at relatively low cost (UNIDO, 2004).

As it was noted with winemaking, fruit juice making is also anchored on the need to find alternative routes for surplus fruits and the fact that juices fetch better market prices on top of having a longer shelf life (Muzaale, 2013; Nakaweesi, 2016). This research focused on pineapple juice making in central Uganda.

2.6 Consequences of Fruit Processing

While processing adds value and improves the shelf life of fruits, more inputs are required to achieve the intended products. Therefore, in addition to human power and gasoline necessary for unprocessed fruits; other forms of energy, water, and machinery (Barta, 2012; Nwakuba, Asoegwu, & Nwaigwe, 2016a) are cardinal requirements in processed fruits. In fact, it is ideally important that each process input is measured and controlled although rarely done especially with water consumption (Klemeš et al., 2008). Table 2.1 illustrates a typical scenario where pineapples are dried or processed into munaanansi, juice, and jam, right from harvesting in Uganda.

Table 2.1: Input(s) – Output(s) in Handling of Pineapples in Uganda

Stage (Activity)	Input(s)	Output(s)
Harvesting	Human power	Fresh pineapples
Transportation to collection, storage or market	Human power and gasoline	Fresh pineapples
Hand washing or cleaning	Human power, water, and containers	Clean and fresh pineapples
Processing into juice or jam	Human power, electrical energy, thermal, biomass (optional), water, machinery and containers	Juice or jam
Processing into munaanansi	Human power, water, biomass, and utensils	Munaanansi
Drying	Human power, thermal energy (can be from electricity, biomass, or solar), and containers	Dried pineapples
Packaging	Human power, electrical energy, and packaging material	Packaged pineapple products
Storage	Space, refrigerators, and electrical energy	Prolonged shelf life for pineapple products

Similarly, washing and cleaning of fruits (e.g. pineapples) and containers requires sufficient and highly clean water to avoid contamination (Barret et al., 2005). However, clean water is not a common commodity in Uganda, and most water might require storage and purification before use (Arthey & Ashurst, 1996; Plappally & Lienhard V, 2012). Protected sources of water are scarce in Uganda, and most of the water comes from open sources such as streams or rivers, swamps, shallow wells, and rainwater. These are particularly difficult to protect from contamination (Kirby, Bartram, & Carr, 2003), which necessitates the use of electrical energy for the purification and treatment of this water to make it safe for use (Plappally & Lienhard V, 2012). Additionally, electrical energy is required to run machines that process fruits into juice and jam, and other general services such as lighting. Juice pasteurization and other fruit processing stages might require thermal energy which can be supplied by grid electricity, biomass, or solar (Kaaya, 2002). These further highlight the extent and the interrelationships between the various forms of energy as well as the level of development of the different processes, and the human involvement in the processing of pineapples in Uganda.

It can therefore be argued that, Uganda's fruits sub-sector is not yet well developed. It is on small-scale mainly relying on human labor for most of the processes and experiencing a lot of inadequacies especially the ones related to engineering and technology. Therefore, there is need to modernize and commercialize the sub-sector through better means of fruits value addition such as mechanization and intensification of skills, and information and communication technology usage. Actually, rather than depending on only human labor for all processes, major processing steps such as juice extraction, pasteurization, and feeling can be done using semi-automated system(s) to reduce errors and wastage. Quality control, packaging, marketing, and branding can be achieved by seeking services of local professionals and those with relevant expertise. Sharing of experiences and practices among small-scale processors can also enhance processing performance. This is already taking place as start-ups seek guidance from those who have been in the processing field for some time, and assumed to be experienced. The Uganda Small Scale Industries Association (USSIA) is another resourceful organization, which prepares and disseminates information to small-scale processors at zero or relatively low costs (USSIA, 2011).

2.7 Simulation and Optimization in Design and Implementation of Systems

Computer simulation and optimization are recent trends, which are currently at the center of most system design and operation. They are closely related and sometimes inseparable especially with complex systems and automation. In fact, several simulation software packages are developed with inbuilt optimization capabilities (e.g. HOMER (HOMER, 2018)) so that they are able to suggest the optimal operating point(s). Additionally, one tool may not be able to fully address all the simulation and optimization requirements at hand, and therefore need some form of modification and improvement to suit the task. Similarly, most tools are not universal but field specific e.g. energy systems tools or process analysis tools (Connolly, Lund, Mathiesen, & Leahy, 2010; Fiedler, 2019). While simulation and optimization were not applied in this study, they remain very relevant for this kind of work and can be very helpful in the techno-economic assessment and performance evaluation of these systems before the actual implementation. Indeed, the frameworks and energy integration diagrams developed in this study fit quite well into the simulation and optimization implementation. In reality, the various energy supply options can be simulated, and the most suitable combination selected based on the set optimization indices(s) e.g. cost of energy or processing time.

2.7.1 Simulation

In the contemporary understanding, simulation is a computer program, software, or action, which imitates the real world systems or processes, and tests the different "what-if" situations. Simulation is a very valuable tool, which has been used for many recent decades in the early stages of design and evaluation of systems. It is also invoked in already existing and running systems in cases where changes and improvements are envisaged (Frontline Systems, 2019; Garg, Mathur, Tetali, & Bhatia, 2017). It can be one of the easiest, cost effective, and efficient tools for evaluating systems without using actual components required in the system. It checks the performance of the system against the anticipated behavior by the designer (Frontline Systems, 2019; Mefteh, 2018). Simulation has a long history coming from pre-existence of the computers and microprocessors where physical and mechanical models would be used to demonstrate the performance of designed or re-designed systems. However, it should closely represent the actual system as much as possible to minimize risks during the actual implementation. While the simulation gives exciting indications on the expected performance of the system, usually actual implementation presents its own challenges. Overall, the goal is to eliminate unsuitable designs and components before significant resources are committed to the implementation of the system (Mefteh, 2018).

2.7.2 Optimization

Optimization can be defined as an engineering process, which enables system designers and analyzers to find condition(s) that give the minimum or maximum values of the optimization indices (Frangopoulos, 2009; Zeng, Cai, Huang, & Dai, 2011). It involves the designing of a system so that it is as good as possible based on the designers' set standards, and this makes optimization a relative design problem (Goren, Crissey, & Hughes, 2008). The interest is usually to obtain minimum values when considering optimization of a cost function, and maximum when a profit function is employed. Technically, system or process optimization is different from improvement but in real applications, there is a tendency to use them interchangeably (Frangopoulos, 2009) probably because they both relate to the same purpose of system performance efficiency.

Under set criteria and constraints, optimization automatically reveals the best design and operating point of the system without requiring the designer to evaluate and test each point or state in the range (Frangopoulos, 2009). It is important to clearly translate the system variables into optimization indices so that they closely represent the system. Furthermore, optimality from mathematical point of view might not mean the best from the users' point of view; thus, user requirements should be embedded into the optimization parameters (Goren et al., 2008). Conceivably, a manufacturer of mobile handset might want to optimize size in order to reduce material cost to the expense of customer requirement of sizable devices. Similarly, where the system targets multiple groups, desirability conflicts might arise such that what one group desires is different from the other group(s). In reality, there is no "one-size fits all" (Tröger, 2019), but it is the designer's job to try as much as possible to develop engineering specifications from user requirements upon which the optimization parameters are based.

2.8 Evaluation and Assessment Framework for Processing Lines

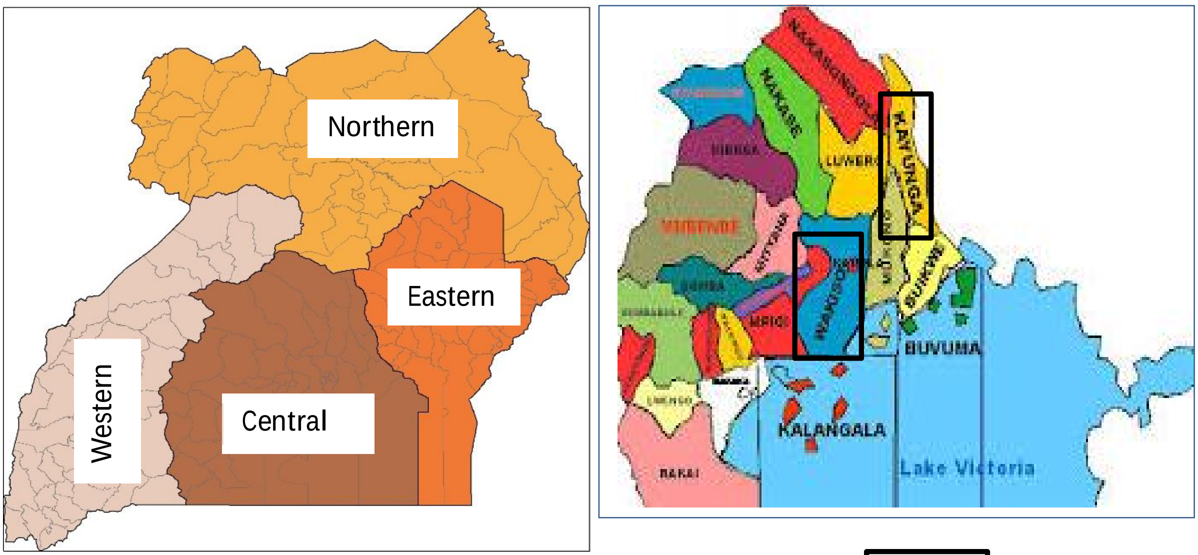
Process evaluation and assessment (sometimes known as production audit) is a very important exercise if resource utilization is to be improved, because it examines the performance of the process based on agreed basic performance indicators. It informs and helps decision and policy makers on which actions to or not to take (Saad, Nazzal, & Darras, 2019). Sometimes, the evaluation is not so extensive, and therefore does not qualify to be a production or manufacturing audit although serving the purpose of process performance assessment (Chaneski, 1998; Drew, 2017). But, performance evaluation of a process should be routine and carried out regularly, which may tackle several aspects including integration (e.g. energy integration), operational policies, schedules, technology and equipment, among others (Menda, 2004). In fact, with the current trend of software development, it can be even more informative to simulate the performance of a process before its establishment or before implementing the proposed changes. It is a step by step process, which should be done systematically to yield meaningful and long term outcomes (Menda, 2004). However, it is a rare practice especially in low income countries and more so among small-scale enterprises to engage in process evaluation and assessment. Moreover, non-consideration of assessments is not unique to processing, but the entire value chain including production such that statistics and information about the value chain e.g. post-harvest losses and waste are limited or non-existent (Tröger, 2019). Therefore, it is a crosscutting challenge especially in developing countries. Actually, record keeping and monitoring on major inputs and outputs is very loose even among medium size enterprises (Sturm, Hugenschmidt, Joyce, Hofacker, & Roskilly, 2013). The practice of closed systems (where "waste" or by-products from one stage is used as input to another stage) is generally unrealistic given such background. Moreover, small-scale and medium enterprises have been pointed out as more prone to inefficiencies, greatly contributing to pollution per unit compared to large industries, and therefore good candidates for evaluation and implementation of process efficiency measures (Sturm, 2018). One of the reasons for such inefficient performance is the fact that most of the SMEs tend to use outdated equipment and technology, which is sometimes based on outdated settings (Sturm et al., 2018). Therefore, the main aspects such as energy and water utilization, raw material and their location, transportation costs, product quality, among others should be investigated to act as the basis for implementing efficiency and optimization measures (Sturm, 2018; Zeng et al., 2011). In some cases, energy assessment is carried out independently, and this is known as "energy audit". The motive is similar to process assessment only that in this case, the target is to understand energy issues such as available energy sources, energy consumers, energy flow, and identification of energy saving opportunities, which might exist. A number of generic steps have been proposed on how to effect energy audits although they seem to be more relevant to mostly large establishments (Andersson, Arfwidsson, Bergstrand, & Thollander, 2016; Kluczek & Olszewski, 2016; Krarti, 2011; Wong & Lee, 1994). Furthermore, the use of low quantities of energy has been cited as one of the barriers to embracing EE solutions in small-scale and medium enterprises in addition to lacking specialized innovations meant for them (Sturm, 2018). Similarly, there are not many well laid procedures and frameworks for carrying out such evaluations tailored towards small-scale enterprises, more so in developing countries. Therefore, this study proposed two generic assessment frameworks based on literature, field experience and findings while working with small-scale pineapple processors in central Uganda.

3 Materials and Methods

3.1 Study Area and Equipment Used

3.1.1 Study area

This study investigated the main pineapple processing methods (drying, munaanansi, wine, and juice making) in three central districts of Uganda (Kampala, Kayunga, and Wakiso). These districts were selected because they are some of the leading districts involved in the growing and processing of pineapples in Uganda (Tröger, 2019). It was noted that advanced drying, wine, and juice making are mainly practiced in Kampala and Wakiso. Samples on munaanansi making were only selected from Kampala where the drink is most popular while wine and juice makers were from Kampala and Wakiso. The two main selection criteria for the enterprises investigated were; the level of activeness in processing, and willingness of the enterprise to participate. This was because the study involved actual measurements, and there was need to have open access to the processing lines and willingness on the side of the processor to clarify on arising issues during and after the study. Some researchers had already covered ground on pineapple value chains in Uganda (Tröger, Lelea, Hensel, & Kaufmann, 2018; Tröger, 2019) , and their findings were valuable in identifying the processors. Additionally, the USSIA (USSIA, 2011) helped out by providing the names and contacts of the small-scale enterprises registered as pineapple processors (drying, wine, and juice making) in the study area. However, on contacting them, some of them were no longer dealing in the registered businesses citing reasons of inadequate capital and seasonality of pineapples. More processors were identified through fellow processors (snowball), a method, which had been employed by earlier researchers in the Ugandan pineapple value chain (Tröger, 2019). Overall, a list of about 30 processors officially known as dealing in pineapple drying, wine, and juice making was generated. Munaanansi makers are not officially registered, and it is also possible a number of other pineapple processors is not yet registered and therefore not known to the formal sector and the umbrella body. Figure 3.1 shows the study area where (a) indicates the four regions making up Uganda and (b) central region with Kampala, Kayunga, and Wakiso marked.



(a) Four regions of Uganda

(b) Central region ▭ indicates study district

Figure 3.1: Map of Uganda Showing the Study Area (source: Google Maps)

3.1.2 Equipment used

Several equipment and devices e.g. electric meters, thermocouples, weighing scales, to mention but a few, were used during data collection and actual measurements. Table 3.1 gives the name and description of each of them to avoid repetition in every section. The actual measurements and corresponding equipment used at processors under the same or similar category e.g. drying are specified after a description of the processors involved. This is because; the same measurements were carried out at each of the processors under the same category. Thus, the same measurement procedures were followed. However, the description of measurements and equipment used among wine and juice makers is combined since the measurements performed and equipment used in those two categories were virtually the same.

Table 3.1: Name and Description of the Equipment Used

No.	Name	Description	Purpose
1.	Thermocouples	K-type thermocouples (−180 ^{0}C to 1,260 °C± 2.2 ^{0}C)	Drying chamber temperature measurement
2.	USB TC-08, Pico	Thermocouple adaptor	Connect thermocouples to the laptop

3.	Laptop	Toshiba, 4 GB RAM, L15W-B1307, Intel Pentium N3540	Temperature logging or recording
4.	Ryobi IR Thermometer	IR002 temperate gun, range (-20 ^{0}C to 315 ˚C ± 5 ^{0}C)	Quick or spot temperature measurement
5.	Weighing Scales	VOLTCRAFT, TS-600, Max 600 g and d: 0.1 g	Weighing quantities below 0.6 kg
		Portable or Pocket Electronic Scale, Y029, max 40 kg, d = 10 g	Weighing quantities below 15 kg
		Electronic Scale, BSE001, Max 150 kg, and d = 100 g	Weighing quantities above 15 kg
		Salter Hanging Scale, 235-6M, max 100 kg and d = 0.5 kg	Weighing charcoal and firewood
		Electronic weighing balance, Brainweigh B1500D, max 1.5 kg, d: 0.005 mg	Measuring weight of crucibles and samples in the laboratory
6.	Absolute Moisture Meter	PCE-MA110, Max 110 g, readability 0.001 g	Fruit moisture content measurement (fresh and dry)
7.	Energy Meters	VOLTCRAFT Energy Logger 4000, 1.5 – 3,500 W, 0.01- 15 A, 1%	Measuring power parameters (power, current, frequency)
		DDS228, IEC 61036, 10(60) A, Veto, single phase meter, 1.5%	Measuring electrical energy (kWh)
8.	Solar Irradiance Meter	VOLTCRAFT SPM-1 DMM, 0 – 1,999 Wm^{-2}, ± 0. 5%	Measuring solar irradiance (Wm^{-2})
9.	Plastic Bucket	Food grade hard plastic bucket, graduated in liters	Measuring water, wine, and juice
10.	pH meter	Mettler-Toledo AG, 0.00 – 14.00, ± 0.01	Measuring pH for fluidized peels and slurry
11.	Mortars	Electric mortar and pestle	Grinding TS in the laboratory
		wooden mortar and pestle grinders	Manual grinding of pineapple peels outside the laboratory

3.2 Pineapple Drying

3.2.1 Introduction

Three processors (i.e. two companies and one cooperative) involved in the drying of pineapples and other fruits were selected from three central districts of Uganda (one from each district) and labeled as (S01) for the one in Kasangati, Wakiso District, (S02) for the other in Kawempe, Kampala District, and (S03) for the cooperative in Kangulumira, Kayunga District. Each processor is further described in sub-sections 3.2.2 – 3.2.4.

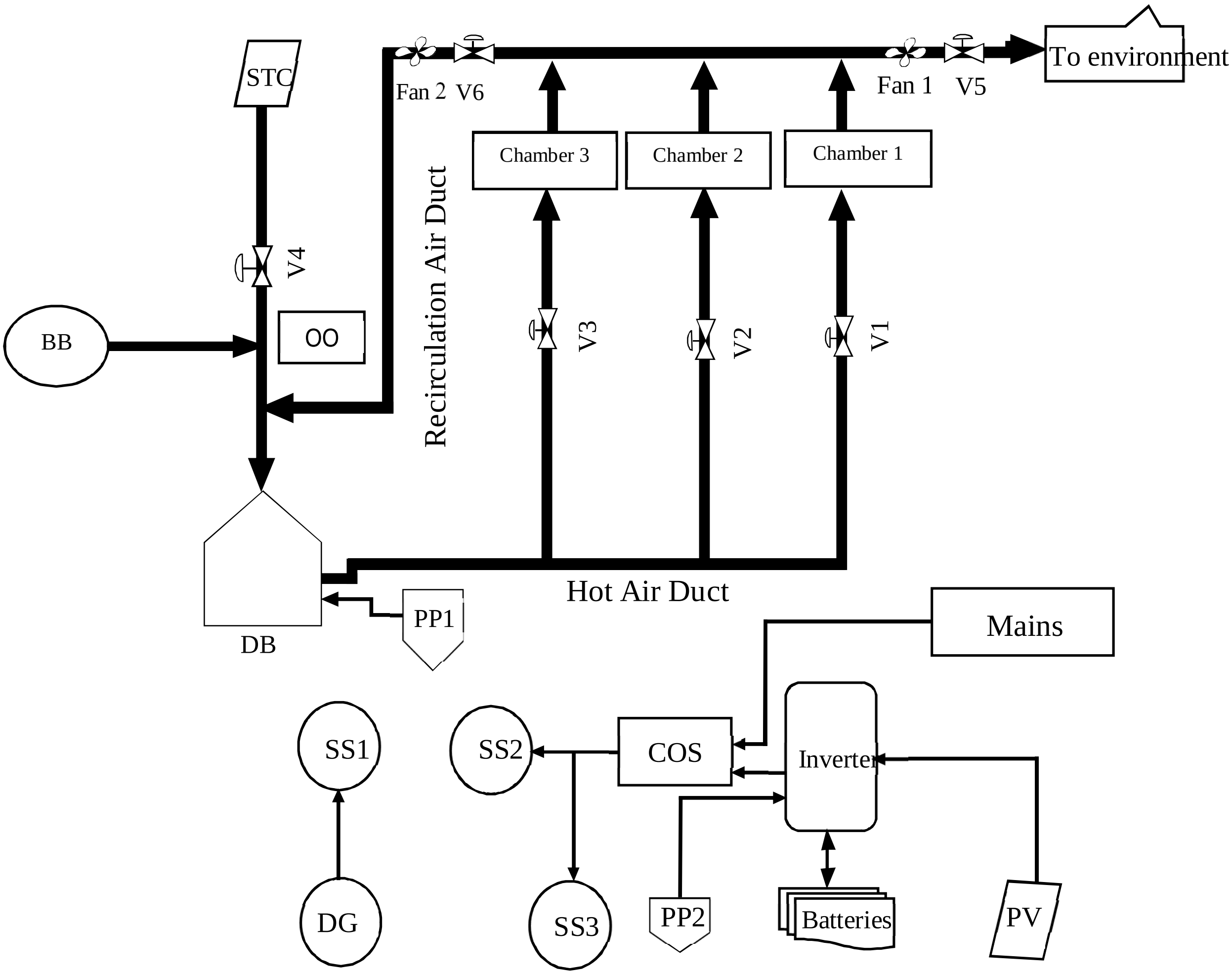
3.2.2 Fruit drying company in Kasangati, Wakiso District (S01)

This is a limited liability company registered in Uganda, located in Kasangati, Wakiso District. It deals in the processing and exportation of both dried and fresh foods including the following: pineapples, mangoes, ginger, bananas (ndiizi), lemon grass, yams, avocadoes, jackfruit, and pawpaw.

It runs a forced convective hybrid drying system consisting of three independent cabinet drying units or chambers interconnected to the same incoming hot air duct. Each cabinet is sub-divided into three internal compartments with three hot air inlets and three exhaust air outlets and a maximum loading capacity of 45 trays. The inside of the drying units is made of stainless steel and enclosed with a brick wall, which is finished with cement screed and paint to limit heat loss. The hot air ducts are insulated with ISOVER Saint Gobain wool, which is covered with an aluminium foil on top. Further, the drying system uses solar thermal to pre-heat (using air heaters) the incoming air during sunny weather or biomass burner during bad weather or at night, and the mains electricity. It is installed with a 0.736 kWe (65.016 kcal/h, thermal), 230 V, 50 Hz, diesel burner (Hercules G65), which controls the inlet air temperature to the dryer. A 5.5 kVA, 220 V, 50 Hz, diesel generator (originally petrol generator) is also installed as back-up to the mains power supply. Similarly, a solar photovoltaic (PV) system (six 252 Wp solar panels and four 230 Ah, 12 V batteries) is installed to supplement the mains electricity. There are three solar thermal flat collectors (made of a 4 mm solar glass) each measuring 1.5 m by 4 m (solar collector area of 6 m^2), and installed on the top of the roof housing the drying system. The pre-heated air from each of the thermal collectors (air heaters) is linked to one pre-heated air duct into the diesel burner.

Figure 3.2 shows the schematic diagram of the drying system at S01. The diesel burner (DB) regulates the inlet temperature of the air into the drying chambers. The valves control the opening and closing of the various inlets. Valve (V4) is open when solar thermal is available and closed otherwise e.g. at night when it is recommended to open opening OO so that warm air from within the room is sucked into the diesel burner. Fan 1 is ON and valve (V5) open at the beginning of the drying cycle to extract cold air from the chambers while Fan 2 is OFF and valve (V6) closed. At temperatures above 40 ^{0}C at the main exhaust to surrounding environment, valve (V5) is closed and Fan 1 turned OFF while Fan 2 is turned ON with valve (V6) open so as to re-circulate the warm air into the drying system.

The diesel burner is plugged into socket (SS2) using PP1 if mains electricity or PV is ON, and plugged into socket (SS1) when both are OFF. The storage batteries can also be charged (apart from solar charging) with mains electricity by plugging PP2 into socket SS3 when grid power is on.



STC	Solar Thermal Collector	PV	Solar Panels
BB	Biomass Burner	PP	Plug
DB	Diesel Burner	V	Valve
DG	Diesel Generator	F	Fan
SS	Socket	COS	Change Over Switch
OO	Opening		

Figure 3.2: Schematic of the Drying System Used at S01

Measurements such as pineapples to be dried, waste generated, inlet and outlet temperatures, output, solar radiation intensity (Wm^{-2}), and energy consumption were carried out twice at S01 for three days each time (in Jan 2017 and Apr 2017) on only chamber 1. After the first assessment in Jan, some recommendations were made because the dryer performance was considered unsatisfactory e.g. taking relatively longer to complete one drying cycle. Therefore, measurements in Apr were carried out after effecting some operational and technical changes, which included reducing the loading capacities (half loading) of the drying units (to improve air circulation), improving the mains electric voltage (made it usable whenever mains was available), and replacing the petrol generator with a diesel one (better energy density). In Jan, it was observed that the petrol generator would be switched on even when the mains supply was on due to low supply voltage of the mains electricity. By troubleshooting the connections and eliminating the leakages, the supply voltage was improved and became more consistent and stable.

A number of activities are involved during the drying of pineapples right from delivery of the raw pineapples to obtaining the dried final products. The flowchart of the drying process activities at S01 is shown in Figure 3.3.

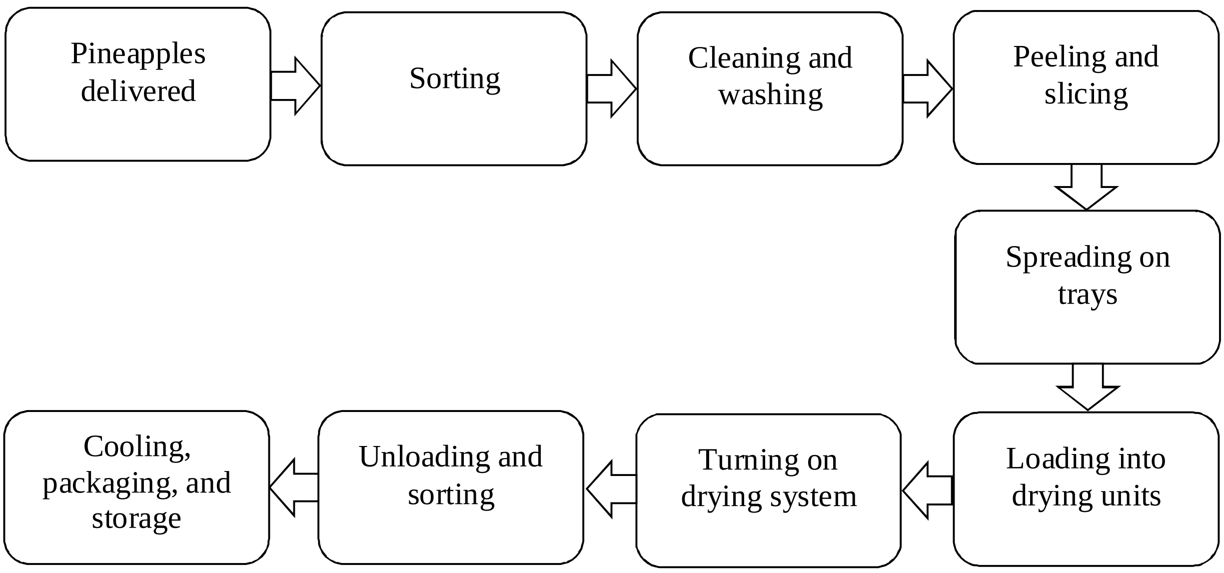
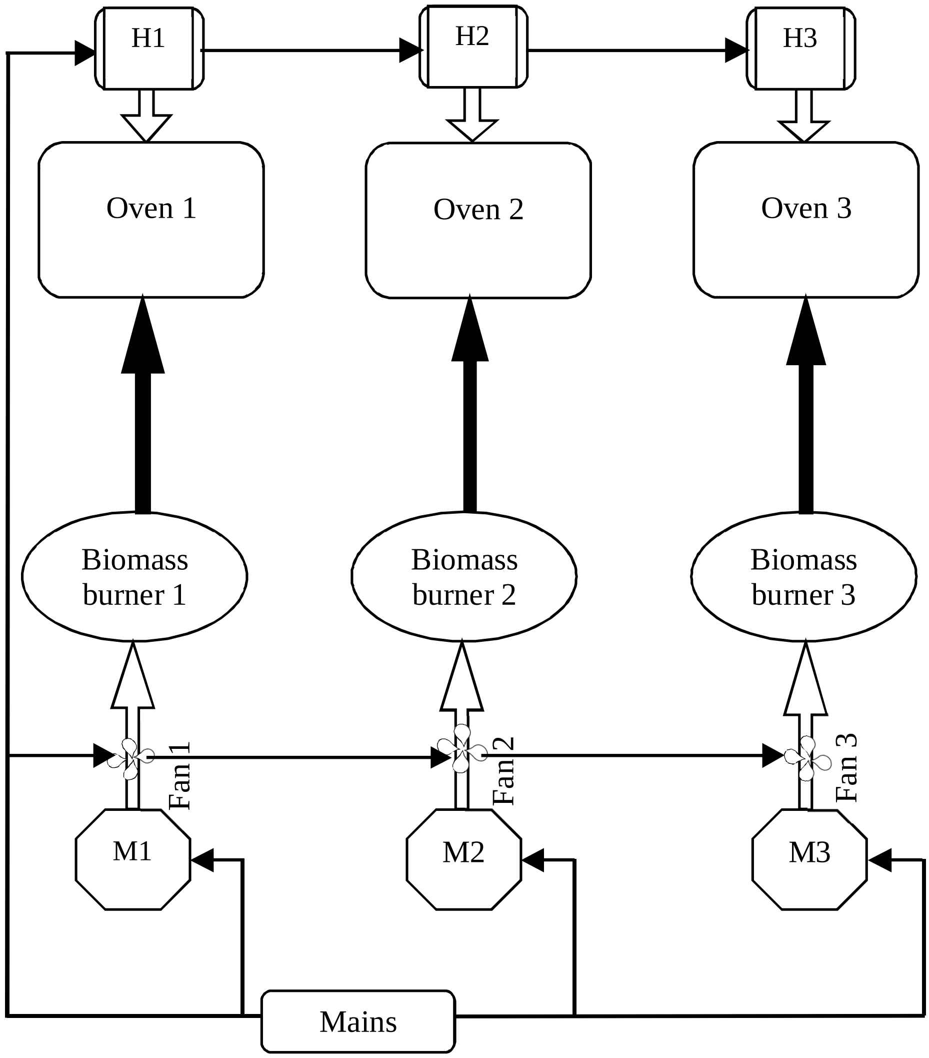


Figure 3.3: Drying Process Activity Flowchart at S01

3.2.3 Fruit drying company in Kawempe, Kampala District (S02)

This is also a limited liability company registered in Uganda and located in Kawempe, Kampala District. It has a drying system that features three independent forced convective hybrid drying units (ovens) designed and fabricated in Uganda in 2014. The inside of each of the drying units is made of stainless steel, encased by a brick wall. This insulation wall is finished with a cement screed and paint. A typical drying chamber is a rectangular room where trolleys that hold trays loaded with sliced pineapples are placed. One drying unit takes a maximum of four trolleys while each trolley can be loaded with a maximum of 18 trays. The drying system runs on mains electricity and biomass (charcoal and firewood). Two of the drying chambers are installed with two ordinary electrical cookers or coils (LOGIK, RSH-246083-018) rated 230 V, 50 Hz, 2,000 W each. Their purpose is to heat or warm the air inside each of the drying units. The schematic diagram of the drying system at S02 is shown in Figure 3.4.



H_1& H_2	Ordinary electric cookers placed inside the drying chambers 1 and 2 respectively
H_3	Specially fabricated electrical heater placed outside drying chamber 3
M_1	Motor for burner 1; no specifications
M_2	Motor for burner 2; 2.3 MVA, 1.6 kW, 450 V, 2,800 r.p.m
M_3	Motor for burner 3; 1.5 MVA, 1.1 kW, 230 V, 2,850 r.p.m

Figure 3.4: Schematic of the Drying System Used at S02

Inside each of the biomass burners are air pipes, so, as the biomass burners combust the fuel, the air inside the pipes is heated up, and forced by the fans into the drying chamber(s). The air found in the drying chamber is ideally already pre-heated using the ordinary electrical cookers. This ensures that the air temperature inside the drying chamber is easily raised without much delay.

Similar measurements as those performed at S01 were carried out on only drying chamber (oven) 1 at S02 in Mar 2017 for six days. The processing procedures at S02 are almost the same as those at S01 so that a similar activity flowchart shown in Figure 3.3 is applicable, but not repeated here.

3.2.4 Fruit drying cooperative in Kangulumira, Kayunga District (S03)

This cooperative is located in Kangulumira, Kayunga District. It brings together pineapple growers and processors (mainly drying) at local level. Locally fabricated traditional direct solar dryers are applied (Figure 3.5). They are made of wooden frames and stands, and covered with a single layer of ultraviolet (UV) stabilized transparent polythene. Some of them have their floors fitted with iron sheets whose inside is painted black and above which are timber rails where mesh trays loaded with sliced pineapples are placed. They are not airtight, but one side (at the bottom) is designated as air inlet and the other (at the top) as air outlet. Most of them are about 1.5 m by 4 m in size (solar collection area of 6 m^2) and inclined to maximize solar radiation capture.

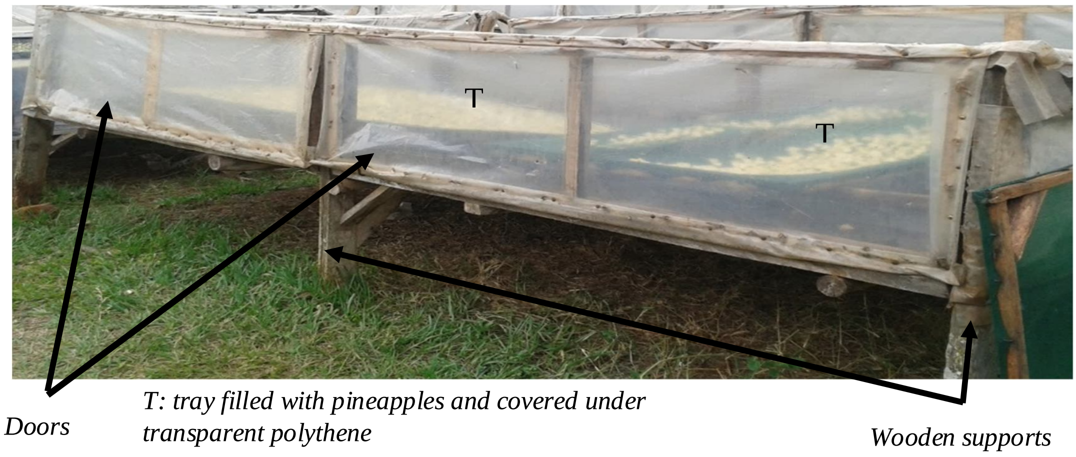


Figure 3.5: One of the Traditional Solar Dryers Used at S03

Comparable measurements as those performed at S01 and S02 were performed at S03 in Feb 2017 for five days. The dryers were being loaded at about 10 am, but preparation of pineapples e.g. peeling and slicing usually started at about 8 am to about 10 am. The fruit trays were left in the dryers overnight, but recording stopped between 4:30 – 5 pm daily when the light intensity had reduced. Additionally, sometimes the sun was already up by 8:30 am and the dryer warming up even before being loaded with fruit trays.

The flowchart of the activities at S03 is shown in Figure 3.6.

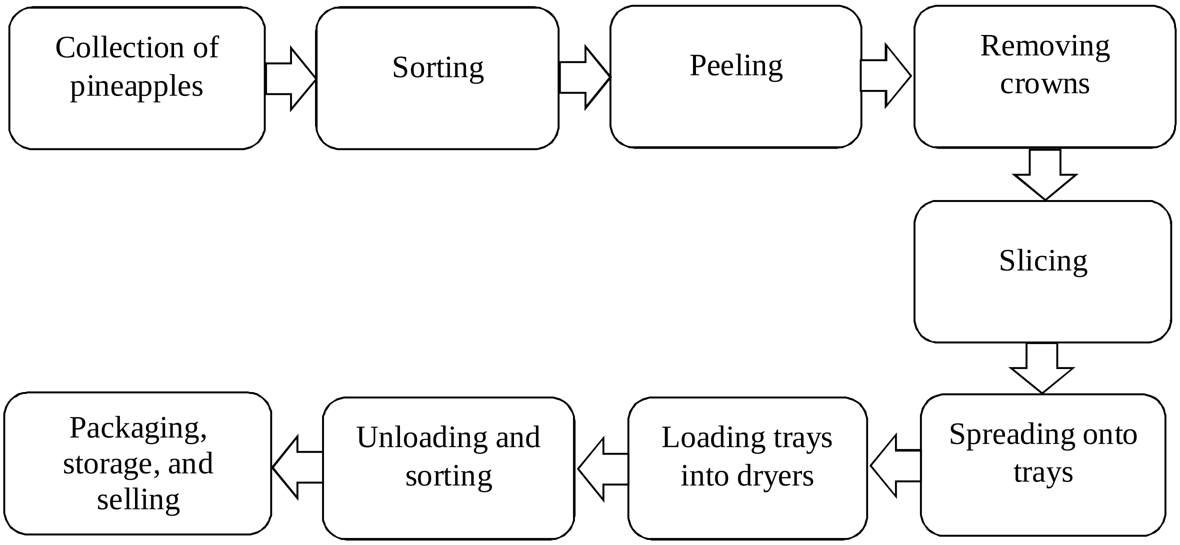


Figure 3.6: Drying Process Activity Flowchart at S03

3.2.5 Measurements related to drying (refer to Table 3.1 for equipment details)

The quantity of raw pineapples (kg) to be dried on a particular day (before peeling) and the resulting waste (peels, cut-offs, cores, and juice) (after the peeling and slicing procedures) were weighed using an electronic scale (BSE001) or portable electronic scale (Y029) for weights less than 15 kg. This was done at all the three sites, and for the respective days. At the end of every drying cycle, S01 and S03 immediately sorted the final products separating browned or bad products from the good ones while S02 did not sort until final packaging after several drying cycles. The sorting was entirely dependent on color and appearance (brown, burnt, and dark). Quantities (kg) for browned or rejected pineapples after drying were measured using a VOLTCRAFT scale (TS-600) while good ones measured using BSE001 or Y029 depending on quantities obtained. The reject or good products to be measured were put into a container of known weight. The BSE001 scale was positioned on a flat surface and the container with its content placed on top of it. The total weight was noted, and net weight determined by subtracting the weight of the empty container from the total weight. Where Y029 was applicable for weight measurements, it was handheld and weights directly noted from the display.

The MC for both fresh and dry pineapples was determined using the absolute moisture meter (PCE-MA110) by taking at least five samples from each, and determining the average MC. The MC meter (PCE-MA110) was plugged into electrical socket, switched on, and left to heat up for about four minutes. An aluminium sample pan was placed into the drying chamber of the moisture balance (PCE-MA110), and the “TARE” button pressed for the display to indicate 0.00 g. A sample of fresh sliced pineapples was selected, and cut into thin pieces of about 8 mm using an ordinary knife. The pieces (equivalent to about 10 g) were evenly spread (single layer) on the aluminium sample pan, initial weight (g) noted, and the chamber closed. The “START/STOP” button was pressed to start drying. The MC meter (PCE-MA110) automatically stopped (with an audio alert) when drying was completed in about 20 – 38 minutes. The final weight (g) and MC (%) were noted. This was repeated for five samples and the average MC was determined. For dried pineapples, random samples were taken and torn into small pieces using bare fingers. The same procedure as described for fresh samples was followed, although drying took less than 10 minutes in all cases.

Biomass (charcoal and firewood) to be used was weighed using a Salter hanging scale (235-6M). An estimated amount of charcoal was collected in a sack of negligible weight, and its weight determined using the Salter hanging scale (235-6M). In a similar manner, firewood was tied into small bundles suitable for hanging on the weighing scale, measured one by one, and their total weight determined. In cases where the initial estimated biomass was not sufficient for the entire drying cycle, more quantities were measured. Similarly, where biomass had been over estimated, the remaining quantities were measured and subtracted from the initial mass to obtain the net weight used.

In some cases, the electrical energy (kWh) was measured throughout the drying period using a single-phase electrical energy meter (DDS228). The single-phase meter (DDS228) was connected in series with the electrical energy consuming device(s) whose energy consumption was to be measured. This was achieved by breaking the existing electrical connections and fixing the meter in the circuit such that the electrical power flowed through the meter as processing took place. In other cases, it was impossible to access the connections since some wires passed through conduits installed in the brick or concrete walls. The energy consuming devices were being plugged into wall socket outlets. In such instances, energy loggers (VOLCRAFT Energy Logger 4000) were plugged into the socket outlet(s) such that the electrical energy consuming devices drew power from the logger(s). These loggers recorded several parameters such as real power (W), voltage (V), current (A), and frequency (Hz). At the end of the processing interval, the average real power was determined, and the energy consumed (kWh) derived from the product of the average real power (W) and the processing period (hours).

In commercial fruit drying systems, drying temperature is one of the most important parameters, which impact the quality and nutrient content of the final products (Sturm et al., 2014). So, temperature variations at each of the dryers were recorded using thermocouples and IR002 temperature gun for random checks. Thermocouples were fixed at inlet and outlet of a particular drying unit, and interfaced to a Toshiba laptop (L15W-B1307) through the thermocouple adaptor. The inlet and outlet temperatures were then logged throughout the drying period at 5 minutes intervals.

The solar radiation intensity (Wm^{-2}) at S01 and S03 was measured using the solar irradiance meter (VOLTCRAFT SPM-1 DMM) at 30 minutes intervals throughout the inlet and outlet temperature recording period for the three and five days at S01 and S03 respectively.

For further analysis, some average values were derived from the individual day measurements, and temperature variation graphs plotted at 0.5-hour intervals. Unlike the drying units at S02 (where there was only one inlet and outlet); the drying unit at S01 had three inlets and outlets whose temperatures were simultaneously measured every day during the three days. Similarly, two points at designated inlets and outlets (usually extreme ends of the dryer) were chosen for dryers at S03 to insert thermocouples, and their respective temperatures recorded during the drying cycles. The average of inlet and outlet temperatures for each day were determined first, and then used in the determination of average temperature for the measurement period (days).

3.3 Munaanansi Making

3.3.1 Selected munaanansi makers and processing flowchart

Five munaanansi makers were randomly selected from Kampala where the drink is most popular. They were labeled as maker one (P01), maker two (P02), maker three (P03), maker four (P04), and maker five (P05). They are home based businesses and mainly depend on family labor during processing. Crushing of pineapples or peels was mainly achieved by pounding in a wooden mortar using a wooden pestle while filtration was done by use of ordinary household sieves and straining using hands. The general munaanansi making flowchart is shown in Figure 3.7 although there are minor variations from maker to maker.

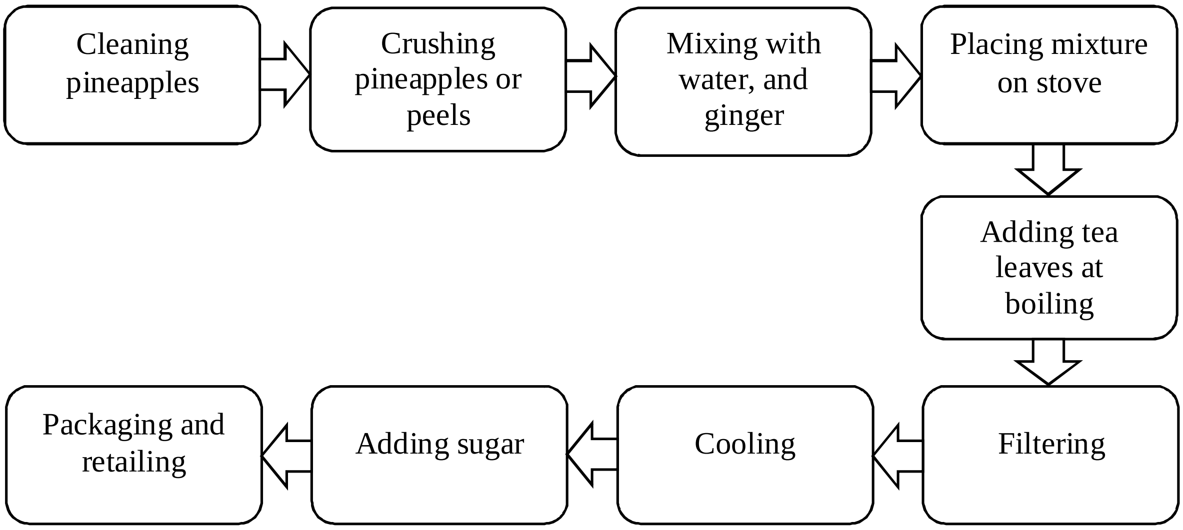


Figure 3.7: The Generalized Munaanansi Making Activity Flowchart

3.3.2 Measurements related to munaanansi making (refer to Table 3.1 for equipment details)

Six times of measurements were performed at P01, two at P02, one at P03, five at P04 and P05, from Nov 2016 to Jan 2017. The mass of pineapples or pineapple peels (kg), amount of water used (kg), mass of firewood or charcoal (kg), amount of munaanansi obtained (kg), amount of pomace (waste or remains after filtering) (kg) were determined using BSE001 and Y029 electronic scales. The quantity of tea leaves (g) were measured using the VOLTCRAFT scale (TS-600). Average values for each of the makers were determined.

3.4 Pineapple Winemaking

3.4.1 Selected winemakers and their making methods

Four pineapple winemakers were randomly selected from Kampala and Wakiso (two from each district). They were labeled as winemaker one (W01) and two (W02) from Wakiso, and winemaker three (W03) and four (W04) from Kampala. Each winemaker makes other wines e.g. mushroom, hibiscus, jackfruit, coffee wines, to mention a few, but this study focused on pineapple winemaking. The wineries are home based mainly using family and/or casual labor (children and relatives) but registered with USSIA. They are very seasonal in their winemaking activities such that some of them make pineapple wine a few times or even once a year during the pineapple peak season (Dec to Mar). Working capital seem to be one of the main challenges to winemakers because wine takes relatively longer periods (at least 3 months) (Berry, 1996) to be ready for sell.

Therefore, recycling capital is quite hard, and someone should have other sources of funds to run several batches at the same time since the peak season for pineapples lasts for about 3 months. However, wine has a unique shelf life, the longer it stays the better it becomes, and this means no concern of losing it if not sold in a given period as long the seals are still intact (Berry, 1996; Grainger & Tattersall, 2005). It is mainly capital that is locked up in there if selling does not happen as soon it is ready.

The general winemaking process is the same although particular variations exist among the different investigated makers e.g., what is done, when, and how. Here two generalized examples (Figure 3.8 and Figure 3.9) of pineapple winemaking activity flowcharts are presented to demonstrate some of those variations.

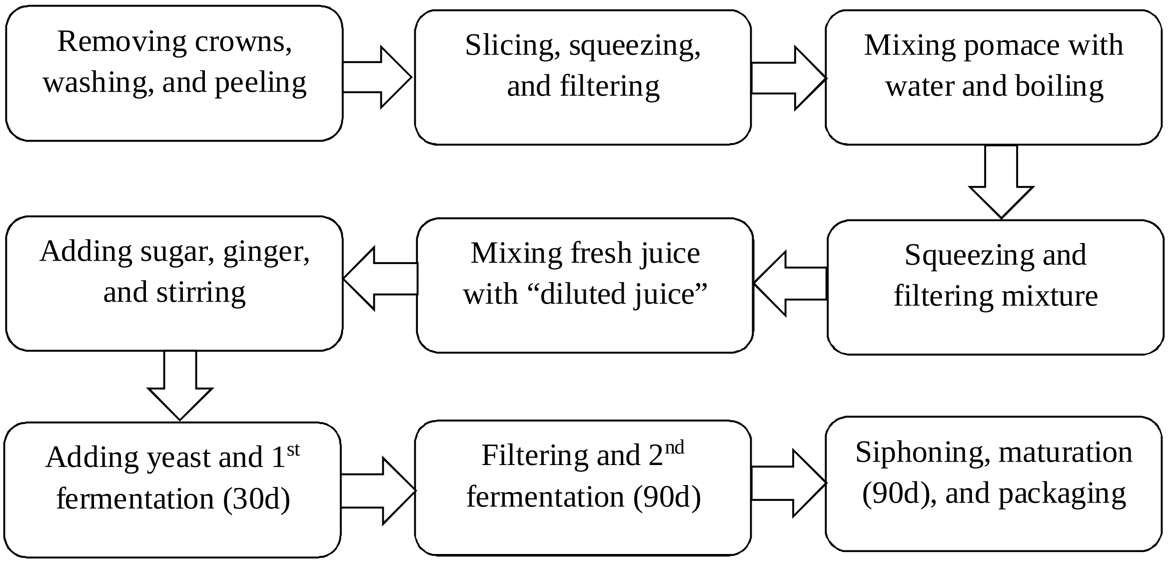


Figure 3.8: Example 1 of Generalized Pineapple Winemaking Flowchart

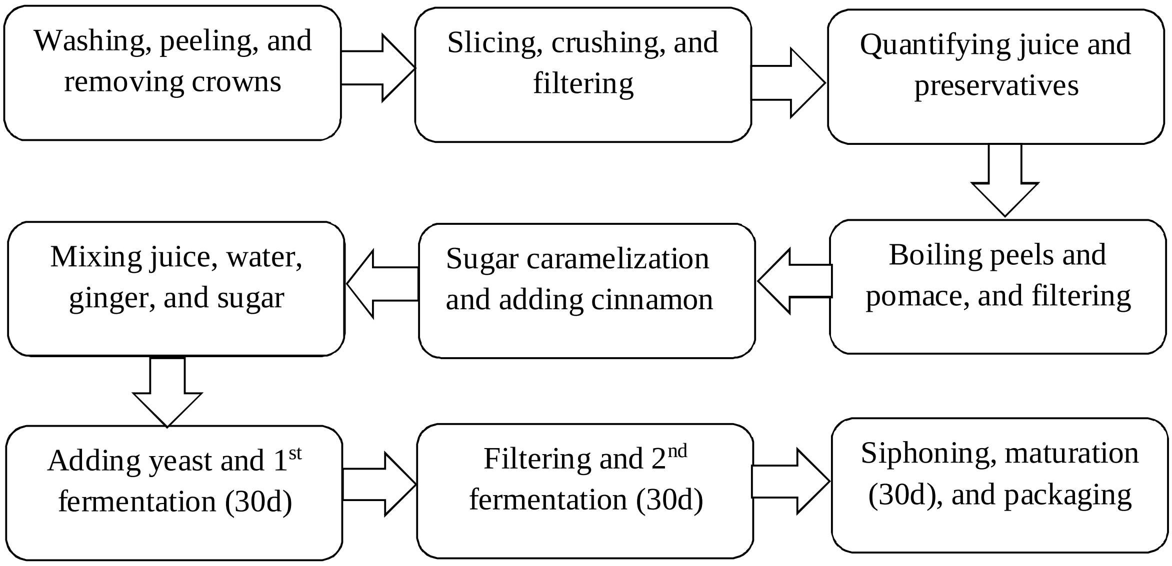


Figure 3.9: Example 2 of Generalized Pineapple Winemaking Flowchart

It can be observed from example 1 that crowns are removed before washing and peeling (recommended) (Bartholomew, Paull, & Rohrbach, 2003; Bates, Morris, & Crandall, 2001) while they are removed after washing and peeling in example 2. The reason given in example 2 is the ease of handling the pineapples while washing and peeling. The other difference is the caramelization of some of the sugar (1/4) to be added and adding cinnamon in example 2 unlike in example 1. Significant variation is also observed in the fermentation process: while primary (1^{st}) fermentation is 30 days (30d) for both, secondary (2^{nd}) fermentation is 90 days in example 1 and 30 days in example 2, and maturation is 90 days in example 1 while it is 30 days in example 2. Therefore, the total processing period is 210 days in example 1 and 90 days in example 2. The methods for determining the quantities for ingredients such as sugar also vary, and not based on the initial sugar content (^{0}Brix) of the juice. Particularly, sugar is determined based on the amount of fresh pineapple juice obtained i.e. the more juice, the more sugar added. Crushing and filtration is mainly a manual process, and it is only one processor (W04) using electric blenders for crushing peeled and sliced pineapples. The fermentation containers are usually 20 l, 180 l, or 300 l plastic jerrycans as shown in Figure 3.10.

Figure 3.10: Pineapple Wine Fermentation Containers

Normally, the fermentation containers are well-sealed (airtight) and placed in a cool, dark room or covered with black clothes to optimize the fermentation process (too much light results into premature wine aging) (Eisenman, 1998; Stávek, Papouskova, Balik, & Bednar, 2012).

3.4.2 Measurements related to winemaking (refer to Table 3.1 for equipment details)

Quantities of raw pineapples (kg) to be used for winemaking on a particular day (before peeling) and the resulting waste (peels, cut-offs, and cores) were weighed using the electronic scale (BSE001) or portable electronic scale (Y029) for weights less than 15 kg. Biomass (charcoal and/or firewood) to be used in the process was weighed using the portable electronic scale (Y029), and the electrical energy measured throughout the processing period using a single-phase electrical energy meter (DDS228) as described in section 3.2.5. An approach similar to the one used in 3.2.5 was employed for cases where direct measurement of electrical energy was impossible. The amount of juice obtained after filtering, final product after processing, amount of water for washing and mixing with juice were measured using a 20 l food grade graduated plastic bucket. The quantities to be measured were poured into the bucket, and readings taken directly from the markings on the bucket. Where a lot more than 18 l had been produced, it was measured in 18 l portions, and the total yield determined by summation. Further manipulation such as determining the average values and energy conversion was then performed.

3.5 Pineapple Juice Making

Three pineapple juice makers were selected from Kampala and Wakiso (two from Kampala and one from Wakiso), and labeled as maker one (J01) from Wakiso, maker two (J02) and three (J03) from Kampala. All of them make other juices such as orange, mango, passion fruits, or a combination. The juices have a short shelf life, and sometimes require refrigeration to keep them longer. They are either made ready to drink (diluted and sugar added) or kept undiluted. Ready to drink juices are usually sold directly to retailers or final consumers while undiluted juice can be sold to bulk buyers who later dilute at their premises for retailing. Preservatives such as Sodium Benzoate and Potassium Sorbate are used especially for diluted juice to be packaged as ready to drink (Mukantwali, 2014). Pasteurization is another treatment to kill germs and harmful bacteria, which can be dangerous to the consumers as well as causing the juice to go bad. However, heating fruit juices can affect their quality e.g. through pigment destruction and non-enzymatic browning, thus the need for heating regulation and control (Mukantwali, 2014). Two examples of generalized activity flowcharts are shown in Figure 3.11 and Figure 3.12.

Maker J01 makes wine as well, but data collected on wine from that enterprise was not included in the analysis on wine because the making methodology is quite different from the rest. During winemaking at J01, the pineapples are simply washed and chopped into small pieces without peeling. The chopped pieces are then mixed with boiled and room temperature water in the fermentation container (usually 180 l jerrycans), sugar and yeast added while stirring. Primary fermentation takes only 21 days, after which filtration and squeezing is done to remove the pomace. The process is left to stand for 90 days (secondary fermentation), siphoning performed, and more 90 days for maturation.

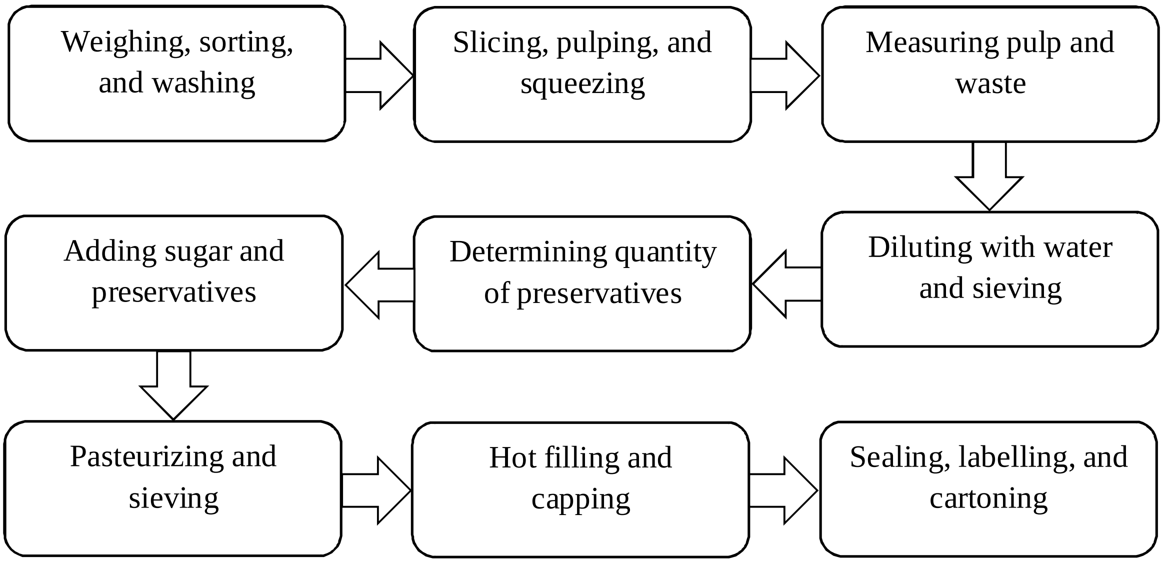


Figure 3.11: Example 1 of Generalized Pineapple Juice Making Flowchart

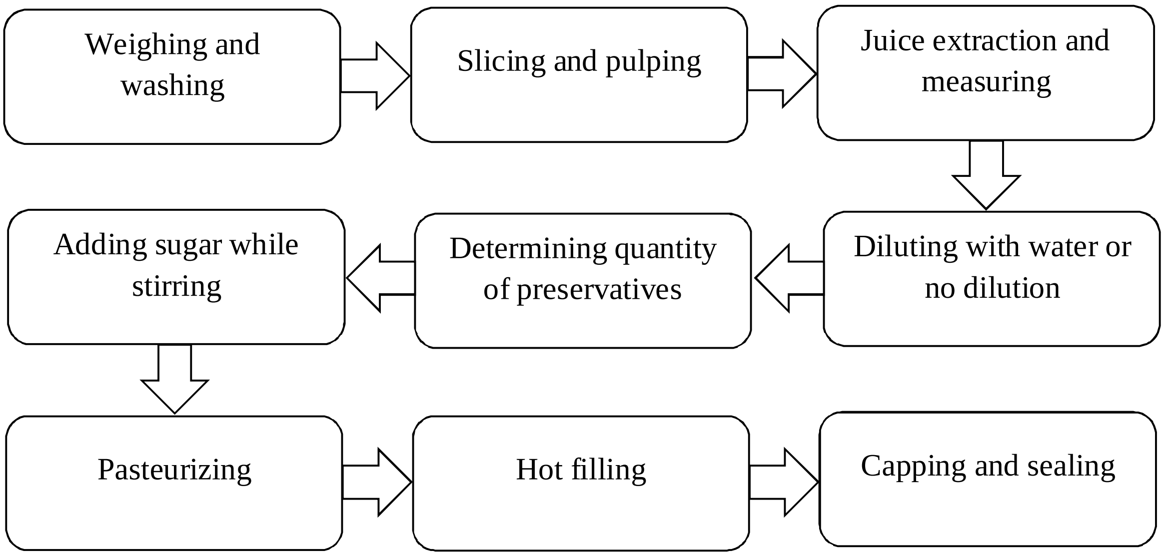


Figure 3.12: Example 2 of Generalized Pineapple Juice Making Flowchart

In example 1, the pulp is diluted immediately after pulping, implying that there is no possibility of making undiluted juice. However, it is possible to make undiluted juice in example 2, and in that case, the juice goes directly to pasteurization after extraction. More sieving (filtration) is done in example 1 unlike in example 2 where sieving after pasteurization is not required. Juice extraction can be done using electric or wooden manual juice extractors and with hands by means of ordinary sieves (Figure 3.13). Sometimes ordinary household sieves are used for the same purpose especially where the pulp is light. Additionally, winemakers employ similar juice extraction and filtering procedures.

Wooden juice extractor

Extraction by hands

Figure 3.13: Manual Pineapple Juice Extraction

The quantities measured under winemaking (section 3.4.2) were virtually the same as those performed under juice making. Therefore, the procedures and the descriptions are not repeated under this section.

3.6 Energy Conversions, Calculations, and Cost

All energy consumed by each of the processes was converted to kWh and MJ in order to determine the specific energy consumption (SEC) in kWh/kg or kWh/l, which is one of the most common indicators for assessing EE of energy consuming processes (Ramírez, Blok, Neelis, & Patel, 2006; Ramírez, Patel, & Blok, 2006; Sakamoto, Tonooka, & Yanagisawa, 1999). While MJ is a common measure of energy, kWh is the conventional unit for energy consumed upon which billing and costing is based, so preferred for determining the SEC. Similarly, the use of SEC enables comparison of different energy consuming devices or equipment used in similar or same processes, since it is a ratio between energy input and process output. It is therefore possible to compare energy consumption by a natural convective dryer and a forced convective or even hybrid one without bias. In other word, the type of the energy consuming device is not the focus, but how much it consumes with respect to the output. However, before deriving the SEC for each processing cycle, individual energy conversions were performed as follows.

Diesel and Petrol: the liters used per day of each fuel were converted into kg (equation 3.1) using their respective densities (density of diesel: 0.80 – 0.86 kg/l; average 0.83 kg/l and density of petrol: 0.71 – 0.77 kg/l; average 0.74 kg/l) (Song, Hsu, & Mochida, 2000).

$$m_f = Q * \rho \ldots \ldots \ldots \ldots (3.1)$$

where m_f is mass of fuel (diesel or petrol) in kg, Q is quantity of fuel in liters, and ρ is density of the fuel in kg/l.

Their respective calorific values (CV) (diesel: 45 MJ/kg and Petrol 46.5 MJ/kg) (Solanki, 2008; Soman, 2011) were used to determine the equivalent energy content (equation 3.2).

$$E_f = m_f * CV \ldots \ldots \ldots \ldots (3.2)$$

where E_f is the equivalent energy content of fuel (diesel or petrol) in MJ and CV is caloric value of the fuel in MJ/kg.

Charcoal and firewood: the calorific value (CV) of wood greatly varies with the type and MC of the wood, and can be specified as gross calorific value (GCV) or net calorific value (NCV) (Ciolkosz, Miller, & Wallace, 2010; Francescato et al., 2008; Härkönen, 2012). For this research, the NCV (where the energy required to vaporize water at 25 ^{0}C has already been subtracted) was chosen for firewood energy estimation (Francescato et al., 2008). Furthermore, a mixture of mainly eucalyptus and pine was assumed based on visual observation by the researcher. Additionally, the MC for firewood at S02 was assumed as 45% with NCV of 9.08 MJ/kg (Francescato et al., 2008). This was because the wood at S02 was mainly fresh cut-offs (bark of timber, locally known as "makooko") collected from the forest and kept outside. Yet, typical fleshly cut timber has a MC of 50 - 60%, and 23 – 35% if kept over summer or several years (Härkönen, 2012; Jacob-Lopes & Zepka, 2019). The rest of the firewood (including for munaanansi making) was assumed to have a MC of 15% with NCV of 15.36 MJ/kg (Francescato et al., 2008). This was because it was visibly dry, and looked like that used by households for preparing meals. All charcoal was assumed to have an average CV of 28 MJ/kg based on the documented range of 23 – 33 MJ/kg (Solanki, 2008). Equation (3.3) was used to determine the energy content of biomass.

$$E_b = m_b * NCV \ldots \ldots \ldots \ldots (3.3)$$

where E_b is the equivalent thermal energy of biomass in MJ, m_b is the mass of biomass in kg, and NCV is the net calorific value of biomass in MJ/kg.

Solar thermal energy at S01 (from solar air heaters)

The average solar thermal energy (E_{Sth} in kWh) contributed by the solar air heaters per day at S01 was estimated using equation 3.4 based on the following:

Total collector area (A_{CT}): 18 m^2 (calculated from the measured dimensions of each air heater multiplied by three air heaters present at S01).

Average solar radiation (H): 478.7 Wm^{-2} in Jan and 602 Wm^{-2} in Apr (measured)

Solar glass transmittance (τ_{sg}): 0.85 (assumed based on theoretical value of at least 0.90) (Drummond, 2010; Pulker, Schmidt, & Aegerter, 1999).

Sunshine hours per day (SSH): 6.5 hours (assumed)

$$E_{Sth} = \frac{(A_{CT} * H * SSH * \tau_{sg})}{1000} \qquad 3.4$$

Solar thermal energy at S03 (by traditional direct solar dryer)

Similarly, the available solar energy (E_{DSD} in kWh) for the drying period (two days) at S03 was estimated using equation 3.5 based on the following:

Collector area (A_C): 6 m^2 (calculated from the measured dimensions of the dryer)

Average solar radiation (H): 592 Wm^{-2} (measured)

Solar collector cover transmittance (τ_{cc}): 0.80 (assumed based on theoretical value for UV of 0.85 – 0.90) (Kohl, Carlsson, Jorgensen, & Czanderna, 2004; Sangpradit, 2014).

Sunshine hours per day (SSH): 6.5 hours (assumed)

$$E_{DSD} = \frac{(A_C * H * SSH * \tau_{cc})}{1000} \qquad 3.5$$

Furthermore, the electrical energy (kWh) was converted to MJ or MJ to kWh using the conversion factor of 3.6 MJ/kWh (Francescato et al., 2008; Pimentel & Pimentel, 2002; Wilcock, 2005).

The total energy consumption per drying or production cycle was determined in both kWh and MJ, and the SEC obtained by dividing the total energy consumption (kWh) with final product output (kg or l).

The average energy cost per processing cycle was determined by multiplying the unit cost (USD/kg, USD/l, or USD/kWh) and the average quantity (kg, l, or kWh) of fuel consumed per processing cycle. The unit cost of fuel (biomass, diesel, or petrol) was derived from the total amount (Uganda Shillings – UGX) spent and total fuel (kg or l) delivered. Those in charge of procuring processing material reported both of these quantities. The unit cost of electricity was derived from the 2017 domestic and commercial electricity tariffs published by Electricity

Regulatory Authority (ERA) of Uganda (ERA, 2016). The March 2017 UGX - United States Dollar (USD) exchange rate was used, which was taken as USD 1 to UGX 3,600 (BOU, 2017).

3.7 Characterization of Pineapple Peels

3.7.1 Background

It was observed that pineapple peels were the most dominant pineapple processing waste. For that matter, it was prudent to characterize them by determining their pH, MC, Total Solids (TS), and Volatile Solids (VS). This would inform any further steps to be taken in exploring the alternative uses for the peels e.g. making animal feeds, fertilizers, or biogas generation. Those parameters are some of the most important factors for preliminary investigation of materials. In fact, they can form an integral part in the final composition of the developed recipes and usually affect the final products. They also influence the steps and processes involved in making products from materials, as well as affecting the stability of the intermediate and final products made. Water content for example, greatly influences the stability of the waste plus that of the derived products (Bradley, 2010; Dzurec & Baptie, 1989; Reh & Gerber, 2003). It was therefore sensible to determine some of these major parameters as a first step into future studies. They were thus determined by following the standard known methods recommended by the Association of Official Analytical Chemists (AOAC) (Helrich, 1990).

3.7.2 pH determination

pH indicates the acidity or alkalinity of a substance ranging from 0.0 – 14.0, where less than 7.0 is acidic, 7.0 is neutral, and greater than 7.0 is alkaline (basic). Water for example is ideally neutral with pH 7.0 (Griffin, 2019; Waugh & Grant, 2014).

Pineapple peels were chopped into small pieces of about 1 cm using a knife, ground using a wooden mortar and pestle, and divided into three samples (S_1, S_2, and S_3) of 200 g. They were placed into beakers, equal amount of distilled water added, and stirred to ensure a homogenous solution. The probes of the pH meter (Mettler-Toledo AG) were immersed into the solution, one at a time ensuring that the probes were washed with distilled water before dipping them into another sample. The respective sample pH values were recorded and the average of the three samples was determined. The average value was considered to be the pH of the peels.

3.7.3 Determination of Total Solids (TS) and moisture content (MC)

Total Solids include organic and inorganic material in a sample, and their determination involves evaporating all the liquid present to obtain a dry sample. The main principle behind this procedure is weight loss of the sample whose TS, VS, and MC are to be determined (Aliyu, 2017; Bradley, 2010; Reh & Gerber, 2003).

Three empty crucibles were selected, labeled (C_1, C_2, and C_3), their respective empty weights measured using a B1500D electronic scale, and recorded. Each crucible was placed on the weighing scale (B1500D) and after taring, homogeneous pieces of peels were added to each crucible and weight of the fresh peels determined and recorded. The three samples were then placed into an oven and kept at 105 ^{0}C for 48 hours. The oven-dried samples were measured and their weights recorded. The TS and MC for each of the samples were determined using equation 3.5 and 3.6 respectively (Aliyu, 2017; Bradley, 2010; Capareda, 2014; Dzurec & Baptie, 1989; Reh & Gerber, 2003), and their averages calculated. Figure 3.14 shows the samples inside and outside the oven.

$$TS(\%) = \left(\frac{Weight_{dried\ sample+crucible\ weight} - Weight_{empty\ crucible}}{Weight_{fresh\ sample}}\right) * 100 \ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

$$MC(\%) = 100 - TS(\%) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

Samples inside oven *Dry samples outside oven*

Figure 3.14: Samples Inside and Outside the Oven

3.7.4 Volatile Solids (VS) determination

Volatile Solids is the organic fraction or digestible portion of the TS, and determined by heating TS at 550 ^{0}C for 24 hours (Helrich, 1990; Subramani & Kumar, 2016).

Three crucibles were selected, labeled (C_4, C_5, and C_6), their respective empty weights measured using a B1500D electronic scale, and recorded. TS in 3.8.3 were ground using an electric mortar and pestle in order to reduce their size and make them more homogeneous. Samples were then placed in each of the crucibles and their respective weights determined and recorded. They were placed into a furnace and kept at 550 ^{0}C for 24 hours. New weights (ash or inorganic portion of TS + crucible) of the samples were determined using B1500D electronic scale, and recorded. The ash content or inorganic portion was determined by finding the difference between new weight and weight of crucible. The VS for each sample were determined using equation 3.7, and their average considered as the VS (Capareda, 2014; Kishore, 2010).

$$VS(\%) = \left(\frac{Weight_{TS} - Weight_{ash}}{Weight_{TS}}\right) * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.7)$$

4 Results

4.1 Pineapple Drying

4.1.1 Average values for the different parameters measured

The average values for the measured inlet and outlet temperature, output (dry product), browned products, percentage of waste (after peeling and slicing), MC of both fresh and dried pineapples, and drying time are shown in Table 4.1.

Table 4.1: Averages of the Various Measured Values for the Three Drying Enterprises

Unit	Inlet Temp (^{0}C)	Outlet Temp (^{0}C)	Pineapples (kg)	Waste (%)	Output (kg)	Browned (kg)	Duration (hrs)	Fresh MC[a] (%)	Dry MC[a] (%)
S01-Jan	69.5	47.11	215.07	58	12.95	0.43	19.67	-	13.3
S01-Apr	55.22	40.15	98.98	62	6.16	0.16	13.83	79.87	11.78
S02-Mar	118.26	59.2	315.55	62	15.00	-	18.67	83.85	13.10
S03-Feb	44.79	45.62	177.95	58	11.47	0.45	48.0	85.53	17.04

[a] Moisture Content

It can be observed that the highest average inlet (118.26 ^{0}C) and outlet (59.2 ^{0}C) temperatures were exhibited by the drying unit at S02 with an average drying time of about 19 hours (Table 4.1). The average values for S01 measured in Jan and Apr showed important differences, e.g. the drying time reduced from about 20 hours to about 14 hours, and final MC reduced from 13.3% (in Jan) to 11.78% (in Apr) (Table 4.1). Similarly, the output (kg of dried pineapples) reduced from 12.9 kg to 6.16 kg. No more firewood and petrol were being used in Apr, and the petrol back-up generator had been replaced with a diesel one. The dryer at S03 attained the lowest inlet average temperature of 44.79 ^{0}C.

Further, the drying ratios (fresh pineapple (kg):dry pineapples (kg)) and SEC at the three drying enterprises are displayed in Table 4.2. The drying ratio indicates how many kg of fresh material are required to obtain one dried kg of the same material (Sudheer & Indira, 2007).

Table 4.2: Drying Ratios and SEC for the Three Enterprises

Unit	Drying ratio	SEC (kWh/kg)
S01-Jan	17:1	28.28
S01-Apr	16:1	13.91
S02-Mar	22:1	32.28
S03-Feb	16:1	3.22

The performance at S01 in terms of drying ratio (fresh pineapple (kg):dry pineapples (kg)) (Sudheer & Indira, 2007) was 17:1 in Jan and 16:1 in Apr, SEC was 28.28 kWh/kg in Jan and 13.91 kWh/kg in Apr (Table 4.2). This was substantial improvement of the two parameters measured in Jan and Apr. Similarly, the lowest SEC (13.91 kWh/kg) among forced convective dryers was obtained at S01 in Apr, and the highest SEC of 32.28 kWh/kg attained at S02. The solar irradiance measured in Jan at S01 was 478.7 Wm^{-2} and 602.7 Wm^{-2} in Apr.

S02 exhibited the highest drying ratio of 22:1 (Table 4.2); which means, it requires 22 kg of raw pineapples to obtain 1 kg of dried pineapples. S01 in Apr and S03 showed the lowest drying ratios of 16:1. Additionally, S03 experienced the lowest overall SEC, but SEC was quite variable even among the hybrid and forced convective dryers.

4.1.2 Temperature variation during drying at the three drying enterprises

The average inlet and outlet (exhaust) temperature variations for each of the drying units at 0.5-hour intervals are graphed in Figures 4.1 – 4.3.

Figure 4.1 shows the temperature variations at S01 in Jan and Apr 2017. The inlet temperature to the drying chamber at this company varied between 52 ^{0}C and 79 ^{0}C in Jan 2017, and varied between 52 ^{0}C and 66 ^{0}C in Apr during the drying cycles. The outlet temperature at the same processor varied between 32 ^{0}C and 71 ^{0}C in Jan 2017, and varied between 28 ^{0}C and 61 ^{0}C in Apr. However, the temperature measurements at different points inside the drying chamber e.g. bottom, middle, and top indicated significant non-uniform distribution of temperature at S01. Usually the bottom, where the hot air entered the drying chamber exhibited the highest relative temperature, and the top the lowest. Similarly, the temperature control knobs and display units were analogue and manual, and presented difficulty in setting and reading them.

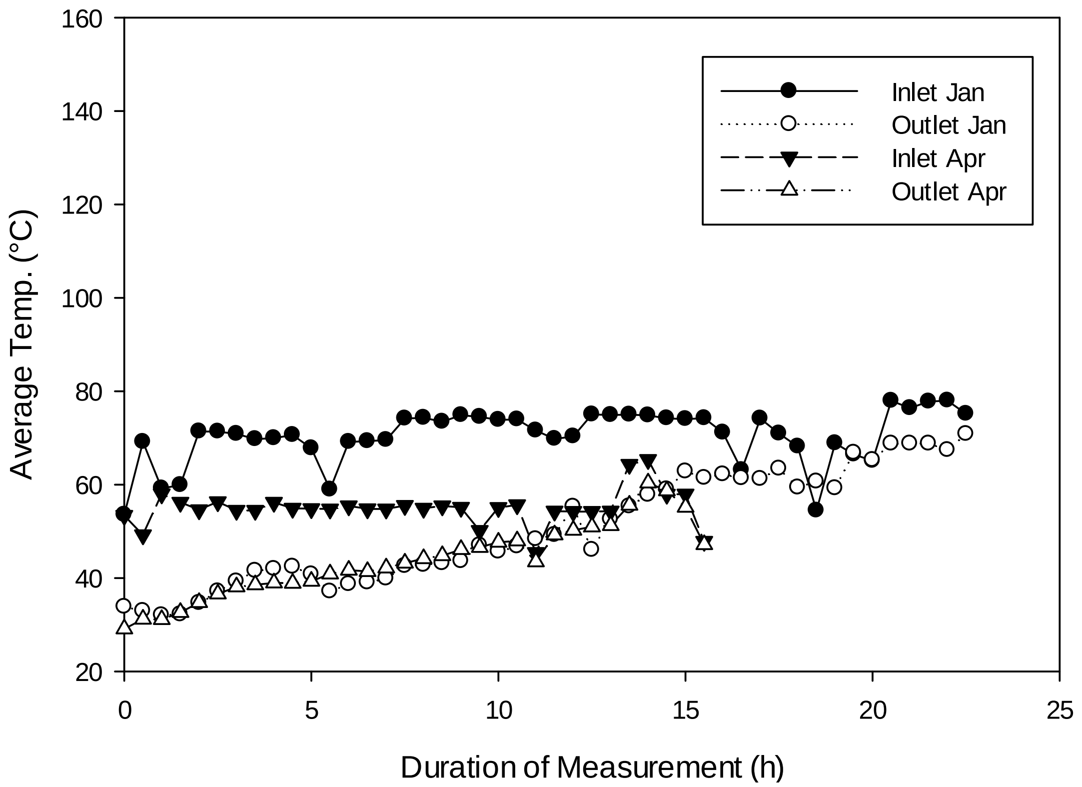


Figure 4.1: Average Inlet and Outlet Temperature Variations at S01 (Jan and Apr)

The temperature variations for the drying unit investigated at S02 are showed in Figure 4.2. The inlet temperature for this unit varied between 54 ^{0}C and 145 ^{0}C, and attained over 120 ^{0}C in about half an hour of drying. It kept swinging between 80 ^{0}C and 145 ^{0}C until about the 16th hour when it fell below 80 ^{0}C, and kept around that value until recording stopped. The outlet (exhaust) temperature varied between 37 ^{0}C and 71 ^{0}C and approached the inlet temperature at the end of the drying cycle. This drying unit exhibited a significant temperature differential (the difference between inlet and outlet). However, it took almost 19 hours for one drying cycle to be completed.

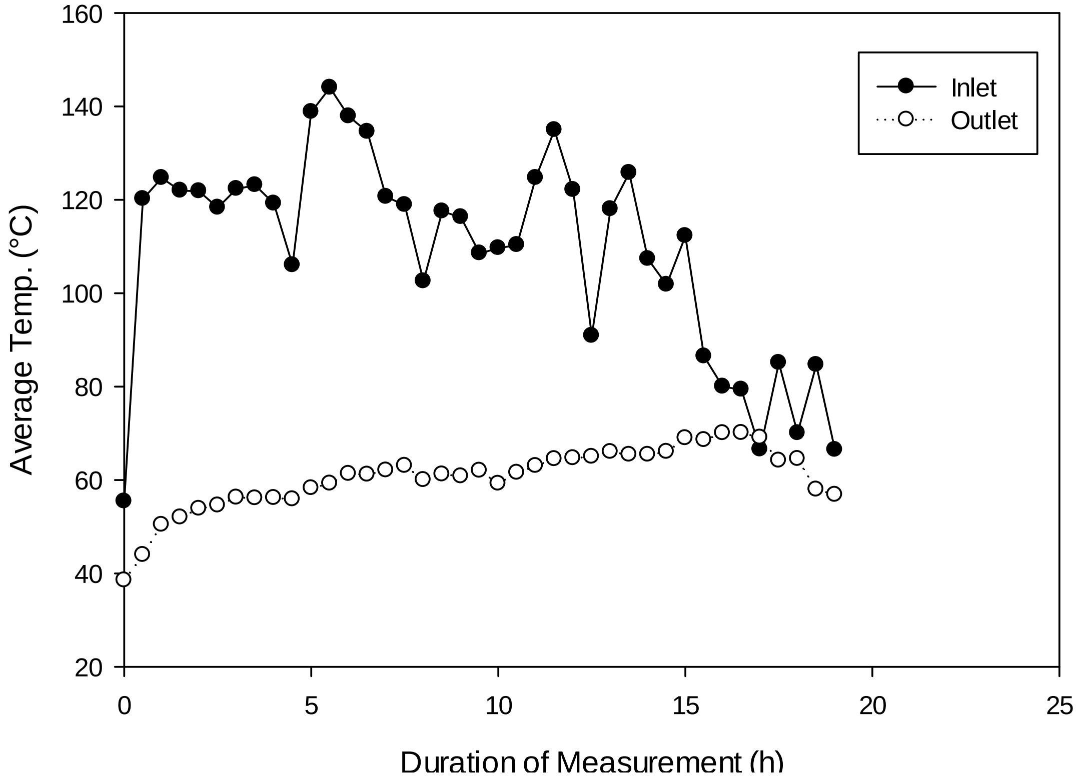


Figure 4.2: Average Inlet and Outlet Temperature Variations at S02

One drying cycle for the unit at S03 took about 48 hours, but Figure 4.3 displays the daily average inlet and outlet temperatures. The inlet and outlet temperatures were measured for about 7 hours per day starting from about 10 am to about 5 pm. The inlet temperature varied between 36 ^{0}C and 51 ^{0}C, and the outlet temperature varied between 38 ^{0}C and 53 ^{0}C. The inlet temperature was generally less than the outlet (exhaust) temperature, and the drying unit behaved like a greenhouse. When it rained, some of the dryers at S03 were observed leaking through the transparent polythene cover.

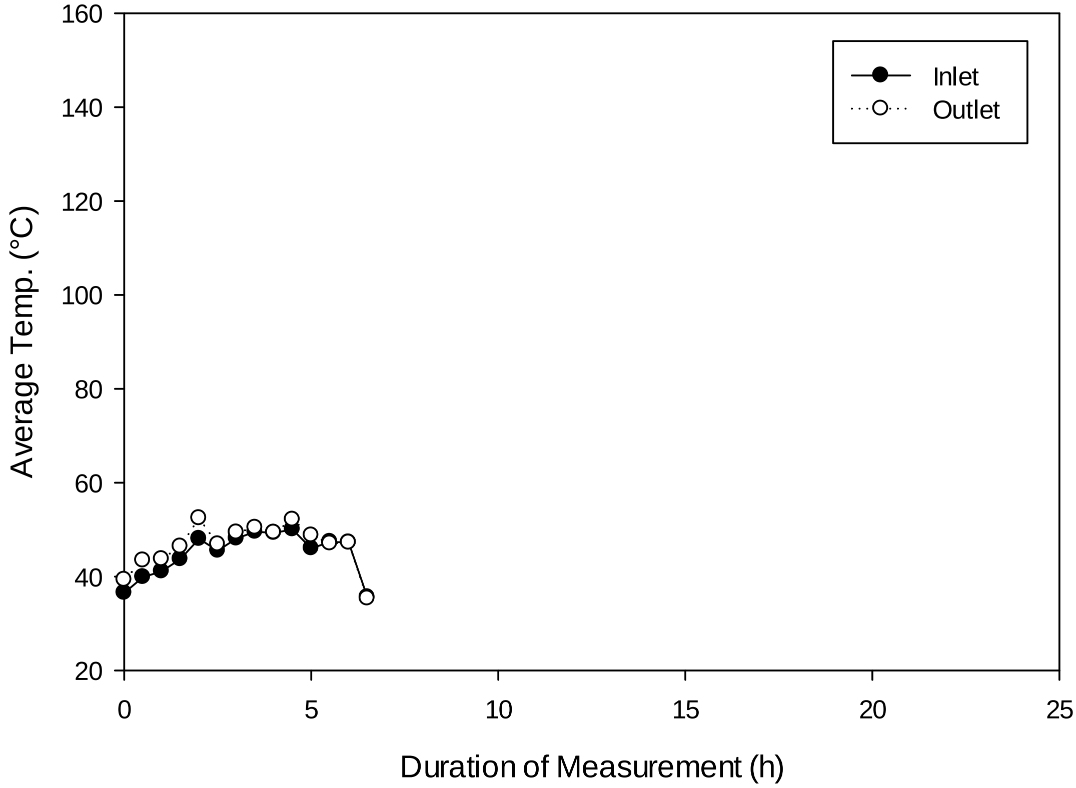


Figure 4.3: Average Inlet and Outlet Temperature Variation at S03

The temperature variations especially at S01 and S02 exhibited a general trend with the outlet temperature being consistently lower than the inlet temperature and almost converging towards the end of the drying cycle.

While nutritional and chemical property determination for the dried products was outside the scope of this study's investigation; S01 produced the best looking products based on the researcher's personal visual observation. In other words, the dried products at S01 exhibited the best visual appearance due to their minimum color change.

4.2 Munaanansi Making

The average values and type of fuel used by each munaanansi maker are presented in Table 4.3 while the per unit values with respective cooking stoves are shown in Table 4.4.

Table 4.3: Average Values for Measured Parameters for Five Munaanansi Makers

P01-P05	Raw pineapple or peels (kg)	Water input (l)	Yield (l)	Fuel Type	Fuel (kg)	Energy (kWh)	Pomace (kg)
P01	12.58	94.08	96.02	Firewood	17.83	76.05	9.7
P02	2.23	9.78	9.95	Charcoal	1.93	14.97	1.3
P03	1.90	23.20	21.50	Firewood	11.50	49.07	1.0
P04	14.12	65.40	62.70	Charcoal	5.09	39.59	7.2
P05	19.94	70.81	62.34	Firewood	16.26	69.39	18.3
Average	**10.15**	**52.65**	**50.50**		**10.52**	**49.81**	**7.5**

Table 4.4: Per Unit Values, Raw Material, and Type of Stoves across the Five Munaanansi Makers

P01-P05	Yield (l/kg)	W:M (l/l)	SEC (kWh/l)	Pomace (kg/l)	Raw material	Stove Type
P01	7.95	0.98	0.71	0.11	Peels	Three stone firewood stove*
P02	4.47	0.98	1.53	0.13	Pineapples	Traditional charcoal stove**
P03	11.32	1.10	2.28	0.05	Pineapples	Three stone firewood stove**
P04	4.45	1.04	0.64	0.12	Pineapples	Traditional charcoal stove**
P05	3.24	1.14	1.04	0.31	Peels	Three stone firewood stove*
Average	**6.29**	**1.05**	**1.24**	**0.14**		

W:M – ratio of water to yield or munaanansi (liters of water in every liter of munaanansi)
*cooking inside kitchen
**cooking outside (open space)

It can be seen from Table 4.4 that on average, 6.29 l of munaanansi were obtained from 1 kg of pineapples or pineapple peels, and maker P03 enjoyed the highest yield (11.32 l/kg). Maker P05 added the highest amount of water per liter (1.14 l/l) of munaanansi made, but experienced the lowest yield per kg (3.24 l/kg). All makers use bare hands to squeeze the pomace, and filter through ordinary household sieves. Therefore, to improve yield, some makers left the pomace to cool down from the pan where boiling was carried out in order to be able to squeeze properly with their bare hands. Irrespective of the method or approach used, a lot of munaanansi seemed to remain in the pomace after filtering on the last run, and was seen (but not measured) seeping through minutes after the process.

P03 exhibited the highest SEC (2.28 kWh/l, Table 4.4), but the average SEC was 1.24 kWh/l. The SEC for P02 was 1.53 kWh/l and 1.04 kWh/l for P05 although they use different types of stove. P03 and P05 operated their respective stoves as shown in Figure 4.4, and the flames were seen being blown all-over the place and open to the environment.

Three stone firewood stove at P03

Three stone firewood stove at P05

Figure 4.4: Operating the Three Stone Firewood Stoves at P03 and P05

On average, to produce 1 l of munaanansi, around 1.24 kWh of energy and 1.04 l of water are required leading to the generation of about 0.14 kg of pomace (waste) (Table 4.4).

Furthermore, munaanansi makers use either firewood or charcoal as fuel (Table 4.3), and either traditional three stone firewood stove or traditional charcoal stove (metallic and locally known as "sigiri") for fuel combustion (Table 4.4 and Figure 4.5).

Three stone firewood stove at P03

Traditional charcoal stove at P04

Firewood at P01

Charcoal at P04

Figure 4.5: Type of Stoves and Respective Fuel

Briquettes and electricity are not common options for making of munaanansi. Electricity is considered relatively expensive and therefore unaffordable, but also limited by site location e.g. some do make munaanansi by the roadside. The briquettes are generally unknown among most Ugandans and usually associated with low combustion rate. In fact, one of the munaanansi makers stated that firewood is preferred because it combusts very fast, thus reducing the processing time. Water supply to both drying and munaanansi production is mainly from National Water and Sewerage Corporation (NWSC), and rainwater is rarely used due to lack of water harvesting roofs and sometimes rainwater visibly looks dirty due to dusty roofs. Additionally, water cleanliness is only based on its physical appearance; otherwise, no means of determining its contamination levels if it appears clear. However, most processors do not take water as a very important input and never considered in the cost of processing.

4.3 Pineapple Winemaking

The energy types, total energy consumption, and conversion devices are presented in Table 4.5 while the average and per unit values for the various measured parameters are given in Table 4.6.

Table 4.5: Energy Type, Consumption, and Conversion Devices at the Four Winemakers

Enterprise	Energy type(s)	Energy (kWh)	Conversion device(s)
W01	Firewood	232.38	Three stone firewood stove in open space
W02	LPG	-	Used directly from the LPG stove
W03	Charcoal	76.57	Traditional charcoal stove outside
	Electricity	0.29	Pulping electric blender
W04	Firewood	75.03	Fixed rocket stove
	Electricity	0.26	Pulping electric blender in kitchen

Table 4.6: Average and Per Unit Values for the Four Winemakers

Enterprise	Pineapple (kg)	Juice obtained (l)	Juice (l/kg)	Juice + Water (l)	Output (l/kg)	Energy (kWh/l)	Waste (%)
W01	212.17	81.17	0.383	158.67	0.748	1.465	44.1
W02	26.62	12.38	0.465	44.88	1.686	-	50.1
W03	123.00	75.00	0.610	266.90	2.170	0.288	37.6
W04	121.00	79.32	0.656	196.46	1.624	0.383	40.5
Average	**120.70**	**61.97**	**0.528**	**166.73**	**1.557**	**0.712**	**43.1**

The average juice yield (amount of juice obtained after extraction, l/kg) was 0.528 l/kg and the highest yield was obtained by W04 (0.656 l/kg) (Table 4.6). The lowest yield was exhibited by W01 (0.383 l/kg). The average percentage of waste was about 43%, with the lowest being 38% experienced by W03 whose yield is also relatively high (0.61 l/kg). The highest percentage of waste (50%) was experienced by W02, who mainly employs grandchildren for human power during winemaking.

The dominant type of fuel was biomass, and those who used electricity, consumed less than 1 kWh on average, and mainly for pulping (Table 4.5). One (W02) of the four winemakers selected used Liquefied Petroleum Gas (LPG) as source of energy (Table 4.5), and gave reasons of being convenient and user friendly. In reality, LPG stove can easily be switched on and off while working in order to avoid wastage of energy. However, it was noted that the very winemaker used the lowest average pineapple input (26.62 kg, Table 4.6). The researcher was unable to measure the quantities of gas used per process due to lack of equipment to do so.

Two out of four winemakers use either a three stone firewood or traditional charcoal stove (metallic "sigiri") and only one (W04) uses the fixed rocket stove (Table 4.5). The highest SEC (1.465 kWh/l) was exhibited by W01 who uses a three stone firewood stove located outside.

It was also observed that the total of juice and water (into the fermentation container) was assumed to be equal to the final wine output in liters. This was so because, the overall loss due to filtering and siphoning is said to be about 2% (not considering accidents leading to pouring or batch going bad). However, the winemakers selected have a practice of adding more water in the process (primary fermentation to maturity) to ensure that the initial targeted quantities are achieved e.g. if someone starts with 20 liters, wants to eventually have 20 liters as wine and therefore adds more water as desired during the process to achieve the 20 liters.

4.4 Pineapple Juice Making

The energy type, total energy consumption (kWh), and the conversion devices used by pineapple juice makers are shown in Table 4.7. Similarly, the average and per unit values derived from parameters measured at the three pineapple juice makers are indicated in Table 4.8.

Table 4.7: Energy Type, Consumption, and Conversion Devices

Enterprise	Energy type(s)	Energy (kWh)	Conversion device(s)
J01	Charcoal	15.56	Traditional charcoal stove outside
J02	Electricity	113.52	Pineapple crushing and juice extraction machine, and electric pasteurizer
J03	Firewood	338.99	Firewood batch pasteurizer
	Electricity	6.29	Pineapple electric pulper or crushing machine

Table 4.8: Average and Per Unit Values for the Three Pineapple Juice Makers

Enterprise	Pineapple (kg)	Juice (l)	Juice (l/kg)	Pasteurized undiluted (l)	Pasteurized diluted (l)	Output (l)	Output (l/kg)	Energy (kWh/l)	Waste (%)
J01	21.05	10.50	0.499	16.20	0.00	16.2	0.770	0.96	60.5
J02	758.00	454.0	0.599	308.73	120.27	429.0	0.566	0.26	37.5
J03	197.50	135.0	0.684	0.00	450.00	450.0	2.278	0.77	36.5
Average	**325.52**	**199.8**	**0.594**	**108.31**	**190.09**	**298.4**	**1.21**	**0.66**	**44.8**

The average juice yield was 0.594 l/kg (Table 4.8), and no significant variations in terms of yield among individual juice makers. The highest proportion of waste (61%) was exhibited by J01, and was quite different from what was experienced by J02 (38%) and J03 (37%). It was also noted that the same maker (J01) consumed the highest amount of energy (0.96 kWh/l) to make 1 l of juice (Table 4.8).

It can also be observed from Table 4.7 that, J02 uses only electricity for all the processes if human power is disregarded as was the case with other processors. Additionally, J02 operates within an incubation center established under an academic institution to enhance students' research and support upcoming small-scale processors who cannot afford advanced equipment. Generally, electricity supply at that institution is more reliable and payment for it is not based on usage but as part of a lump sum paid per month in form of "goodwill" or rental fees. Electric equipment is used right from pulping to pasteurization although the processing line is not continuous e.g. pulped material must be manually moved to the juice extraction machine, and the obtained juice manually transferred to the pasteurizer. Such practices were identified as soft spots for losing the material and juice although relatively better than purely manual process. Variations were noticed in juice extractors as shown in Figure 4.6 (hydraulic electric and wooden manual juice extractor).

Electric Hydraulic Juice Extractor

Manual Wooden Juice Extractor

Figure 4.6: Electric and Manual Juice Extractors

The hydraulic presses when the user activates electricity, and the manual one, generally requires two people to achieve the pressing. The juice, which is stored undiluted e.g. by J02 requires minimum energy input thereafter because what remains is dilution, filing, sealing, and branding.

This is done either on-site by the maker or off-site by the retailer, but with minimum energy input. It was performed manually in some cases e.g. at J02.

4.5 Characteristics of Pineapple Peels

4.5.1 pH values

The measured and average pH values are presented in Table 4.9. The average pH of the pineapple peels was 4.7 and quite acidic.

Table 4.9: Measured and Average pH Values

Sample label	pH
S_1	4.7
S_2	4.7
S_3	4.7
Average	**4.7**

4.5.2 Total Solids (TS) and moisture content (MC)

The individual measured and average values as well as the calculated TS and MC, and respective average values are given in Table 4.10. The average TS and MC was 18.38% and 81.62% respectively.

Table 4.10: Total Solids (TS), Moisture Content (MC), and Related Values

Crucible label	Weight of crucible (g)	Weight of fresh sample (g)	Weight of dry sample + crucible (g)	TS (%)	MC (%)
C_1	3.79	46.79	11.40	16.26	83.74
C_2	3.76	44.17	12.39	19.54	80.46
C_3	3.76	50.03	13.44	19.35	80.65
Average	**3.77**	**47.00**	**12.41**	**18.38**	**81.62**

4.5.3 Volatile Solids (VS)

The measured sample values and averages, plus the derived VS are shown in Table 4.11. The average VS was 95.83% (Table 4.11). In general, the TS, MC, and VS for the individual samples did not show pronounced variations.

Table 4.11: Volatile Solids and Related Values

Crucible label	Weight of crucible (g)	Weight of sample (TS) (g)	Weight of ash + crucible (g)	Weight of ash (g)	VS (%)
C_4	24.52	4.19	24.70	0.18	95.70
C_5	21.00	4.34	21.18	0.18	95.85
C_6	21.01	4.68	21.20	0.19	95.94
Average	**22.18**	**4.40**	**22.36**	**0.18**	**95.83**

5 Discussions

5.1 Pineapple Drying

The significant difference between inlet and outlet temperature (temperature differential) at S02 suggests that the hot air duct is too small compared to the surface area of the drying chamber, and the installed ordinary electrical cookers or coils inside the drying chambers have negligible contribution to the overall drying air temperature. This means that, the energy consumed by the ordinary heaters does not effectively add to the actual drying process. Figure 5.1 demonstrates the elements of the drying system at S02. The hot air is expected to flow from the biomass burner into the drying chamber. In principle, it spreads from higher to lower heated area due to the forcing fan, and is able to pick up much more moisture from the fruits than when it is a natural air convection (Varun, Sunil, Sharma, & Sharma, 2012). This is because the rate of heat transfer is higher under forced convection than under natural convection, hence higher drying rate for forced convective dryers (Elhage, Herez, Ramadan, Bazzi, & Khaled, 2018). The situation of high differential temperature might be solved by introducing multiple hot air ducts at various points in the drying chamber so that the hot air supply is evenly distributed. This is likely to reduce the duration of the drying cycle and overall energy consumed per drying cycle.

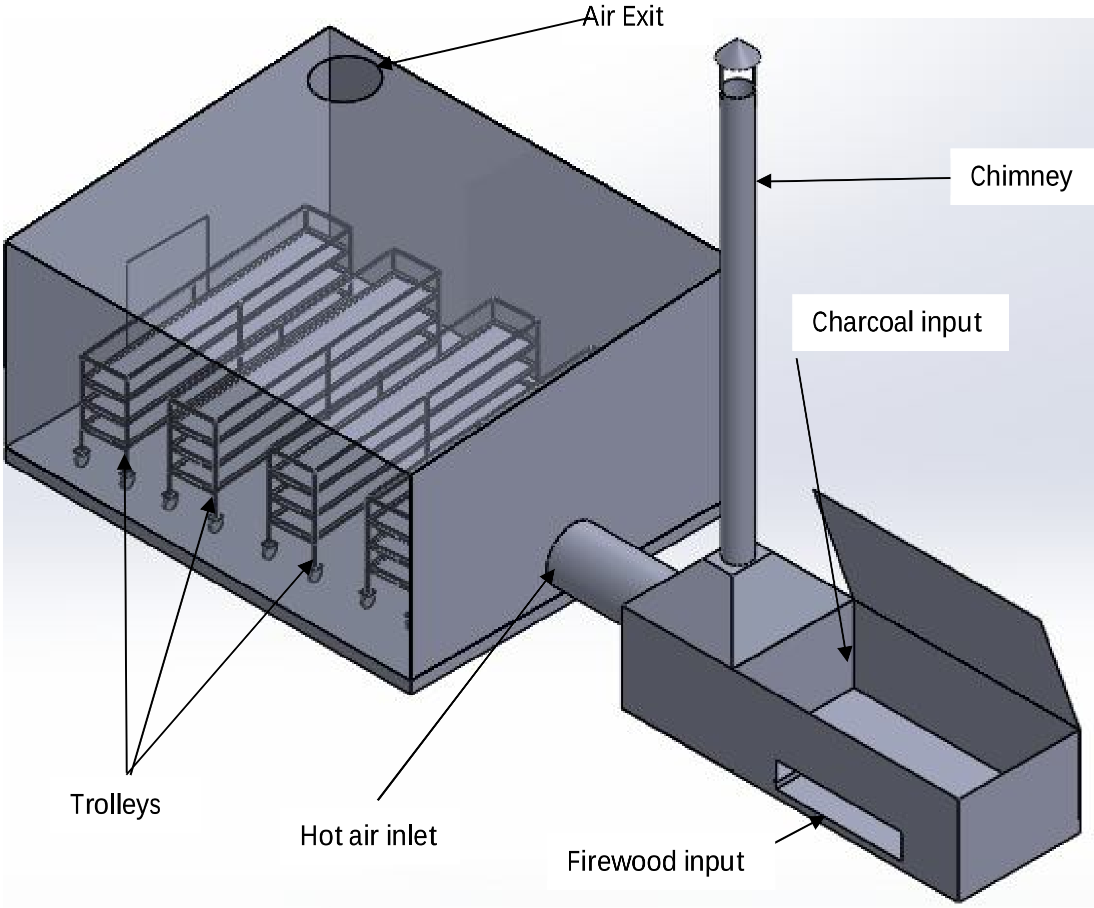


Figure 5.1: Drying System Orientation at S02

Similarly, the differences in inlet and outlet temperatures at S01 for Jan and Apr might be explained by the fact that, temperature settings changed from (75 – 80 ^{0}C) in Jan to not more than 65 ^{0}C by Apr. The changes in temperature settings were recommended after noticing that a relatively large volume of pineapple slices were being “burnt” during drying. On measuring spot temperatures inside the drying chamber (using IR002 temperature gun), it was found that some sections attained temperatures above 65 ^{0}C, yet it was not supposed to exceed 65 ^{0}C for this particular dryer. Indeed, relatively high temperatures e.g. above 65 ^{0}C are discouraged for fruit drying since they can lead to discoloration especially browning and scorching (Akoy, 2014; Ramallo & Mascheroni, 2012; Sturm et al., 2019). Actually, the first quality attribute that consumers look out for is the visual appearance of the products. Color is certainly one of the most important attributes that influence consumer acceptability or rejection of a product. Unusual colors that are inconsistent with customer expectation are associated with spoilage and low quality. In fact, many consumers focus on visual appearance of the product and relate it to the overall quality of the merchandises in question. They thus reject or accept the product based on appearance, and sometimes other sensory attributes like taste (Crichton et al., 2017; Leon, Kumar, & Bhattacharya, 2002; Masamba, Mkandawire, Chiputula, & Nyirenda, 2013). Amongst the investigated enterprises for example, the researcher may have selected products from S01 judged on low color change and perceived quality. Therefore, the final product color is paramount.

It is therefore conceivable that, human involvement and adherence to equipment settings, processing and operational guidelines is very relevant in achieving desired product quality and performances. But, non-conformance might not only affect the output (color and quantity), but also inputs such as energy plus the unseen quality of the product especially nutritional and chemical properties of the products (Akoy, 2014; Masamba et al., 2013; Sturm et al., 2019). Close monitoring and periodic process performance evaluation (including visual observation) can be very helpful in keeping track of the process especially after introducing some changes (Menda, 2004). Additionally, the unequal distribution of temperature in the drying chambers at S01 is likely to be due to using only one fan located in the diesel burner, which forces the hot air all the way to the drying chambers through the hot air duct. Actually, fan ineffectiveness due to under-dimensioning has been cited as one of the causes of failed transportation of evaporated water from the dryer (Sturm et al., 2019). Therefore, it might be instructive to have dedicated fans placed at the entrance of each inlet in order to improve air circulation in the drying chambers. They can be solar powered in order to avoid total reliance on grid electricity. This is likely to reduce the drying time and total energy consumed as well as the energy cost. Such changes can be a design consideration for the new dryers such that those modifications are well thought out before fabrication and installation. Similarly, the airflow through the dryer should be controlled such that it attains sufficient contact time with the fruits in order to evaporate and pick substantial amount of moisture from the fruits (Elhage et al., 2018; Sturm et al., 2019).

The situation of higher outlet temperature than inlet at S03 could be explained by the fact that the inlets are taking in air, which is almost at ambient temperature especially at the beginning of the drying cycle in the morning. The ambient temperature in Kangulumira is reported to range between 22 – 35 ^{0}C depending on the time of the day and month of the year (Ahumuza, Zziwa, Kambugu, Komakech, & Kiggundu, 2016). Therefore, when the air enters the solar collector, it gets heated up (greenhouse effect), and leaves the dryer hotter but wet after picking moisture from the fruits. This means that, the inside of the dryer is always hotter than the outside (Elhage et al., 2018; Varun et al., 2012). The products are also ideally protected from direct rain, dirt, and dust, hence, minimizing some of the limitations associated with open sun drying (Varun et al., 2012). However, the dryer purely depends on direct sunrays, and the inlets and outlets are directly exposed to the environment. Similarly, there is no form of air heating control, and the users only depend on the mercy of nature (weather dependence) (Doymaz, 2004). The situation becomes worse when it starts raining or the sky becomes cloudy after loading the dryer, and usually this leads to spoilage of the products (Chongtham et al., 2010). In fact, the users have to closely "forecast" the weather for a particular day based on traditional knowledge and experience rather than scientific methods and equipment. The traditional approaches include; looking at the sky, formation of clouds, recent history, wind direction, season, to mention a few (Okonya & Kroschel, 2013; Orlove, Roncoli, Kabugo, & Majugu, 2010). While such approaches are considered quite unreliable, they generally guide the processors in avoiding total spoilage due to bad weather (Okonya & Kroschel, 2013). Indeed, these processors and farmers are left with limited options since national weather stations in Uganda are sparse and not accessible to everyone with ease (Nsabagwa, Byamukama, Otim, & Okou, 2016). The leaking of dryers at S03 could be due to aging of the polythene and limited maintenance of the dryers. The users indicated that most of the dryers had existed for more than five years, yet their life span is said to be limited based on literature (Kiggundu et al., 2016). Certainly, a number of them are no longer usable. However, the total drying time of about two days is in agreement with what other researchers have reported for natural convection solar drying (Kiggundu et al., 2016; Varun et al., 2012). Additionally, the total drying time for solar dryers normally includes even the time (e.g. at night) when solar is unavailable. It is estimated from the time the dryer is loaded until the products being dried are considered dry, ideally based on required MC (Leon et al., 2002). For the investigated drying enterprises, the dryness of the products was based on operators' knowledge and experience through checking brittleness and stickiness of the pineapples by touching and pressing. They were considered dry if they were feeling leathery, not sticky, and sometimes a bit brittle. Furthermore, the inlet and outlet temperature profiles at S03 were similar to what another independent study on similar dryers in the same area reported. The same study reported that the inlet temperature varied from about 37 ^{0}C at the beginning of the measurement in the morning to about 30 ^{0}C in the evening of the same day (Ahumuza et al., 2016), which is comparable to the findings of this study.

The tendency of the inlet temperature approaching the outlet temperature at the end of the drying cycle can be attributed to the fact that, at the beginning of the drying cycle, a lot of moisture is absorbed by the hot air from the pineapples. Indeed, it is reported that a lot of water is available in wet fruits at this time than at later stages (Sturm et al., 2019). This leads to a significant temperature reduction of the incoming hot air, hence the resulting difference between inlet and outlet temperatures. However, the rate of moisture absorption by the hot air reduces as the process of drying goes on, and at some point, minimum absorption takes place. This is an expected response for drying processes (Haddad, Mounir, Sobolik, & Allaf, 2007; Maskan, Kaya, & Maskan, 2002; Tippayawong, Tantakitti, Thavornun, & Peerawanitkul, 2009). It was also an operational practice observed in the field to reduce the incoming hot air temperature towards the end of the drying cycle, and since minimum absoption takes place at this stage, the inlet temperature approached the outlet temperature. Reduction of the incoming hot air temperature was achieved by limiting the biomass into the burners at S02. Alternatively where there was control e.g. at S01, the incoming hot air duct valve was adjusted to limit the amount of hot air into the drying chamber.

Further comparison of inlet and outlet temperatures for the dryers at the three drying entreprises is demonstrated in Figure 5.2 and 5.3.

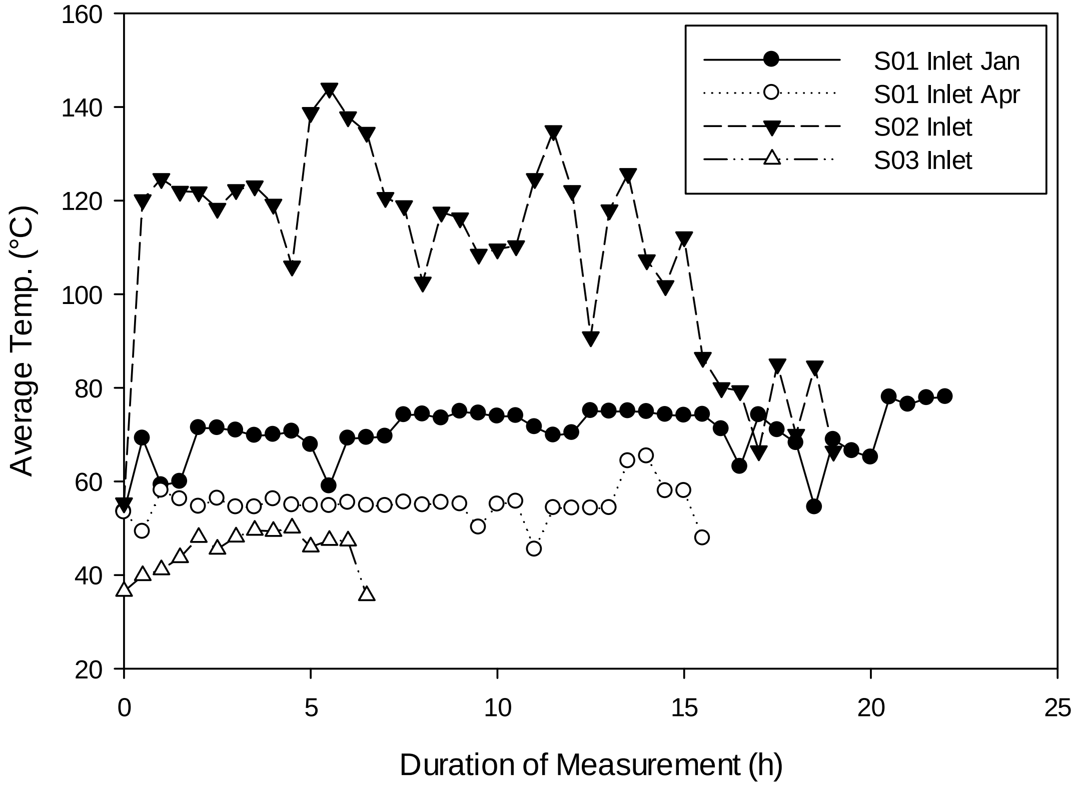


Figure 5.2: Inlet Temperature Variation at S01, S02, and S03 Compared

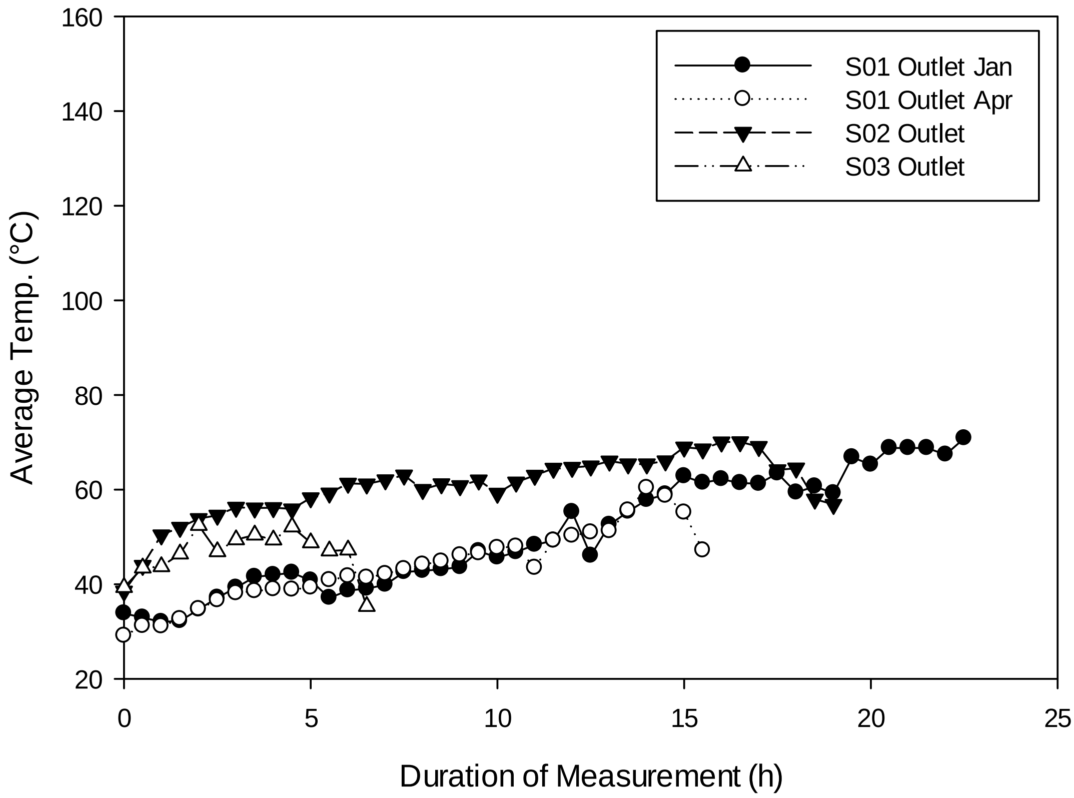


Figure 5.3: Outlet Temperature Variation at S01, S02, and S03 Compared

It can be observed that the dryer at S02 maintained the highhest inlet and outlet temperature for the duration of the experiment (Figure 5.2) although its drying time was not much less than that for the dryer at S01. The possible cause for this situation has already been attributed to the surface area of the drying chamber being too large such that the volume of the air inside the drying chamber was significantly higher compared to the incoming hot air. Similarly, Figure 5.1 demonstrates that, it is possible that hot air had minimum contact with fruits, and simply found its way through the spaces in between the trolleys and walls of the drying chamber to the exit. It is therefore reasonable to argue that the actual drying temperature attained by the surface of the fruits was less than 72 ^{0}C most of the time judging from the exit temperature, which was between 37 ^{0}C and 71 ^{0}C. In such cases, a properly designed and fabricated cabinet dryer with air forcing fan(s) preferably solar driven would be more relevant and applicable since its airflow is well directed and through the trays. It is also much more compact and takes less installation space (Mustayen, Mekhilef, & Saidur, 2014; Tippayawong et al., 2009). The spiked crests and troughs exhibited by the S02 inlet temperature variation can be attributed to inconsistent fuel burning in the biomass burner.

Someone was supposed to keep monitoring the burner and properly directing the firewood into the burner whenever required. However, it was oberseved during operation that this was not always the case, thus the swing in the inlet temperature since the hot air whose temperature was being measured as inlet temperature was coming directly from the burner. In other words, the fire tended to extinguish and dwindle naturally until the burnt-out firewood and sometimes new ones were added. In fact, the operational and precautional requirements for these burners is similar to those provided for campfires and outdoor open fireplaces (Kulibert, 2007).

The inlet temperature especially at the beginning of the drying cycle at S03 was relatively less than that attained by dryers at both S01 and S02 (Figure 5.3) because the dryer at S03 was only using direct solar radiation without being assisted with any other source of heating. A similar observation was reported by another research team that performed evaluation of similar direct solar dryers (Ahumuza et al., 2016). Indeed, solar heating is known to be gradual, and cannot attain high temperature values as those experienced at S01 and S02 (Elhage et al., 2018; Kiggundu et al., 2016; Varun et al., 2012). However, its (S03) outlet temperature was the highest at the beginning, and remained higher than that measured at S01 for most of the time until almost at the end of the day, when sunrays were no longer strong enough to raise the internal dryer temperature since there was no alternative heating.

The inlet and outlet temperature for the dryer at S01 (Figure 5.2 and 5.3) portrayed similar behaviour in Jan and Apr despite the fact that the settings for the maximum allowable temperature had changed by the time of taking the measurements in Apr. This suggests that the drying profile for that particular dryer at S01 maintains comparable behaviour even when the temperature settings change.

The performance improvements achieved by S01 might have been as a result of operational, technical, and behavioral changes effected after the Jan measurements. They included; half loading of the drying units (which might have improved the internal airflow in the units) (Elhage et al., 2018), improving electrical voltage to become more stable and usable, and replacing petrol generator with a diesel one whose fuel is denser (Song et al., 2000) and cheaper. Improved airflow in the drying unit results into reduced conduction and radiation losses, hence more efficient energy use (Elhage et al., 2018). It could also mean that full loading of the dryer was actually overloading it. This is because overloading dryers prevents sufficient airflow and proper extraction of evaporated water from the products (Sturm et al., 2019). This suggests that the full load is not the optimal load for this particular dryer. Indeed, such could have contributed to appreciable improvement of SEC at S01 by Apr. In addition, the solar irradiance in Apr was particularly higher than what was recorded in Jan. This confirms the seasonality and variability of solar radiation depending on the area in Uganda and month of the year (Karume, Banda, Mubiru, & Majaliwa, 2007; Mubiru et al., 2007).

The MC achieved by the drying unit at S02 (13.1%) was comparable to that attained by one at S01 in Jan (13.3%). However, the SEC for the unit at S02 (32.28 kWh/kg) was relatively different from that at S01 (28.28 kWh/kg) (Table 4.2). The constructional capabilities of the drying units and operational factors such as airflow rate in the drying unit, operating temperatures, initial MC, to mention a few, greatly influence the drying process including the overall energy consumed (Sagar & Suresh Kumar, 2010; Sturm, Hofacker, & Hensel, 2012; Tippayawong et al., 2009). Similarly, the significant variations observed in the drying systems (described in sections 3.2.2 and 3.2.3) could have contributed to the difference in SEC for the two drying units. To aid further comparisons, Figure 5.4 demonstrates the biomass burners associated with the respective drying systems.

At S01 *At S02*

Figure 5.4: Biomass Burners at S01 and S02 Compared

Clearly, the biomass burner constructions are different e.g. the one at S01 has a door and firewood should be chopped to size, loaded into the burner, and the door closed after firing the burner. Thus minimum interference from external blowing wind. But, this is relatively complicated with the one at S02 (Figure 5.4), since there is limited control of the fire. From that picture (Figure 5.4, at S02) captured during operation, what is happening can be described as open burning to say the least. This indeed could have influenced SEC at S02 compared to that at S01. At S02, someone might simply “throw” the firewood onto the fireplace, and departs, which would eventually lead to firewood burning outside the burner i.e. open burning. This means, more firewood being used unnecessarily. Ideally, there should be minimum interruption with biomass burner (e.g. opening the door) during the combustion process of the burner, but the practice of periodical removal of ash preferably daily or after every drying cycle and its proper management should be emphasized (James, Thring, Helle, & Ghuman, 2012; Van Loo & Koppejan, 2012). The influence of the environment should be minimized to optimize fuel combustion e.g. blowing wind, and absorption of moisture by biomass (which lowers combustion efficiency while increasing carbon emissions) should be avoided (Chen et al., 2010; Vamvuka & Sfakiotakis, 2011; Van Loo & Koppejan, 2012). The rate of combustion is slowed at high MC of fuel, but reducing the size of biomass e.g. by chopping improves combustion (Yang et al., 2005). Similarly, the rate of external airflow influences biomass combustion, and if the fire is exposed to wind, the flames will be blown away from the fire place leading to wastage of biomass, and if energy consumption is measured, higher than normal consumption will be determined (Rasoulkhani, Ebrahimi-nik, Abbaspour-fard, & Rohani, 2018).

Overall, the obtained SEC figures confirmed the variability of energy consumption for drying. There are several factors, which influence energy consumption for drying processes such as airflow rate and air distribution in the dryer, humidity, initial and final MC, drying temperature, to mention but a few. Additionally, the drying time also greatly influence the final energy consumption. Therefore, such variability is expected when energy consumption for various drying systems is evaluated, which is even conceivable for the same dryer if the influencing factors change (Galanakis, 2018; Roohinejad, Parniakov, Nikmaram, Greiner, & Koubaa, 2018; Sturm et al., 2012). Moreover, it is possible that SEC varies from zero (for sun drying) to over 30 kWh/kg in hybrid solar dryers (Dutilh, Blonk, & Linnemann, 2018; Nwakuba, Asoegwu, & Nwaigwe, 2016b). The “zero” SEC for sun drying assumes that sun drying is associated with “zero” energy cost since the sun energy supply is taken to be “free” (Dawe, 2019; Dutilh et al., 2018). Even when it was considered in this study, it was the lowest (3.22 kWh/kg) among the three drying enterprises. This can be explained by the high final MC (17%) attained at S03 such that more significant amount of energy is required for further drying in order to achieve comparable MC figures as those achieved at S01 and S02. Additionally, the dryer employs direct solar heating method where the fruits are directly exposed to solar rays through the transparent cover. The surface of the fruits and the surrounding air heats up due to the transmitted solar energy through the cover (Islam, Islam, Tusar, & Limon, 2019). Therefore, most of the transmitted energy into the dryer goes into evaporating moisture from the fruits.

Moreover, it was observed that the drying temperatures were close to the ranges for which other studies investigating quality and nutrient retention have been carried out. Such studies were performed at temperatures in the range 40 ^{0}C to 70 ^{0}C, and concluded that drying within that range especially 40 ^{0}C to 60 ^{0}C does not greatly compromise quality and nutrients of the dried products when other factors are kept constant (Akoy, 2014; Murthy, 2009; Ramallo & Mascheroni, 2012). It can therefore be assumed that nutrients were not greatly affected when the investigated enterprises carried out drying within such temperature ranges. Drying temperature is very crucial for drying processs such that it should not be too low to result into browning or too high to cause burning and skin hardening. Such quality attributes can visibly be seen by most people and should be circumvented since many consumers take appearance as the first criterion guiding the selection of the products (Leon et al., 2002; Sagar & Suresh Kumar, 2010; Tippayawong et al., 2009).

The drying ratios demonstrate to the evaluator of the drying process the number of kg of raw material e.g. raw pineapple required to obtain 1 kg of dried product (Sudheer & Indira, 2007), but should be related to the respective final MC. At S03 for example, a drying ratio of 16:1 and final MC of about 17% were attained, and if compared with S01 in Jan whose MC was about 13.3% and drying ratio 17:1, it might appear as if S03 performed better than S01 did in Jan. However, reducing the MC from 17% (at S03) to 13.3% (at S01, Jan) would mean reducing the overall weight of the final product such that the drying ratio increases from 16:1 to more than 17:1, plus requiring more energy to achieve moisture reduction.

The average percentage of waste at S01 - Jan (58%) and S03 (58%) (Table 4.1) are not very different from the 50% reported in an independent experiment (Joy & Rashida, 2016; Ketnawa, Chaiwut, & Rawdkuen, 2012) while those for S01 – Apr (62%) and S02 (62%) were very different from the 50% although still reasonable. The handling practices while conditioning the pineapples e.g. peeling, slicing, and basis of rejection could have influenced such variability (Bartholomew et al., 2003). All the above actions are performed by human beings at the investigated enterprises, and very hard to achieve and repeat the specific dimensions. Similarly, some individuals are keen while sorting pineapples while others are a bit lax, and this affects the overall quantities eventually rejected contributing to the waste. The selection of pineapples is usually based on shell color, appearance of the fruit, and personal experience. All these depend on individual judgement although in more developed countries, they are enhanced by scientific approaches e.g. using weight graders, density sorting, microbial load, pathogen, and pesticide residue analysis (Bartholomew et al., 2003; Bates et al., 2001; Lobo & Paull, 2017). Such scientific methods ease the sorting process and make rejection more consistent.

The daily measured values in Jan and Apr for S01, and for S02 are further compared in Table 5.1.

Table 5.1: Measured Values for the Two Enterprises Using Advanced Drying Systems Compared

Unit	Date	Pineapples (kg)	Output (kg)	Energy (kWh)	Waste (%)
S01-Jan	10-11/01/17	231.50	14.05	390.65	57.78
	11-12/01/17	238.21	11.25	361.51	58.12
	12-13/01/17	175.50	13.54	350.03	56.80
Average		**215.07**	**12.95**	**367.40**	**57.57**
S01-Apr	26-27/04/17	103.5	6.5	74.79	56.46
	27-28/04/17	92.27	6.17	68.22	67.80
	28-29/04/17	101.17	5.8	54.52	61.68
Average		**98.98**	**6.16**	**65.84**	**61.98**
S02-Mar	21-22/03/17	358.00	9.50	500.00	67.88
	24-25/03/17	266.65	17.60	616.77	59.76
	26-27/03/17	301.50	13.45	469.22	69.80
	27-28/03/17	330.47	18.75	459.94	64.60
	28-29/03/17	301.15	16.40	544.36	46.74
	29-30/03/17	335.50	14.30	539.42	63.83
Average		**315.55**	**15.00**	**521.62**	**62.10**

From the daily measured values in Table 5.1, the variability of measured parameters can be observed. Such variability could have been influenced by several factors e.g. human factors during fruit selection and peeling (Bartholomew et al., 2003), spreading sliced pineapples on trays, loading and unloading, overloading the dryer (limits airflow and increases heat loss) (Elhage et al., 2018), firing and maintaining of the biomass burners, among others. There is also a possibility that reporting on procured and used fuels especially diesel and petrol was unreliable. This was noticed in the reported figures, which sometimes defeated logic by comparing usages on the different days, but those figures contributed to the derived energy consumption per processing. This relates quite well with the "fine line between trusting and cheating" (Tröger, Lelea, & Kaufmann, 2018). On the one hand, "you" have to trust what is reported while on the other hand suspicious, but the relationship must be sustained to complete the value chain. Therefore, optimization approaches in such systems may not be linear problems but a combination of factors, which must be translated into the appropriate optimization indices. Furthermore, human factors are generally more complicated to optimize, and humans are very dynamic (Tröger, Lelea, & Kaufmann, 2018). Therefore, the parameters representing humans are quite variable and can rapidly change. However, among the investigated enterprises, simple and basic optimization measures can be adopted e.g. direct contact to the suppliers to minimize misinformation and inflated costs. Similarly, dedicated and well trained individuals in charge of sorting raw materials especially pineapples can enhance consistence and minimize rejects.

To probe further, the processing energy cost among the drying enterprises was considered and presented in Table 5.2. The table considers the unit cost for each fuel or energy type and quantities used during processing. The costs (USD) to obtain one kg of dried pineapples were derived.

Table 5.2: Energy Consumption and Costing among Pineapple Drying Enterprises

Energy Source	Unit Cost - S01	Unit Cost - S02	Average Quantities Consumed - S01 - Jan	Average Quantities Consumed - S01 - Apr	Average Quantities Consumed - S02	Total Cost - S01 - Jan ($)	Total Cost - S01 - Apr ($)	Total Cost - S02 ($)
Firewood	0.07 $/kg	0.02 $/kg	33.55 kg	0.00 kg	82.67 kg	2.35	0.00	1.65
Charcoal	N/A	0.14 $/kg	0.00 kg	0.00 kg	26.5 kg	0.00	0.00	3.71
Diesel	0.82 $/l	N/A	13.13 l	6.05 l	0.00 l	10.77	4.96	0.00
Petrol	0.97 $/l	N/A	6.45 l	0.00 l	0.00 l	6.26	0.00	0.00

Electricity	0.19 $/kWh	0.17 $/kWh	5.73 kWh	2.96 kWh	47.94 kWh	1.09	0.56	8.15
Total						**20.47**	**5.52**	**13.51**

N/A: Not Applicable

The energy cost for drying one kg of pineapples at S01 – Jan, S01 – Apr, and S02 was determined as USD 1.58, 0.90, and 0.90 respectively while those using traditional direct solar dryers ideally did it at zero cost. It can be observed that, in Jan, S01 spent almost twice of what it spent in Apr. This could be attributed to the fact that, in Apr, S01 had abandoned using petrol whose unit cost is more expensive compared to diesel. Similarly, there was no more use of firewood since the electricity voltage was more reliable and stable. The other contributing factor to using less energy could have been the half loading of the dryer, which might have improved airflow within the drying units, an argument well rooted in literature (Elhage et al., 2018; Sturm et al., 2019), hence requiring less energy. Traditional direct solar dryers were considered to have used “free” energy (zero cost) since solar energy is assumed to be freely available (Dawe, 2019; Dutilh et al., 2018). While the SEC for S02 (32.28 kWh/kg) was very different from that experienced by S01 in Apr (13.91 kWh/kg), they spent the same amount of money to dry one kg of pineapples. This could be due to the cost of energy used; S02 used electricity on a commercial tariff plan (USD 0.17/kWh) while S01 used it at a domestic tariff plan (USD 0.19/kWh), hence the difference in the overall cost of electricity consumed. Similarly, S01 used diesel whose unit cost is relatively higher (compared to other fuels like firewood) while S02 did not apply diesel at all and instead exploited biomass in combination with grid electricity. Additionally, the unit cost of biomass by S01 (USD 0.07/kg) was significantly higher compared to that of S02 (USD 0.02/kg). Therefore, the choice of energy made is very important in the overall cost of energy. However, the choice is influenced by several factors such as the cost and availability of energy source, application, convenience, opportunity cost, to mention but a few (Heltberg, 2005).

5.2 Munaanansi Making

The high yield (munaanansi) of 11.316 l/kg achieved by maker P03 can be attributed to the high amount of water added (1.079 l/l) by maker P03. The low yield by P05 can be due to the inability to squeeze the pomace to remove as much munaanansi as possible, which can for example be confirmed by comparing the pomace by (P03 versus P05) as a fraction of munaanansi (0.047 versus 0.306). Clearly, the pomace per liter generated by P03 is far less than that generated by P05.

Therefore, the squeezing method, approach, and effectiveness greatly influence the yield. The quality of the final product can also be influenced by such factors since the sanitation of the various actors is difficult to enforce. In fact, street vended munaanansi has been reported as one of the causes for typhoid fever in Kampala, Uganda (Kabwama, 2015; Kabwama et al., 2017). Moreover, the Uganda National Bureau of Standards (UNBS) warned Ugandan consumers about contaminated soft drinks on market in Uganda in 2012 (Nalubega, 2012). The other factor, which could have influenced yield is how long the mixture was left on the cook stove after boiling. Some makers left the pan on the fireplace for some time (e.g. 5 minutes) after boiling while others immediately discharged it from the stove after boiling. Such time delays are likely to have resulted into differences in the yield since keeping the mixture on the fireplace reduces the overall content. This is because evaporation of the content continues leading to decreased volume of the content when the mixture cools down. Indeed, it is a known principle that when the temperature of a fluid is raised, its molecules become more mobile due to reduced density, and eventually escape from the container into the space above the container (Fromm, 2000; Jain & Soni, 2012; Park, Lamsal, & Balasubramaniam, 2014). This usually happens at evaporation point although it sometimes takes place even before that point. The escaped molecules in form of vapor or gas generally do not return to the container, and when the fluid is cooled, the net volume in the container is reduced. In fact, if heating is not stopped, the fluid will solidify, and become a burnt solid (Jain & Soni, 2012; Park et al., 2014).

The relatively high SEC by maker P03 might be due to the fact that P03 uses a three stone firewood stove whose efficiency is known to be relatively low e.g. 8% (Hafner et al., 2018; Pimentel & Pimentel, 2007; SNV, 2015). Additionally, the stove is located outside and therefore continuous interference from the environment e.g. the fire being blown away by the wind. Environmental interference can lead to more energy consumption and significantly contribute to poor SEC. This is because most of the heat is transmitted to the surrounding air rather than the cooking pot, and the combustion of the fuel is rapid (Pimentel & Pimentel, 2007). Therefore, to complete the cooking, more cooking time and fuel is required (Hafner et al., 2018). A similar situation could have affected the SEC for P05 since the stove was being operated in almost an "open environment" as the one at P03. Even with the three stone firewood stove, the fire should be tended quite well and sufficiently to the pot to ensure optimal utilization of the device irrespective of the location of the stove. The other desirable option would be to replace the three stone stove with improved and more efficient ones whose efficiencies are in excess of 30% (Hafner et al., 2018). Regardless of the stove chosen, the actual cooking should be performed in an environment with minimum interference. The overall energy consumption has a bearing on total cost of processing. Here, the respective costs for making munaanansi are shown in Table 5.3.

Table 5.3: Energy Consumption and Costing among Munaanansi Makers

Enterprise	Unit Cost Firewood ($)	Unit Cost Charcoal ($)	Used Quantity Firewood (kg)	Used Quantity Charcoal (kg)	Total Cost ($)	Cost ($/l)
P01	0.07	N/A	17.83	0.00	1.25	0.013
P02	N/A	0.15	0.00	1.93	0.29	0.029
P03	0.02	N/A	11.50	0.00	0.23	0.011
P04		0.17	0.00	5.09	0.87	0.014
P05	0.00	N/A	16.26	0.00	0.00	0.000

N/A: Not Applicable

The energy cost per liter among munaanansi makers was comparable apart from maker P02 whose expenditure per liter was quite different (almost three times). This could be due to inability to adequately squeeze the pomace in order to obtain maximum yield. Unlike the other makers, P05 collected wood free of charge from building sites located close to the processing site. Therefore, P05 spent zero amount of money on energy, and this is a recognized practice in Uganda where it is possible to obtain wood at zero cost (Price, 2017; SNV, 2014). The per unit cost of firewood by P01 (USD 0.07/kg) was higher than the unit cost paid by P03 (USD 0.02/kg). This can be due to the location of the enterprise and how distant it is from the source of fuel, which is known to influence the cost of fuel due to transportation cost (Searcy & Flynn, 2009).

5.3 Pineapple Winemaking

Several factors influence the juice yield (l/kg), and include but not limited to the state of the pineapples (very ripe, moderately ripe, unripe, damaged, to mention a few), ability to squeeze the juice out, amount of peel removed, and handling. Similarly, the sorting mechanisms and criteria also influence the overall available pineapples for juice extraction (Bartholomew et al., 2003; Bates et al., 2001; Lobo & Paull, 2017).

The relatively high waste by W02 could be because the grandchildren are unable to properly squeeze the juice out of the pomace and probably not very careful to minimize wastage during handling. Similarly, the percentage of waste is influenced by most of those factors especially peeling and selection of pineapples (Bartholomew et al., 2003). It was also observed that W02 obtained more juice per kg of raw pineapples (0.465 l/kg) than W01 (0.383 l/kg). However, W02 experienced a higher proportion of waste generated (50.1%) than W01 (44.1%). The possible cause for such scenario could be the state and source of pineapples as well as the season. Very ripe pineapples will yield much more juice with ease than unripe ones for example. Equally, pineapples from areas, which went through a dry spell, will yield less than those sourced from areas that experienced abundant rains (Bates et al., 2001).

Additionally, the use of LPG by W02 could probably become unsustainable when the amount of raw pineapple input is increased close to what the rest are currently processing. The goal of most entrepreneurs and business persons is to grow in order to enjoy economies of scale. It is therefore predictable that this particular processor will keep growing, and probably reconsider using LPG since it is not commonly used for processing in Uganda. In fact, very few households in Uganda use LPG for day-to-day applications such as cooking because it is considered to be for "high-class" category of people and associated with bulky cylinders plus limitations while re-filling (Price, 2017). Moreover, there is no room for buying in small quantities (divisibility) as it is with other fuels such as kerosene. It (LPG) comes under pre-determined quantities e.g. 13 kg (Bizzarri, 2011; Garland et al., 2015; Habermehl, 2007; Lee, 2013). This limits adoption among low income individuals and enterprises. There is also fear of the potential danger, which might be caused by leaked gas if not well handled especially with children.

The relatively low application of grid electricity even where it exists, is thought to be the general feeling that grid electricity is relatively more expensive, and very few opt for it especially where alternatives like biomass exist. Furthermore, the reliability and availability of grid electricity in Uganda is quite unpredictable characterized by rampant blackouts especially in rural and peri-urban areas. This situation is worse during rainy seasons (Lee, 2013; MEMD, 2007).

The comparatively high SEC by W01 could partially be due to the use of a three stone stove located in the open, which leads to interference of the fire flames by the blowing air. As pointed out in section 5.2, three stone stoves are quite inefficient while combusting firewood, and being located in an open space worsens the situation (Hafner et al., 2018; Pimentel & Pimentel, 2007; SNV, 2015). The other factor, which might have influenced SEC (a function of the output), was the amount of water added to the juice, which could explain the performance of W03. The amount of water added by the investigated winemakers vary from one maker to another, and this affects the overall output (wine), which in turn affects SEC (kWh/l). In theory, the amount of water added should be based on various factors such as sugar content (Brix) and acidity of the fruit juice. In other words, basing on only the quantity of juice obtained can be misleading since fruits normally have varying characteristics especially sugar content (Dellacassa et al., 2017; Rupasinghe, Joshi, Smith, & Parmar, 2017). However, among the investigated winemakers, the amount of water added generally depended on only the amount of raw juice obtained i.e. the higher the amount of juice, the higher the amount of water added. Ideally, those who are able to obtain maximum juice per kg of pineapple, enjoy maximum output in form of wine. But it also depends on the training the maker attained since there are various training individuals and organizations such as Caritas Uganda, Uganda Investment Authority (UIA), Uganda Cooperative Alliance, to mention but a few. That means, various winemakers were trained differently and tend to follow their respective training and winemaking recipes (Muzaale, 2017; UIA, 2016). Such differences in training and handling eventually lead to differences in the yield. However, all investigated winemakers share the concept that, the starting quantities (juice + water) are equal to the final product (wine) at the end of maturation. As already described under results, they keep topping up with water whenever the targeted quantity reduces. However, no more of the other ingredients such as sugar are added as more water is being introduced. This study did not investigate how more water added eventually affects the taste of the final product, and whether the consumers are able to detect significant variation in the taste of the final product.

In order to understand energy costs associated with winemaking, energy consumed and related costs are illustrated in Table 5.4.

Table 5.4: Energy Consumption and Costing among Pineapple Winemakers

Enterprise	Unit Cost Firewood ($)	Unit Cost Charcoal ($)	Unit Cost Electricity	Used Quantity Firewood (kg)	Used Quantity Charcoal (kg)	Used Quantity Electricity	Total Cost ($)	Cost ($/l)
W01	0.04	N/A	N/A	54.47	0.00	0.00	2.18	0.014
W03	N/A	0.16	0.19	0.00	9.85	0.29	1.63	0.006

W04	0.03	N/A	0.19	17.59	0.00	0.26	0.58	0.003

N/A: Not Applicable

It was observed that W01 and W04 collected some of the wood used for processing from building and processing sites free of charge. However, it was assumed that all firewood used was paid for at the same per unit cost. Maker W02 was not included in the energy cost analysis since the energy used per processing was not measured due to limitations in measuring LPG. Maker W01 spent the highest amount of money (USD 0.014) while making one liter of wine. However, her unit cost of buying firewood is almost the same as that spent by W04. The difference could be due to the effectiveness of squeezing the pomace, but also the cooking stove. Maker W04 applied a fixed rocket stove known to have better efficiency than the three stone stove employed by W01 (Habermehl, 2007; Hafner et al., 2018). This may have influenced the total quantity of firewood consumed, and therefore the total cost of fuel.

5.4 Pineapple Juice Making

The factors, which influence the amount of waste in pineapple processing have already been discussed especially under winemaking (section 5.3). They include pineapple rejection criteria (differs from individual to individual and company to company), squeezing ability, state of the pineapples, to mention but a few (Bartholomew et al., 2003; Bates et al., 2001; Lobo & Paull, 2017). The average juice yield (0.594 l/kg, Table 4.8) is comparable to what was obtained among winemakers (0.528 l/kg, Table 4.6) although the variation in terms of yield among the juice makers is not as pronounced as it was among winemakers. The 61% wastage by J01 was very different from that of J02 (38%) and J03 (37%) although still reasonable enough if compared to what is reported elsewhere (Joy & Rashida, 2016; Ketnawa et al., 2012). The rather high SEC experienced by J01 could be explained by the fact that this particular maker does not dilute the juice after extraction, yet SEC is based on the overall final yield (product). The other factors such as extraction methods and equipment, and squeezing abilities have already been pointed out, which influence the percentage of waste as well (Bartholomew et al., 2003; Bates et al., 2001; Lobo & Paull, 2017). J01 stores the pineapple juice undiluted, but in reality, very little energy is required after this stage. The pending activities such as dilution, filling, and cupping, do not consume a lot of energy compared to the preceding stages. They can actually be manual as observed in some cases at J03. Therefore, the total energy consumption may not be significantly affected after that stage.

As was done for the other categories of enterprises, energy costs among pineapple juice makers are compared in Table 5.5.

Table 5.5: Energy Consumption and Costing among Pineapple Juice Makers

Enterprise	Unit Cost Firewood ($)	Unit Cost Charcoal ($)	Unit Cost Electricity	Used Quantity Firewood (kg)	Used Quantity Charcoal (kg)	Used Quantity Electricity	Cost ($)	Cost ($/l)
J01	N/A	0.20	N/A	0.00	2	0.00	0.40	0.025
J02	N/A	N/A	0.19	0.00	0	113.52	21.57	0.050
J03	0.02	N/A	0.17	79.45	0	6.29	2.78	0.006

N/A: Not Applicable

Maker J03 incurs the lowest cost (USD 0.006) of making one liter of pineapple juice, which can be attributed to consuming electricity at a commercial rate and using a significant amount of biomass whose unit cost is very low compared to the other energy types. While J02 pays a lump sum for all the services including electricity, it was assumed that it consumed electricity at the domestic rate, which is the tariff plan for the incubator where it performs its processing activities. The unit prices of charcoal and firewood among all processors ranged from USD 0.02 to USD 0.2, and are comparable to what other studies have reported e.g. USD 0.17/kg of charcoal (Earth Finds, 2017) and USD 0.05/kg of firewood or USD 0.10/kg of charcoal (Habermehl, 2007).

The unit cost of electrical energy has since increased for both domestic and commercial users from USD 0.19/kWh (domestic) and USD 0.17/kWh (commercial) in 2017 to USD 0.2/kWh (domestic) and USD 0.18/kWh (commercial) in 2019 (ERA, 2016, 2019). Similarly, the value of UGX has also depreciated against the USD from USD 1 = UGX 3,600 in March 2017 to USD 1 = UGX 3,718 in Oct 2019 (BOU, 2017, 2019a). This means, much more is required to procure one kWh of electricity in 2019 than it was in March 2017.

Additionally, most of the investigated enterprises especially those involved in munaanansi, wine, and juice making were dominated by use of firewood and charcoal. This could be due to the fact that, firewood can easily be obtained sometimes free of charge, yet other fuels such as LPG are more expensive in Uganda (Price, 2017). Similarly, the three stone firewood and traditional charcoal stoves could be preferred because they are relatively cheap to buy compared to improved ones. Their prices range from zero (for three stone stoves) to about USD 1.14 (for the traditional charcoal stoves) while improved ones range from about USD 4.56 to USD 51.3 (Price, 2017; SNV, 2014). Furthermore, it has been documented that three stone and traditional charcoal stoves are the most used stoves by the households in Uganda (Price, 2017; SNV, 2014). It is therefore not surprising that the same devices are frequently used by munaanansi, wine, and juice makers since these businesses are domesticated as already pointed out. That means what is applied for household cooking is also applied for munaanansi, wine, and juice making.

5.5 Characteristics of Pineapple Peels

The characterization of peels revealed some important parameters e.g. the pH of 4.7 is close to what has been reported elsewhere for pineapple peels (Kodagoda & Marapana, 2017), but indicates that pineapple peels are quite acidic, and this should be taken into account as alternative uses for the peels are sought. Regarding biogas generation for example, pH of 6.5 to 8.5 is recommended, so pH adjustment is needed if the peels are to be used for biogas generation. Indeed, anaerobic digestion is inhibited if pH is outside that range (Deressa, Libsu, Chavan, Manaye, & Dabassa, 2015; Waldron, 2007; Weiland, 2010). Similarly, the acidity level might need adjustment if the peels are to be used for animal feeds, depending on the target animals. This is because some animals especially ruminants prefer low acidic feeds. Therefore, fermentation and ensiling can be employed in order to reduce the acidity of the peels and improve their storability (Sruamsiri, 2007; Wadhwa & Bakshi, 2013). The average TS (18.38%) and MC (81.62%) are comparable to what was reported elsewhere on fresh pineapples and fruit waste in general (Nyamwaro et al., 2018; Vögeli, Lohri, Gallardo, Diener, & Zurbrügg, 2014). But, TS need to be adjusted to within 6-10% in case of biogas application (Deressa et al., 2015; Subramani & Kumar, 2016), while the VS are quite impressive for biogas generation. There is also an inverse relationship between TS and MC, so that to change TS, MC has to be adjusted (Deressa et al., 2015). However, TS are intrinsic characteristics of a material, and can be conserved in the process of adjusting the MC. Therefore, the characterization of Ugandan pineapple peels by this study contributes to the existing body of knowledge, and a basis for further research especially by those interested in providing alternative uses for the peels e.g. making animal feeds and fertilizers.

5.6 Material Flow and Energy Integration Diagrams for Pineapple Processing

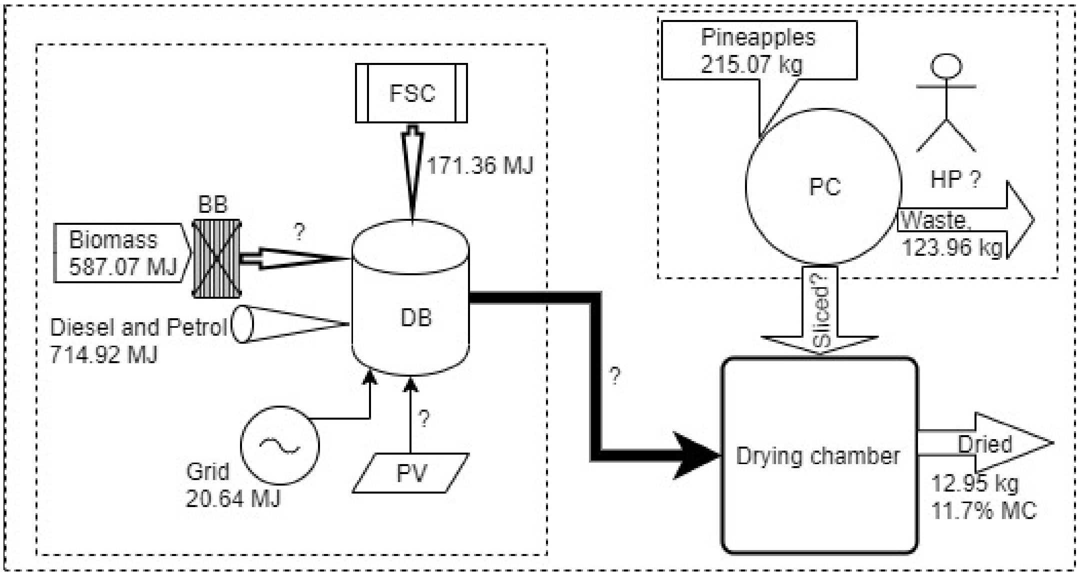
5.6.1 Introduction

This section illustrates typical examples on material and energy flow, and energy integration diagrams related to process evaluation and assessment performed on small-scale pineapple processing lines in central Uganda. Sub-section 5.6.2 exhibits some of the illustrations from process evaluation and assessments completed. Similarly, sub-section 5.6.3 contains demonstrations on some of the energy integration possibilities, which might be of interest to the processing lines investigated in this study, but also applicable to other SMEs.

5.6.2 Typical examples of material and energy flow diagrams for pineapple processing lines

Here, three examples coming out of the field interactions and measurements among small-scale pineapple processors are described. They are presented in form of material and energy flow diagrams, which can be very helpful in understanding the situation at hand and for illustration to the stakeholders. They are some of the immediate outputs expected at the end of any evaluation and assessment process. Therefore, material and energy flow diagrams for every pineapple processing line selected except for munaanansi were developed. In this sub-section however, only one example is presented on drying, wine, and juice making (Figure 5.5 – Figure 5.7). The rest are included in appendix C. The question mark indicates that a quantity or variable was not measured or derived due to limitations with equipment, and sometimes by choice. It is proposed that, effort is made to have most of those variables determined, and furnished to the stakeholders. Any decisions and steps towards resource use improvements would be informed by such reports among other considerations.

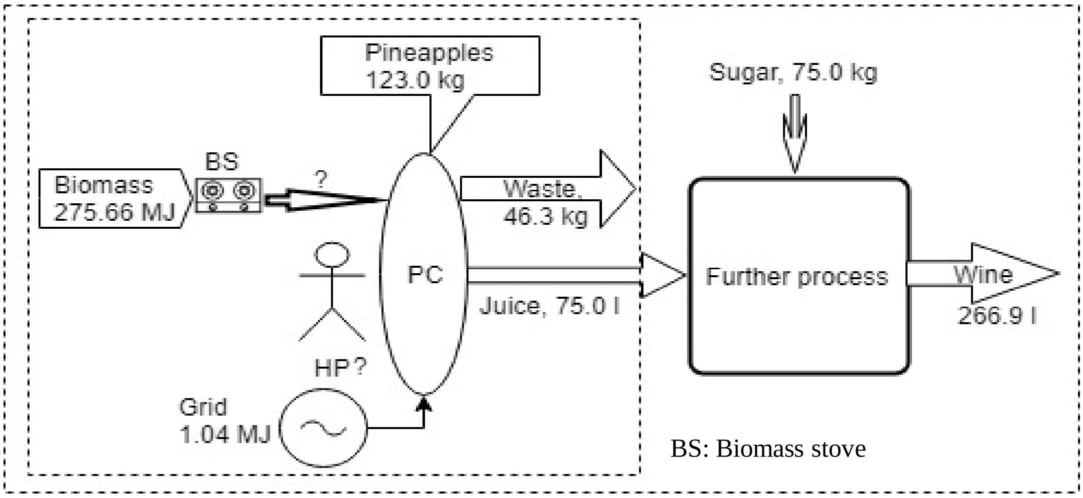
Example one (S01)



BB: Biomass burner, DB: Diesel burner, FSC: Flat solar collector, PC: Pineapple conditioning (e.g. peeling, slicing…), HP: Human power, and PV: Photovoltaic

Figure 5.5: Material and Energy Flow Diagram at S01 in Jan

Example two (W03)



BS: Biomass stove

Figure 5.6: Material and Energy Flow Diagram at W03

Example three (J03)

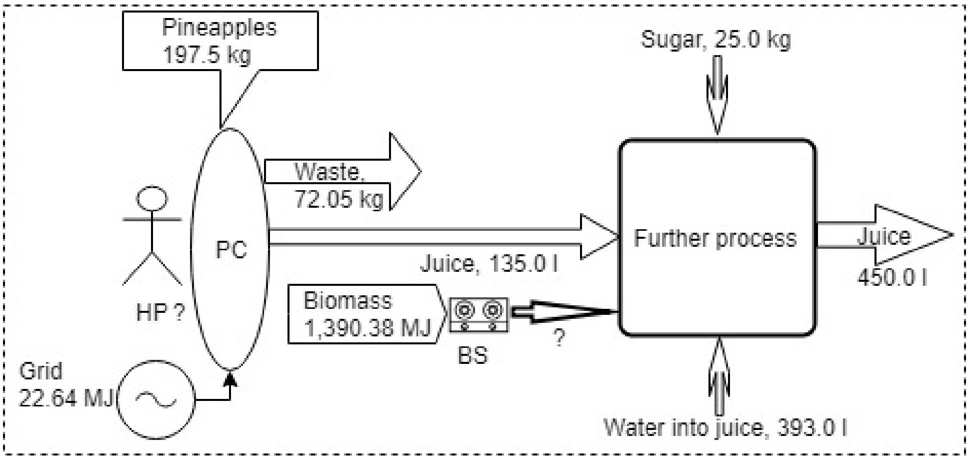


Figure 5.7: Material and Energy Flow Diagram at J03

These energy and material flow diagrams clearly indicate the various inputs and outputs at the various stages. Therefore, the particular figures can be compared with processor target levels or even against standard performance indicators. It is also possible to determine which inputs are required and consumed at each stage as well as the respective outputs, and resource efficiency. Similarly, the most resource intensive stages can be identified and the waste generated determined. If any resource improvement schemes were to be employed, the presented values are used as the benchmark, and easy to assess the effects of the interventions. Human power (HP) may also be computed based on known human energy capacity (Oyedepo, Olayinka, & Oladele, 2013; Ozkan, Akcaoz, & Karadeniz, 2004) although very variable especially for the investigated systems since some of them employ children and family members. Additionally, being home based businesses, not every individual involved in processing is fully committed to only processing. There is a tendency to multi-task home chores e.g. cooking and cleaning utensils. Therefore, the net number of hours spent on processing is relatively hard to estimate for the investigated enterprises.

5.6.3 Energy integration and hybrid energy systems for pineapple processing lines

In this section, the most salient possible energy supply and combinations for each of the processing lines are illustrated. Such illustrations are very important because they show the possible energy supply and utilization alternatives, which are the basis for any simulation and optimization steps. In fact, simulation would be impossible without such diagrams, which exhibit the existing and the possible energy supplies. As observed, simulation is a very strong tool for assessing proposed systems before actual implementation to limit loss and waste of resources (Frontline Systems, 2019; Mefteh, 2018). Therefore, energy supply and utilization diagrams (Figure 5.8 to Figure 5.10) were developed upon which simulations should be based. One of such diagrams is presented from each category (drying, wine, and juice), and the rest are placed in appendix D. Certainly, the findings clearly indicated that most processors use more than one source of energy although no interaction information among the various energy sources is known. Among winemakers for example, a processor uses electricity and biomass, but no connection linking the two energy sources. Indeed, it would appear that hybrid energy systems already exist, but with the current set ups, they fall short of ideal hybrid energy systems. In the diagrams, the existing supplies are represented with solid lines and the possible alternatives with dashed ones. Priority would be given to renewables during the implementation of alternative energy supplies but simulation results can play an important role in the eventual decision.

Example one (S02)

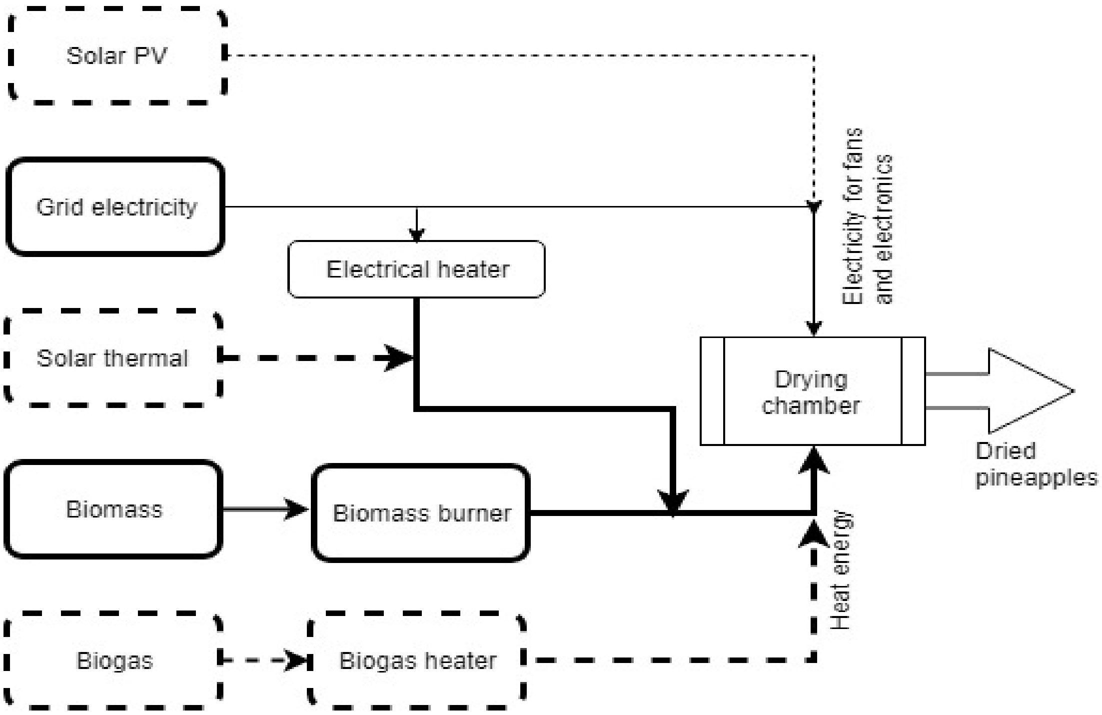


Figure 5.8: Possible Energy Integration and Hybrid System at S02

Example two (W03 and W04)

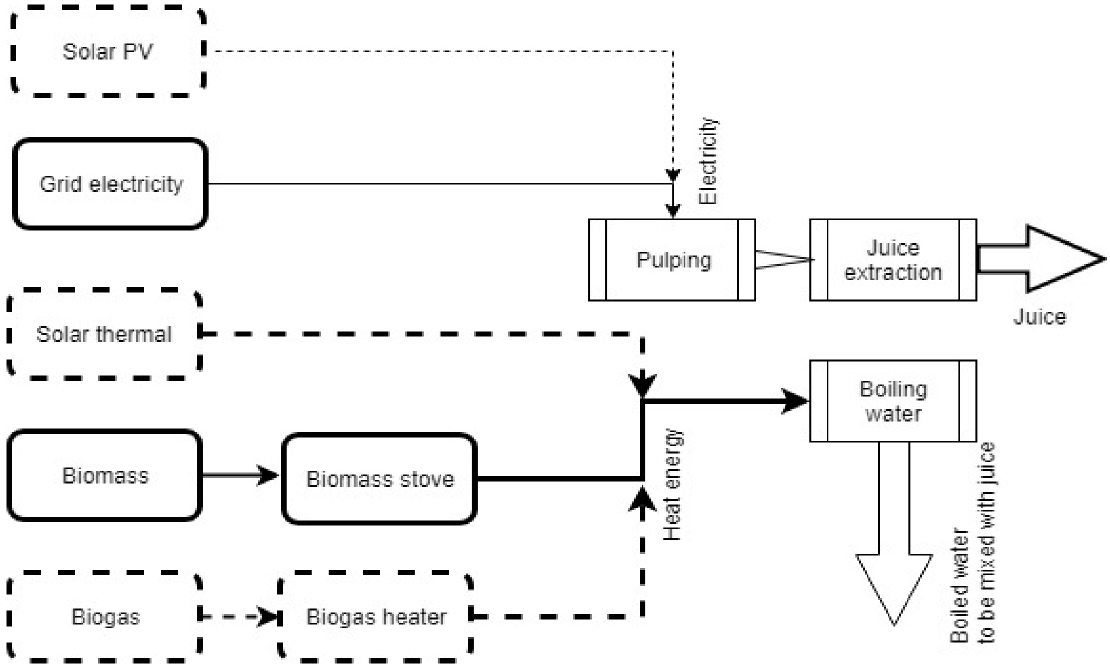


Figure 5.9: Possible Energy Integration and Hybrid System at W03 and W04

Example three (J02)

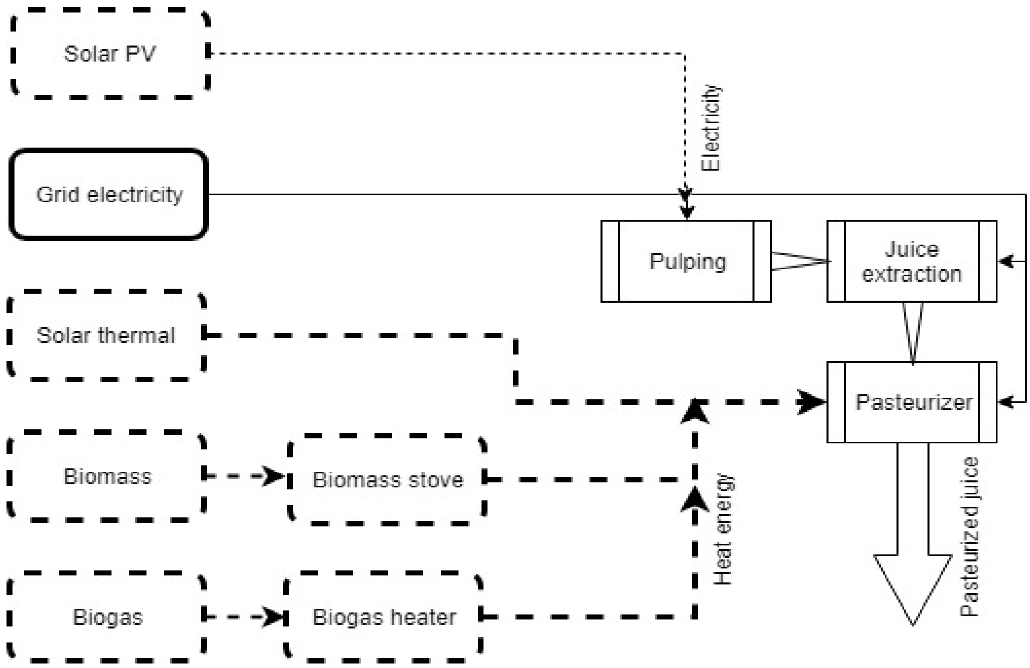


Figure 5.10: Possible Energy Integration and Hybrid System at J02

It is shown from Figure 5.8 to Figure 5.10 that hybrid energy systems or the concept of multiple energy supply to a single processing line is viable since they are already common practices among the investigated enterprises. The energy choice among the investigated processing lines is mainly based on affordability, personal incomes, availability of energy, applicability, and convenience. Some of such factors have already been cited as influencing energy choice in Uganda (Lee, 2013). However, the techno-economic aspect seem to be ignored among the investigated enterprises, yet it would provide for the best case scenarios in terms of optimal supply. The issue in focus would be the integration of renewable energy sources especially solar energy, which is readily available in Uganda (an average of about 5 kWh/m^2day) (Adeyemi & Asere, 2014; Ssennoga et al., 2016). This can be exploited in form of standalone PV systems, which provide for battery storage for application during bad weather and at night. While PV systems are still relatively expensive, their prices are coming down day by day, and a bright future for such systems can be predicted (Ssennoga et al., 2016). Additionally, the several low temperature applications such as drying, pasteurization, and water boiling make solar thermal quite attractive given that solar thermal collectors are relatively cheap and straight forward to apply (Mekhilef, Saidur, & Safari, 2011; Sturm et al., 2015). Innovative thermal storage solutions like the one proposed by a Makerere researcher (Okello, 2012) can be adopted for low temperature applications in order to provide thermal energy buffer in case of unforeseen bad weather conditions or even at night. The percentage of share in the energy mix for both solar PV and thermal will depend on entrepreneur's financial abilities and applications. The other emphasis should be put on the integration points e.g., the location of the thermal collectors and process, so that thermal losses are minimized by minimizing the distance between the collectors and processing points (Sturm, 2018). Similarly, proper insulation and proportionate sizing where the heat energy is to be delivered should be carefully considered e.g. at S01 where the diesel burner is relatively far from the drying chambers. This should be in line with new equipment and technologies, which might be required for proper integration with the existing ones. Some new technologies for example, come embedded with delicate electronics that require stable and reliable power supplies. Solar PV can be applied to such fragile components, otherwise, breakdowns are likely to result leading to undesired downtime (Mesa, 2018).

5.7 Evaluation and Assessment Framework for Small-scale Processing Lines

5.7.1 Introduction

This study proposes two generic assessment frameworks based on literature, field findings, and experience gained while working with small-scale pineapple processors in central Uganda. In sub-section 5.7.2, the main framework, which considers the entire processing line is described. A sub-framework whose focus is on energy is illustrated in sub-section 5.7.3. Particular attention is put on energy since it is one of the major driving factors to process modernization and mechanization, and a key consideration across processes. Additionally, energy supply and utilization is very important in order to achieve sustainable processing especially at a time when fossil fuels are getting depleted globally (Zeng et al., 2011). While literature was very informative in developing the proposed frameworks, the layout and flow of activities are entirely the author's brainchild based on practical steps taken during data and information collection among pineapple processors. To the best of the author's knowledge, there is no single source, which provides the guidelines and frameworks particularly for small-scale processing lines. It should also be noted that simulation and optimization are a focus of the proposed frameworks. In other words, the adoption of software packages in process assessment is paramount in order to forecast the expected impact due to proposed changes. Furthermore, the proposed frameworks were developed into a single desktop application for easy access and convenient practical use. However, due acknowledgement is given in the description of the various framework steps since a number of authors have already pointed out similar steps.

5.7.2 The proposed main process evaluation framework

The main steps involved in the evaluation and assessment of small-scale processing lines are illustrated in Figure 5.11, and details of each step are described thereafter. The information collection (block B) should be performed at least three times for each selected enterprise before final analysis and proposal of modifications. This means, further considerations and decisions will be based on average values in order to better represent the performance of the processing line.

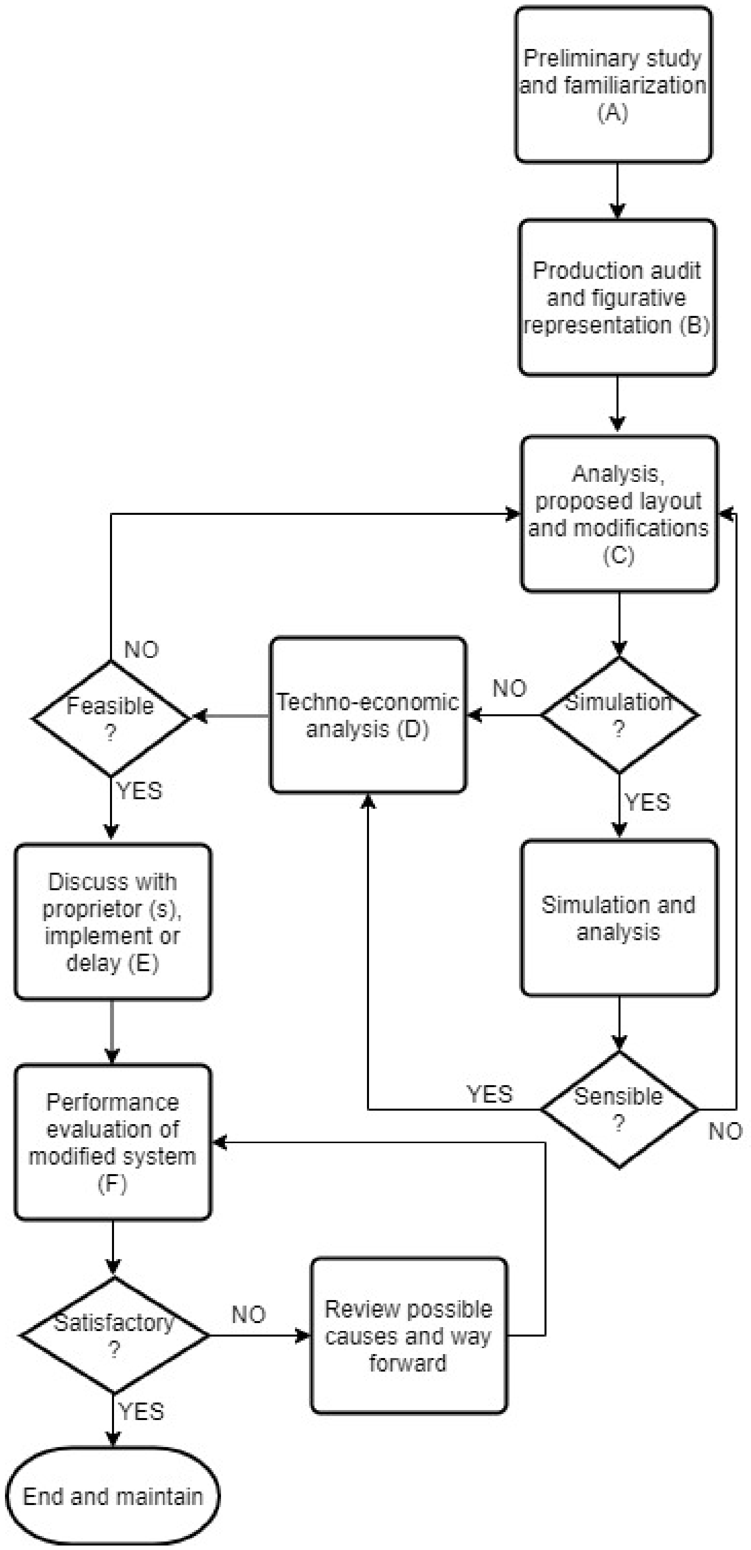


Figure 5.11: The Main Process Evaluation and Assessment Framework

Details of activities in the labeled sections or blocks (main framework)

A: Preliminary study and familiarization

I. Site visit(s), visual observations, interviews and interactions with the main stakeholders such as proprietor(s) and operators.
II. Identification of major processing stages, players, main equipment and their location.
III. Pinpoint the energy supply sources and forms, and preparation for the next step (production audit).
IV. The production audit can be the standard or basic one intended to measure the key variables in the process (Drew, 2017). This should be clearly stated before preparation so that the requirements for the exercise are obtained in advance, and all stakeholders brought to speed with the exercise (Chaneski, 1998; Drew, 2017).

B: Production audit and figurative representation

I. Site visit(s) during production audit, formal and informal conversations and interviews, and visual observations during processing (Sturm, 2018).
II. Carryout actual measurements of the various inputs and outputs at each stage (e.g. fruits, water, energy, and other ingredients).
III. Estimate the generated waste and any other material losses.
IV. Determine the state of the waste (solid, liquid, or gas), and identify waste disposal mechanisms being employed.
V. Establish the alternative uses for the waste.
VI. Assess the current level of automation and mechanization, weaknesses, and other related information. The set targets before starting the audit should guide all activities at this stage.

C: Analysis, proposed layout and modifications

I. Analyze the collected information especially after multiple times (e.g. using statistical methods, graphs, and pie charts) and interpret what it means in terms of process performance (e.g. SEC and USD/output).
II. Represent the main collected and analyzed information and data on a flow diagram (material flow diagram) with actual figures at major stages in the process.
III. Assess the possibility of automation or semi-automation, possible modifications on current set up, resource (especially water and energy) re-use and recovery, and present the schematic of the proposed layout.

IV. At this point, a decision has to be made; if the proposed layout cannot be simulated, go to block D, otherwise, perform the simulation.

V. If the overall results from the simulation are positive (based on set indicators), proceed to block D, and if not, review analysis and proposed layout. The suitability for simulation should be based on but not limited to whether there exists simulation software to implement the proposed layout or the components can be modelled in other software or implemented using other programming languages, the cost, and time implication of the simulation, and whether linear or non-linear components or subsystems.

D: Techno-economic analysis

I. Consider the human capacity and main equipment required to implement the proposed layout. Perform economic analysis, for instance using net present value (NPV), internal rate of return (IRR), and simple payback period (PBP).

II. If not feasible, return to analysis, modifications, and proposed layout; else, proceed to E. NPV, IRR, and PBP are determined using standard mathematical equations illustrated in equation 5.1 to 5.4 (Drury, 2008; Meyers et al., 2016; Ruppert, Kappas, & Ibendorf, 2013).

$$NPV = -I_0 + \sum_{t=1}^{t=n} \frac{NCF_t}{(1+r)^t} \quad \text{.......} 5.1$$

$$IRR = NPV = -I_0 + \sum_{t=1}^{t=n} \frac{NCF_t}{(1+r)^t} = 0 \quad \text{.......} 5.2$$

$$PBP = \frac{I_0}{NCF} \quad \text{.......} 5.3$$

where I_0 is the initial investment cost, NCF_t is the net cash flow in time t (usually year), NCF is annual net cash flow (equal for every year of the investment), r is the discount rate, t is the time (year) for a particular cash flow, and n is the time period for the cash flows or life span of the investment.

When the net annual cash flows are uneven (unequal), cumulative cash flow per year may be determined and equation 5.4 used to evaluate PBP. Alternatively, graphical methods may be employed to determine PBP (Lang & Merino, 1993).

$$PBP = X + \frac{Y}{Z} \quad \text{.......} (5.4)$$

where X is the last year number with negative cumulative cash flow, Y is the magnitude of the cumulative cash flow at the end of year X, and Z is the actual net cash flow for the year after X.

E: Discuss with proprietor(s), implement or delay

I. Share with the proprietor(s) (IEA SHC, 2015), outline main requirements especially human capacity and equipment, financial commitment, expected benefits, challenges, and probable implementation approach (e.g. in stages or at once).

II. Receive and document feedback from the proprietor(s) and main stakeholders, and allow independent decision. The proprietor(s) may choose to implement, delay implementation or reject; but on implementation, proceed to F. If simulations were carried out, then the explanation to stakeholders is more illustrative than simply being imaginative.

F: Performance evaluation of modified system

I. Assess performance in terms of the main performance indices (e.g. SEC, USD/output, quality and quantity of output), document lessons learnt, challenges so far, and areas for improvement. May also compare current performance against the performance before; if the performance is not sufficient, review the main causes, discuss with proprietor(s), and outline the way forward for better performance.

II. Otherwise, stop but encourage the operators to maintain the status and where possible keep improving the performance.

Some authors have proposed similar categorization of steps e.g. selection of an audit team, pre-feasibility, feasibility, analysis, data acquisition, to mention but a few, where each category involves various activities (Drew, 2017; IEA SHC, 2015; Sturm, 2018). In such cases, energy assessment would lie under one of the categories, and the target is generally relatively large enterprises. However, there are several crosscutting issues, which must be addressed irrespective of the size of the enterprise. The goal is to ensure optimal utilization of resources while meeting customer expectations (Chaneski, 1998; Sturm, 2018). In this study, deliberate effort was made to be more specific and particular in addressing assessment approaches for small-scale enterprises. Transforming the proposed frameworks into “soft copies” is an added advantage, which is likely to encourage process evaluation and assessment although the required equipment might be among the main hindrances.

5.7.3 The proposed energy supply and utilization assessment framework (sub-framework)

This sub-framework describes the evaluation and assessment of energy utilization in small-scale processing lines. It is illustrated in Figure 5.12, and the related description of the various blocks follows. A processing line may choose to start with the general evaluation (following the main framework), where the entire processing line is evaluated for resource use efficiency, which would also include the energy use evaluation. Such an approach would be the recommended one especially with small-scale processing lines. However, the energy evaluation (energy audit) may be carried out independent of the general process evaluation (Dongellini, Marinosci, & Morini, 2014; Kluczek & Olszewski, 2016), and what is described here is deemed as the most relevant for such an assessment. In a similar manner, this sub-frame is developed with hints from the general guidelines and procedures recommended for energy audits. Energy audit is one of those concepts that have been discussed and applied in reality, although the tendency is to focus on relatively large enterprises. In fact, some policy instruments do not make it obligatory for SMEs to perform energy audits e.g. the European Union (EU) Energy Efficiency Directive 2012/27 (Schleich & Fleiter, 2019). Indeed, energy audit can also be broken down into main steps e.g. preliminary audit, detailed audit, further audit, to mention a few, but the overall goal is to ensure efficient utilization of energy. It ensures continuous monitoring and periodic evaluation of energy use (Dongellini et al., 2014; Kluczek & Olszewski, 2016). The actual energy consumption measurements, analysis, and determination of SEC should be carried out at least three times. The final assessment should be based on the average values obtained from the various assessments.

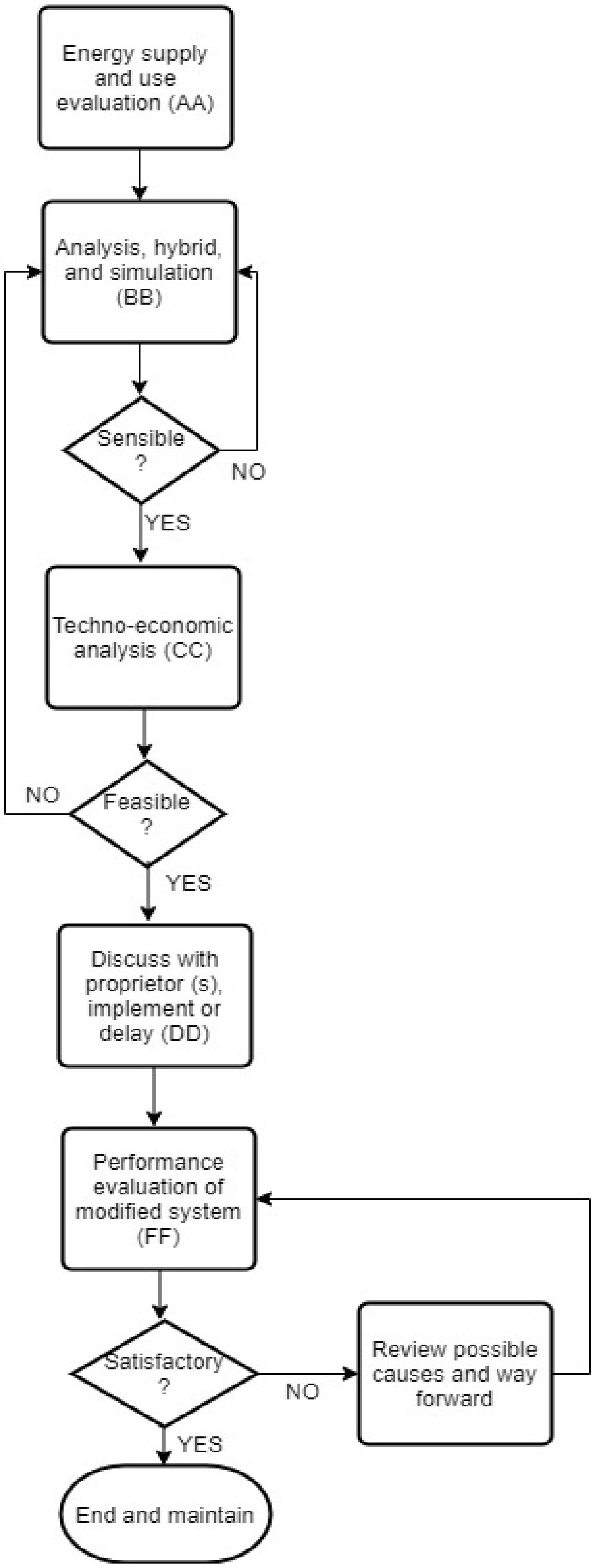


Figure 5.12: The Energy Evaluation and Assessment Framework

Details of activities in the labeled sections or blocks (sub-framework)

AA: Energy supply and use evaluation

I. Identify and document current energies applied (Wong & Lee, 1994), all energy consuming devices, energy needs, and opportunities.

II. A quick walk through the processing enterprise may be performed before the actual detailed assessment (Dongellini et al., 2014; Kluczek & Olszewski, 2016) although can be combined with detailed audit for small-scale processing lines.

III. Determine the actual energy consumption (MJ or kWh), energy cost from each of the sources, SEC, EE of existing equipment, and current EE and conservation measures.

IV. Identify the possible alternative energy sources, possible EE and conservation measures, current energy use behavior and EE awareness. Similarly, identify the energy intensive processes or equipment and their respective daily, weekly, or monthly consumption, and clearly describe the energy flow and type at every stage of the processing line, indicating the exact amount used from stage to stage.

V. Establish the main and supplementary energy supplies if any, and possibility for alternatives.

VI. The previous energy bills should be reviewed and related to the identified energy intensive processes or equipment.

BB: Analysis, hybrid, and simulation

I. Evaluate the possibility of using only single renewable source or a combination (renewable hybrid).

II. Consider mixed hybrid e.g. grid power in combination with renewables, and energy recovery possibilities.

III. Determine where modern energy e.g. electricity can have the greatest impact and expected cost especially where the enterprise mostly depends on traditional sources of energy e.g. firewood.

IV. Show at what points new energy supplies and machinery can be introduced, and the expected integration challenges. Simulations can be done to evaluate how the proposed energy supply alternatives would interact and what would be the impact on the major performance indices e.g. SEC.

V. Optimization can also be done to choose the most sensible alternative, and if the results are positive, proceed to CC, otherwise review the suggested options.
VI. Assess any energy saving and conservation opportunities, and requirements if they are to be pursued.
VII. Outline the possible energy conservation and saving awareness themes to be shared with the decision makers and stakeholders.

CC: Techno-economic analysis

I. Consider human capacity and the main equipment and integration required.
II. Base financial viability analysis on NPV, IRR, and PBP (equations 5.1 to 5.4) criteria. Such financial assessments are very important in informing decisions and policies for appropriate action (Drury, 2008; Gebrezgabher, Meuwissen, Prins, & Lansink, 2010; Ruppert et al., 2013).
III. If not feasible, review suggested changes and modifications, else, proceed to DD.

DD: Discuss with proprietor(s), implement or delay

I. Share with the proprietor(s), outline the main requirements especially human resources and equipment, financial commitment, expected benefits, challenges, and probable implementation approach (e.g. in stages or at once).
II. Analysis and related assumptions leading to the stated benefits and energy savings should be clearly described.
III. Receive and document feedback from the proprietor(s) and main stakeholders, and allow independent decision. The proprietor(s) may choose to implement, delay implementation, or reject; but on implementation, proceed to FF.

FF: Performance evaluation of the modified system

I. Assess performance in terms of the main performance indices (especially SEC), lessons learnt, challenges so far, and areas for improvement. May also compare current energy performance against the performance before; if the performance is insufficient, review the main causes, discuss with proprietor(s), and outline the way forward in order to achieve the desired or acceptable performance.
II. Otherwise, stop but encourage the operators to maintain the status and where possible keep improving the performance.

Some of the above steps have been suggested and applied by a number of authors. It is mainly the emphasis and focus that differs among authors and implementers. Sometimes it also depends on the motivation and background to the energy audit e.g. company initiative or government policy. Therefore, variations are normally observable while discussing and implementing energy audit procedures (Andersson et al., 2016; Dongellini et al., 2014; Krarti, 2011; Kumar, Ranjan, Singh, Kumari, & Ramesh, 2015; Sturm et al., 2013).

5.8 Energy Reduction Concepts in Pineapple Processing

The discussions are concluded by considering the possible options for reducing energy use in the pineapple processing lines in central Uganda. It was observed that the GoU through the Ministry of Energy and Mineral Development (MEMD) in collaboration with its development partners took up energy use reduction concepts after realizing that improving energy access by only increasing supply was not sustainable (de la Rue du Can, Pudleiner, Jones, & ALeisha Khan, 2017). From such realization, a number of energy use reduction models have been introduced focusing on EE among domestic and industrial energy consumers. Initiatives such as Sustainable Energy for All (whose core focus was on EE) were born out of such recognition that only expanding supply may not be the only solution to ending energy poverty in Uganda (de la Rue du Can et al., 2017).

With the zeal to arrest the then acute situation in electricity availability and accessibility in Uganda, the GoU embarked on both demand and supply side management from about 2004. In partnership with its development associates e.g. United States Agency for International Development (USAID), they engaged into sensitization and awareness campaigns among domestic electrical users about EE (de la Rue du Can et al., 2017). About 2006, an enhancement to the process was introduced of replacing the traditional incandescent filament lamps (IFLs) with compact fluorescent lamps (CFLs) targeting domestic users. It was assumed that CFLs consumed 70 – 75% less than IFLs with a life span of 10 – 13 times that of IFLs. Typical IFLs were assumed to waste over 90% of the energy they consumed in form of heat. In the project, each domestic user (in selected areas) was required to surrender three IFLs in exchange of three CFLs. In circumstances where users had more than three IFLs, they were advised to buy CFLs and replace the rest of IFLs on their own (DCI & CREEC, 2007). On evaluation of the project after about 10 years, it was established that the program had reduced power demand by 32 MW at an investment cost of USD 0.5M per MW. It is reported that, this was more than 50 times cheaper than investing in a new baseload hydropower plant (de la Rue du Can et al., 2017; de la Rue du Can, Pudleiner, & Pielli, 2018). A similar project was implemented in Kenya and Ghana with funding from UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS). The evaluation of the project rated it as having been successful in the two countries (Byrne, 2013). A related project funded by the World Bank targeted industrial and commercial energy users in Uganda for EE in 2009 (Okoboi & Mawejje, 2016b). It involved power factor correction, and resulted into a reduction of energy demand by 8.6 MW. It also stimulated the establishment of EE consultancy firms in Uganda (de la Rue du Can et al., 2017). With more efficient and durable devices especially for lighting e.g. Light Emitting Diodes (LEDs) on market, EE can become a reality not only in Uganda, but in many developing countries (Byrne, 2013).

The other area of intervention where the GoU, development partners, and private sector have put a lot of emphasis is cooking stoves for domestic application. This goes as far back as 1980s stimulated by increasing population, which was putting a lot of pressure on forest and forest products. Many households were depending on fuelwood collected from forests, which resulted into deforestation, and a threat to the future generation. Moreover, most of them were using very inefficient cook stoves especially the three stone firewood stoves whose efficiency can be as low as 3% (Wallmo & Jacobson, 1998). This definitely had long term impact not only to the forest resources, but also to human health due to indoor pollution, which contributes to about 3.3% of disease burden globally (Lewis & Pattanayak, 2012). Efforts to halt the situation were engaged through sensitization and distribution of free improved cook stoves, which were thought to have better efficiency and ventilation to reduce on indoor pollution. The dissemination approach was later criticized because it was not self-sustaining (Kees & Feldmann, 2011). Additionally, monitoring and evaluation was not a core element of the drive such that the bad and good, plus areas for improvement were difficult to enumerate (Wallmo & Jacobson, 1998). However, this did not totally suffocate the long term goal of the initiative. In fact, to date (2020), there are many cook stoves on market e.g. Makiri hybrid, Makastoves, Ugastoves, to mention but a few, which are said to be fuel-saving up to 50% (GVEP, 2012; SNV, 2014; T4T, 2015) although the three stone stoves are still applied. Additionally, the intervention approaches have also changed to become more community centered and participatory e.g. the one adopted by German International Cooperation (GIZ) (the then German Technical Cooperation (GTZ)) (Kees & Feldmann, 2011). In this project, GIZ successfully implemented an energy saving stove project in Uganda on behalf of the German Federal Ministry for Economic Development and Cooperation. It was co-funded by the Dutch government and part of the wider Ugandan-German ‘‘Promotion of Renewable Energy and Energy Efficiency Programme’’ (PREEEP) (Kees & Feldmann, 2011). It started from one district of Bushenyi in 2004, and later expanded to several districts in Uganda. A Rocket Lorena stove (similar to the one showed in Figure 5.13) was developed mainly from local material.

Figure 5.13: Rocket Lorena Wood Stove (Source: Google Images)

The project trained several rural trainers from various Non-Governmental Organizations (NGOs) who later trained local artisans in making the improved stove. Thereafter, the trained artisans built stoves on demand and got paid by the households that contracted them. GIZ further monitored and evaluated the project. Similarly, GIZ supported the setting up of a testing center at Makerere University known as Centre for Research in Energy and Energy Conservation (CREEC) where continuous research and development of efficient cooking stoves is carried out (Kees & Feldmann, 2011). This project became self-sustaining, and a number of benefits have since accrued from its implementation e.g. time saving of seven hours per week on cooking and collection of firewood. There are also several health benefits such as reduced respiratory diseases and eye irritation especially among women and children (Habermehl, 2007). It was implemented in close cooperation with MEMD, and over 500,000 households started using the improved rocket stove (Kees & Feldmann, 2011).

It can be noted from the above interventions that, a lot of focus has been on domestic and industrial users to some extent without much emphasis on SMEs, yet they significantly contribute to Uganda’s economy. They actually contribute about 75% to Ugandan GDP, and consume significant amount of energy in the long run (Kirabira, Nalweyiso, & Makumbi, 2014). Therefore, this research complements the existing efforts by suggesting some energy use reduction ideas with emphasis on small-scale processes. They are based on literature, fieldwork, and interaction with pineapple processors but might be applicable across different small-scale processors at similar processing levels. While the list may not be exhaustive, what is pointed out here is considered to be the most relevant to the investigated pineapple processing lines. Additionally, the energy consumed by such processors may not be high looking at the individual energy consumption, but their aggregated consumption can be significant, and their consumption actions may greatly impact the environment and ecosystem. A similar argument has been raised about the energy consumption for SMEs whose individual consumption is low but with a combined demand of over 13% of total global energy demand (Henriques & Catarino, 2016). The other point of view is based on the fact that, the energy bill actually "eats" up the would be profits, so that a reduction in that bill might translate into more profits (UMEME, 2018). It is therefore prudent to suggest some energy reduction ideas deemed most relevant to the investigated enterprises. In general, four concepts are advanced, which may not necessarily require a lot of funds to implement, but rather concentrate on issues of staff awareness, trainings, and behavioral change in energy utilization. Moreover, most of the investigated enterprises already utilize renewables to a large extent in their processing stages especially biomass although using inefficient conversion devices e.g. the three stone firewood stove. Therefore, the energy use reduction suggestions focus on equipment, application, and behavior.

I) Application of improved cook stoves. This is mainly applicable to those who perform heating and cooking using the three stone firewood and traditional charcoal stoves e.g. munaanansi, wine, and juice makers. The approach should target various small-scale processors who depend on biomass for their energy needs while using the already known inefficient conversion devices especially the three stone stoves (Hafner et al., 2018). The strategy employed by GIZ (IMC Worldwide, 2014) should be adopted starting with awareness, sensitization, and target group participation. Thereafter, at least three suitable processing enterprises should be selected for their respective sites to be used as demonstration sites. But, individual enterprises may also mobilize their own resources and implement improved stoves. Improved stoves that use locally available materials should be chosen for this purpose e.g. the Rocket Lorena stove, where users can easily get trained in its construction, hence a possibility of constructing new ones especially when the demonstration ones get damaged (Kees & Feldmann, 2011). USSIA can mobilize and take the lead since it is already working closely with these enterprises doing a lot of training and awareness workshops (USSIA, 2011). However, the prospective users and proprietors should be actively involved in the implementation through hands-on participation and provision of material required for the construction of the stoves. In doing so, they are likely to own them and handle them with the care they deserve to last the anticipated life span. Additionally, the selected stove should have a high fuel saving rate e.g. the ones reported to save over 50% of fuel (Habermehl, 2007; SNV, 2014). This reduction in fuel consumption comes with several direct and indirect benefits such as the reduction of indoor pollution and disease burden especially among women and children (Lewis & Pattanayak, 2012; Rosa et al., 2014). In terms of direct benefits, a saving in fuel translates into financial saving since less will be spent on buying fuel per processing. This can be demonstrated by considering one case of munaanansi maker P01.

Recall: On average, P01 consumed 17.83 kg of firewood per processing cycle at a unit cost of USD 0.07/kg.

Assumptions

P01 prepares munaanansi 5 times per week (20 times per month or 240 times per year), and the output (munaanansi) per processing is the same as the current average and remains constant.

The improved stove may be used for preparing meals for 5 people (based on average size of Ugandan household) (UBOS, 2014). Hence replacing the three stone stove assumed to consume 6 kg of firewood for cooking per day (Habermehl, 2007).

The average fuel saving rate for the selected improved stove is assumed to be 30% although some stoves e.g. the Rocket Lorena stoves are said to save up to 55% (Habermehl, 2007; SNV, 2014). However, it is reported that the field test results of cooking stoves tend to be poorer than the laboratory test results, thus the conserved nature of the assumed fuel saving rate in this estimation (Rosenthal, Quinn, Grieshop, Pillarisetti, & Glass, 2018).

The initial cost of the improved stove is USD 8 (SNV, 2014) with the life span of the stove assumed to be four years (Habermehl, 2007).

The annual savings on firewood are the same for each of the four years, and taken as the annual cash flow.

The unit cost of firewood does not change over the four years, and no maintenance and operational costs are involved.

Discount rate applied for NPV calculation is 10% based on Bank of Uganda (BOU) Central Bank Rate (CBR), Apr 2019 (BOU, 2019b).

Therefore, Table 5.6 compares firewood consumption by a three stone stove and an improved one of assumed fuel saving rate of 30%.

Table 5.2: Comparison of Firewood Consumption between Three Stone and Improved Stove

Firewood Application	Three stone stove (kg/year)	Improved Stove (kg/year)	Fuel Savings (kg/year)
On munaanansi	4,279.2	2,995.44	1,283.76
On Meals	2,190	1,533	657
Total	6,469.2	4,528.44	1,940.76

Case I: improved stove used for munaanansi making only (no cooking meals).

Total saving per year: USD 89.86

NPV: USD 276.84

PBP: USD 0.09 years or 1.1 months

Case II: improved stove used for both munaanansi making and cooking meals for a household of five people (most likely case).

Total saving per year: USD 135.85

NPV: USD 422.63

PBP: USD 0.06 years or 0.7 months

The NPV for both cases is positive, and the simple payback period (PBP) is under one year (about one month). This means, the investment makes sense and can be implemented (Meyers et al., 2016; Ruppert et al., 2013). Furthermore, assuming one of the most expensive improved stoves of USD 50 (SNV, 2014) was chosen, while keeping the other assumptions constant. The following would have been the NPV and PBP for case I: NPV (USD 233.84) and PBP (0.6 years). These are still attractive even without considering the other associated health and environmental benefits e.g. reduced deforestation. Therefore, replacing inefficient biomass stoves with improved ones is feasible and economically sound.

II) Measurement and understanding of the energy flow at every stage of the processing line.

This is very important especially to the operators of energy consuming devices or systems, who should measure and have a better understanding of what is measured during processing. It includes energy education such that the persons in charge of the processing line can trace the energy flow and know how much energy is used at each stage, for what, and where it comes from. Such persons should fully understand the measured energy quantities and communicate to the rest with the level of credibility required. They should be able to make informed energy decisions based on their understanding and anticipated consequences. If for instance, the output at a particular stage is 10 units and energy consumption is say 5 kWh or 20 kWh, what does that mean, and how does it affect the process, and cost of the final product. They should be well versed with the main performance indicators, so that they are able to advise the decision makers from a knowledgeable position. Such practices are in line with some of the recommended best practices related to energy use and management although many energy users are still weak in adhering to them (Henriques & Catarino, 2016; Kirabira et al., 2014). Indeed, the current "careless" tendency by the operators could be one of the causes for energy loss, and the operators tend to execute their routine duties without any form of personal input for the betterment of the process. Certainly, someone running a biomass burner in an open burning mode (S02) without being bothered by how biomass is being wasted can be unfortunate. Interaction with operators seemed to suggest that they are actually unconcerned, and since biomass is always available at someone else's cost, they rarely pay attention, thus continue such practices. It was also noted that biomass is generally less expensive in Uganda, and sometimes collected free of charge (SNV, 2014) and thus, usually ignored in the processing cost estimation. Additionally, they cannot cost what they do not measure, so they must set their minds to measuring fuel and energy consumption first, and in the end cost it. Even when the direct energy cost is disregarded, there are other indirect costs e.g. the environmental and health costs resulting from extensive combustion of biomass using relatively poor conversion devices (Kees & Feldmann, 2011; SNV, 2014). Therefore, the reduction of energy consumption does not only reduce the energy bill but also contributes to conserving the environment and health improvement (Kees & Feldmann, 2011; Lewis & Pattanayak, 2012; SNV, 2014). The ideas under this concept feed quite well into the concept of applying devices that are more efficient since operation and maintenance are key determinants in the performance of devices. In other words, even the so-called efficient devices must be operated and maintained as per specifications in order to attain their respective efficiencies (Darabnia & Demichela, 2013). This intervention may not require a lot of financial commitment, but mainly soul-searching, awareness creation, and responsible behavior. It is also possible to consider replacing some of the current energy supply sources especially biomass for drying with solar thermal in form solar air heaters. However, economic analysis needs to be performed in order to determine the economic viability status of the proposed alternatives. To illustrate this point, solar air heaters are proposed to replace some of the firewood being used at S02.

Recall: S02 derives about 208.5 kWh (82.67 kg) from firewood at a unit cost of USD 0.02/kg. The goal is to reduce this firewood consumption by using solar thermal from solar air heaters. One of the constraints is the roof where to mount the air heaters in order to minimize space and mounting costs.

Several solar air heaters are available for sale in China, but this analysis was based on the vacuum solar collector with the following details. Model Number: IPRB E-B, Collector area: 2 m^2, Transmittance of glass: 87%~91%, Conversion efficiency: 77.3%, and made in China, at a cost of USD 86 per piece (Free On Board - FOB).

Assumptions

Ten units (panels) equivalent to 20 m^2 (to be mounted on the roof housing the dryer, store, and offices).

Average solar radiation of 600 Wm^{-2} per day, and 6.5 sunshine hours per day.

Total cost including transport to Uganda and installation of one unit is USD 120 (USD 1,200 for ten units).

Zero maintenance cost, and life span of 15 years for the panels.

Savings on firewood per year is taken as net cash flow and the same for 15 years.

The processor dries four times per week or 192 times per year.

Discount rate applied for NPV calculation is 10% based on BOU CBR, Apr 2019 (BOU, 2019b).

Thus collected solar thermal energy per day at transmittance of 87%: 67.86 kWh (244.296 MJ), which is equivalent to 26.9 kg of firewood (saved per processing).

Firewood saved per year: 5,164.8 kg/year, and financial savings per year: USD 103.3/year.

NPV: USD -414.29 and PBP: 11.62 years.

The NPV derived is negative, which suggests the investment is not economically viable. In fact, even when the average solar radiation intensity is assumed as 700 Wm^{-2} per day, the NPV remains negative (USD -283.47). This could be because this particular enterprise buys firewood relatively cheaply, thus minimum savings per year. In fact, if the enterprise were buying firewood at the same cost (USD 0.07/kg) as munaanansi maker P01 or drying enterprise S01, the following would have been true. Annual savings: USD 213.76, NPV: 425.88, and PBP: 5.6 years; thus viable investment. Therefore, the cost of fuel is very influential in the overall economic performance of the enterprise. So, this particular enterprise would not be advised to invest in replacing some of the firewood (at its current cost) with solar air heaters based on the direct benefits of savings on firewood and considering only NPV economic evaluation criterion (Meyers et al., 2016; Ruppert et al., 2013). To the contrary however, the PBP at current fuel cost suggests that the initial investment can be recouped within the life span of the air heaters (after about 12 years), hence viable investment. But, it should be recalled that, PBP has been criticized especially for ignoring the time value of money, and some argue against it as a criterion upon which investment decisions should be based. The critics consider it as quite unreliable and misleading. Nevertheless, it is simple, widely used, and very relevant in giving a quick overview of an investment opportunity. It is advisable that it is used hand-in-hand with other evaluation criteria especially NPV (Lang & Merino, 1993; Lefley, 1996; Woodruff, 2019).

Additionally, other indirect benefits such as reduced emissions and deforestation can be brought into the whole picture of the evaluation. However, decreasing deforestation may not be very relevant in the current scenario since the enterprise makes use of the would be waste from timber lumbering. The enterprise collects timber cut-offs directly from the forest, and probably why relatively cheaper. So, whether they collect it or not may not effectively influence the primary purpose of logging, which is obtaining timber for the various applications such as house construction and making furniture. But indirect benefit consideration can be an additional evaluation procedure for projects whose NPV is zero or negative but close to zero (Lang & Merino, 1993; Lefley, 1996; Woodruff, 2019). Certainly, all such analysis and argument are stimulated by measurement and understanding of energy consumption in the processing line. In other words, it is practically impossible to perform such assessment without the support of figures e.g. energy consumption, cost, and other variables.

III) Improving energy monitoring and measurement. There is generally no energy monitoring and measurement in the current pineapple processing setups. For instance, those who use grid electricity e.g. at S01 have single main meters, which record the total electrical energy consumption for the whole processing plant including offices. There is therefore no way of determining the energy intensive stages, which makes it impossible to come up with appropriate measures to reduce energy consumption. It is also impossible to determine the actual amount of energy consumed by the drying system for example. This further affects the estimation of the contribution of the drying process to the energy bill. Monitoring and measurement of energy can be implemented especially at S01 (where the processing area is physically separated from the office area) by providing a separate sub-meter for the processing line or several sub-meters at key strategic positions or stages. For instance, the drying system, preparation room, and packaging room can be installed with independent sub-meters to measure their respective energy consumption. However, the staff need to have the capacity to read the meters, analyze, and relate to the main energy bills issued every month by the distribution company. The current main meter should not be tampered with, but only sub-meters be added at selected locations. A similar scenario exists among biomass users, where sometimes the same delivery of firewood for instance is used for preparing food and the actual processing. It is therefore difficult to pin point to the definite consumption by the process. Such energy consumption behavior does not help the desire for knowledge on existing performance and how to improve the status. It is indeed possible that most of the energy consumption and wastage takes place somewhere else, not in the actual processing line. This concept emphasizes the recording of units consumed per processing cycle or per month and the cost involved. It feeds into the second one where understanding the measured energy quantities is pointed out. For electrical energy in particular, the tariffs in Uganda are adjusted every three months (quarterly) under the oversight of Electricity Regulatory Authority (ERA) of Uganda (ERA, 2018; U.S. Embassies Abroad, 2019). Therefore, the tariff changes should be closely monitored, and correlated with the issued bills. There are also possibilities of power tapping from neighbors where neighbors may connect to the enterprises' power network leading to unrealistic bill to the affected processing enterprise. Monitoring and measurement, plus keen analysis of the bill can easily detect such anomalies, and appropriate steps can be taken to avert the situation. Such intervention may not require a lot of financial commitment since it is built and complements the existing measurement system.

IV) Use of natural daylight. Due to sanitary and hygienic requirements, processing rooms and areas must be tightly closed to avoid entrance of animals, flies, insects, and dust in order to minimize contamination of the food being processed. Additionally, potable running water should be readily available to the handling and processing line (Dong & Jensen, 2008; Holah, 2014). While many processors rarely adhere to such requirements, those who do so find themselves on the wrong side of inefficient energy utilization. The lights are usually on throughout the conditioning process (e.g. peeling and slicing) even during day when the sunlight is bright. This can be checked by using transparent sheets and strategic positioning of the processing room(s) or area(s) in order to maximize the use of daylight (Tassou et al., 2014). Similarly, processing rooms may be painted with white or lighter colors, and provided with light reflectance to maximize brightness. These should be coupled with the concept of "**time of use of grid electricity"**, where someone is billed based on the time of the day when electricity from the main grid is used. Generally, the off peak period in Uganda is associated with the lowest average tariff, although the concept of time of use applies to commercial and industrial users (Okoboi & Mawejje, 2016a; UMEME, 2017a). However, it has already been suggested that, awareness is generally inadequate and some processors are not yet aware of such possibilities of reducing the cost of using electricity by strategically choosing when to use grid electricity. The lack of accurate information regarding availability and use of energy is a crosscutting issue, which contributes to uneconomical and unsustainable use of energy (Henriques & Catarino, 2016). As already pointed out, many processors lack internal competent staff to propose and implement energy use reduction strategies making them vulnerable. In fact, there is a general lack of capacity to identify energy saving opportunities, and evaluation of their suitability especially in terms of cost and performance (Henriques & Catarino, 2016). Normally, learning about good energy use practices, energy conservation and efficiency is not an event, but a life time experience, which should continue throughout someone's life. This is because the energy sector is quite dynamic, and a number of changes and advances keep on being introduced driven by consumption behavior. In effect, the main grid keeps changing due to connection of new customers and new power plants, making it dynamic. In a sense, Uganda's energy situation fits quite well into the description since the Ugandan energy demand and supply continuously keep varying characterized by peak and off-peak demands (Meyer, Eberhard, & Gratwick, 2018; Okoboi & Mawejje, 2016a). Therefore, stakeholders must keep track of the advances, and make sense of them for the betterment of their enterprises and the planet as a whole.

6 Summary and Conclusion, Recommendations, and Limitations

6.1 Summary and Conclusion

A number of small and micro enterprises are associated with pineapple processing in central Uganda targeting not only the local but also the international market. As such, some of the enterprises have joined formal organizations especially the Uganda Small Scale Industries Association for visibility, training, and marketing opportunities. While most of them are still small-scale and home based, there seem to be great potential for them given that there are already recognized organizations tailor made for them (USSIA, 2011). With increasing pineapple production in this region, processing and preservation are seen as having positive contribution towards having the pineapples and related products available throughout the year, which minimizes seasonal demand and supply mismatches (Muzaale, 2017). Additionally, processing contributes to reducing the high losses reported among fruits and vegetables, as well as contributing to food security and SDG #02 (World Bank, 2016b).

Among the processing methods, drying is one of the most developed and formalized methods in this region mainly dominated by solar and biomass energy supply. The availability of solar energy almost throughout the year in Uganda (Adeyemi & Asere, 2014; Gustavsson et al., 2015) means that solar energy can be extensively utilized in the processing of pineapples as thermal and PV. This is seen as a solution to the current unreliable electricity supply in Uganda (Lee, 2013). However, solar PV utilization is still limited due to the relatively high initial costs (usually required as a lump sum) for procuring solar panels and batteries (Piggins, 2014).

Two out of the three drying systems investigated were forced convective hybrid drying systems (at S01 and S02) while one was purely traditional direct solar dryer (at S03) locally fabricated in Uganda. Fans for air circulation (forced convection) and diesel burner ignition at S01 obtained power from either grid electricity or solar PV while air heating was achieved by use of solar thermal or biomass (pre-heating) and diesel burner. At S02, the fans and motors were powered by grid electricity while heating was achieved by use of biomass burners and ordinary electrical cookers or coils. Additionally, most of the operations are manual even with the so-called advanced dryers, which might lead to inconsistent quantities and quality of the dried pineapples. A lot of room for improvement for most of the existing drying equipment remains, for example, automation or semi-automation of some of the operations.

Relatedly, munaanansi is such a promising product, which may require the current makers to look at it from a different point of view, so that it is not only a “local” product, but a drink which can attract attention in the local and international market. It is purely local innovation with most of the inputs locally available, and can play a significant role in reducing pineapple wastage. As this study indicated, some makers use pineapple peels as raw material, hence providing an alternative channel to the would be waste from other pineapple processing methods. It is also a cottage business, which can be set up with minimum initial human and financial capital (Ecuru & Lating, 2014; Martinez, Blattman, & Fiala, 2014).

Similarly, wine and juice making present good opportunities for utilizing pineapples, which would otherwise go to waste during the peak seasons, thus contributing to over 50% loss reported among fresh fruits and vegetables in Uganda (Akaki, 2012; UNIDO, 2007). Such solutions also create employment and probably improve family incomes since most of them are family based businesses. They are a recipe for innovations since operators have to always think about how to minimize the operational costs to maximize profits (Ecuru & Lating, 2014; Martinez et al., 2014). Based on interactions and engagement with pineapple processors, it is suggested that the main driving force behind most of the enterprises is profitability and pineapple waste reduction is a consequence. This means, the enterprises are open to ideas that would lead to profit improvement, and efforts geared towards resource use enhancement are likely to interest them. In effect however, post-harvest losses are reduced, hence contributing to the global need of ensuring food availability although food availability may not necessarily mean accessibility. This is because accessibility is a function of many variables such as distribution and financial ability or inability (Schiller, 2016) but this does not undermine such efforts. However, the results revealed that the dominant source of energy among the main pineapple processing methods is biomass (charcoal and firewood) while the conversion devices were the three stone and traditional charcoal stoves. Those two situations warrant concern as regards to sustainability, energy use and pollution reduction, and environmental protection. This is because, a combination of such stoves with firewood and charcoal is associated with indoor air pollution and deforestation (FAO, 2012; Lewis & Pattanayak, 2012). It also implies that automation or even semi-automation is still farfetched given the current state of affairs. Relatedly, most of them are currently described as using very small amounts of energy, which suggests that energy reduction and efficiency concepts may not make sense at all or to some extent to them. This is aggravated by the fact that, some of the processors can easily obtain biomass from around their homesteads and/or building sites almost free of charge. Which means, it may not be attractive for example to invest in energy saving firewood stoves when there is almost no cost on firewood (Price, 2017). However, for process intensification and advancement, more energy input and better conversion devices will be required. Systematic approaches to process performance assessment and energy supply scenarios are required. This study developed such procedures, which can be applied to not only pineapple processing lines but also to any other small-scale processes.

Alternative energy supplies e.g. solar thermal heating, which is rarely applied for processing purposes in Uganda can become influential in these processes. This research work proposed a number of supply combinations involving renewables especially biomass and solar energy, which are readily available (Gustavsson et al., 2015; Mukwaya, 2016) and need better conversion devices and matching with the loads. The revelation that most of the processes use relatively small quantities of energy implies that those processes are very good candidates for renewable energy supplies. This is based on the point often raised by renewable energy critics that renewables cannot meet industrial energy demands because of their limited supply intensities and prohibitive upfront costs (Trainer, 2007; Vivoda, 2012). This is surely a great chance for whoever is interested in alternative energy supply more so in processing and industrialization. The potential of using RE in food processing and value addition is plentiful with several advantages compared to traditional energy sources such as the diesel generators (Gustavsson et al., 2015; Puri, 2016). Humanity should always seek ways of tapping nature's vast energy sources, and work to integrate renewables into food processing. This is likely to lead to high efficiency, low production costs, and low environmental impacts. Moreover, there is always some form of renewable energy resource in any location especially in SSA, and always advisable to choose the best option or combination (Fatona, 2011).

So, this study's results enable deductions on the current utilization of resources especially energy and pineapples in relation to output e.g. energy utilization decreased with decreasing drying time. They highlight the current processing practices and energy situation as well as illuminating on the little information there is concerning small-scale processes. This means, proprietors can use such information while considering the possibilities of improving their respective processing lines. Similarly, USSIA and MEMD can be informed by these findings in the process of making policies and programs, which are relevant to such processors. Furthermore, this research gives ground for more interest in such processes because it points out the potential resource optimization opportunities which are not necessarily technological but inclusive. However, all deductions must be conceived by taking into consideration of the following: firewood used during processing was quite variable especially in terms of type of wood (mixed up) and its state (dry or wet). Hence, moisture and respective energy content were assumed based on literature during conversion from kg to MJ. Similarly, the quality aspect of the dried pineapples, wine, and juice made would have probably given more insights and created more interdependences especially in relation to drying temperatures and energy utilization but was outside the scope of this study. Therefore, future studies should also consider quality evaluation of the processed pineapple products.

Overall, the effort by the private enterprises and individuals is so encouraging, and the involvement of scientists and professionals can greatly complement such effort. Through collaborations, scientific findings and knowledge can be transferred to the entrepreneurs and other stakeholders e.g. USSIA and MEMD. This can be achieved by preparing and sharing findings in form of pamphlets, processing guides, and policy briefs. Publications in peer review journals will ensure knowledge transfer to the wider and global community. The purpose is to ensure system performance improvement and sustainable use of resources especially solid fuel based energy whose use impact has been cited as contributing significantly to climate change and environmental dilapidation (European Environment Agency, 2017). Indeed, human choices and behavior greatly influence process efficiency, product quality, and EE. Therefore, best processing and energy use practices are very relevant. They should be transmitted to target beneficiaries using the most appropriate and suitable mechanisms.

6.2 Summary and Implications

This investigation aimed at developing energy use profiles, energy use reduction ideas, and determining the possibilities of using renewable energies in pineapple processing in central Uganda. Three specific objectives were formulated, and respective research questions stated. From the first objective, the research was to provide answers related to yield in terms of kg of dried pineapples and liters of munaanansi, wine, and juice with respect to raw pineapples (input-output relation). It would further state the current energy use profiles, SEC, and the energy sources being applied by small-scale pineapple processors. In line with the second objective, the research sought to propose general frameworks for resource use assessment and evaluation, and in particular, energy performance evaluation in small-scale processing lines. From the third objective, the research intended to provide answers to do with energy use reduction options, potential alternative energy sources, and possibilities of integrating renewables into small-scale pineapple processes.

First, four main pineapple processing methods in central Uganda were identified i.e. drying, munaanansi, wine, and juice making. Through personal visitations, observations, and real time measurements during processing, the set research questions were answered as follows:

I) It was observed that all the processors investigated were profiled by relatively low energy consumption judged by their respective total energy consumption per processing cycle. Similarly, their respective inputs and outputs or yields per processing cycle were relatively low. The munaanansi makers use the lowest inputs, which is understandable since their market is generally localized, and can always process any time when need arises e.g. if all munaanansi made is sold off early in the day. They also consume the least amount of energy although their average SEC is the highest among the three enterprises (munaanansi, wine, and juice makers) whose output is in liters. This suggests that, despite consuming relatively low energy, their net effect is likely to be more compared to the other two (wine and juice making). With such understanding, there is need to become more critical with the so-called low energy consumers, who may not be very open when it comes to EE and conservation. Such low energy quantities are consumed almost on a daily basis, and sometimes more than once a day, thus, their cumulative impact can become significant over years. The SEC figures invite investigators into further examination of the numbers, and the possible influencing factors. In this study, it was noted that biomass (charcoal and firewood) was the dominant source of energy, and in fact, all munaanansi makers only use biomass. Furthermore, the most common conversion devices are the traditional three stone firewood and charcoal stoves. These influence the overall energy consumed since they are known to have low conversion efficiencies (SNV, 2015; Wang, Duanmu, Yuan, Ning, & Liu, 2015). Other sources of energy included grid electricity, petrol and diesel generators, and solar thermal and solar PV. However, the use of these other sources is quite limited, and most of the processors do not give them priority mainly due to their perceived cost and inadequacy. Additionally, biomass is generally readily available in Uganda, and sometimes free of charge especially in rural and peri-urban areas (Price, 2017; SNV, 2014). Many processors tend to opt for it, and thus its dominance. It can be collected from building sites, newly cleared lands, and forests at almost zero cost. It becomes more attractive in that sense, which may limit the adoption of advanced forms of energy and better conversion devices. The situation might continue like this for many years to come unless scientific investigations like this are further done and their findings disseminated to stakeholders especially the decision makers. Energy education and awareness is paramount if energy sustainability is to be achieved in the near future. This can be done through countrywide campaigns and promotion of efficient use of energy e.g. encouraging replacement of the existing inefficient devices with more efficient ones. Collective effort by government and private sector is required, but should be coordinated to ensure coherence in the same direction of sustainable energy use. All stakeholders must be brought to speed in order to appreciate the challenge at hand, and the need for everyone's support. The EE interventions effected so far (de la Rue du Can et al., 2017) can be very helpful in informing the future strategies, so that some of the pitfalls experienced during implementation of those interventions can be avoided. Other lessons can be drawn from EE approaches employed by the now developed countries in order to avoid some of downsides they experienced during and after the implementation (Koskimäki, 2012).

II) This work proposed two frameworks for processing line and energy use assessment and evaluation. The focus is small-scale processing lines, and simulation as a tool for process performance assessment although some of the ideas have been adopted from literature. The processing line framework is the main framework, and an enterprise would be advised to carry out such assessment periodically e.g. quarterly, semi-annually or annually. Due to the role played by energy, a specific framework on energy supply and utilization was proposed, and labelled as sub-frame. These frameworks highlight the need for periodic resource use assessment and evaluations because any enterprise would want to gauge how efficient its resources are being utilized. In order to ease the assessment exercise and encourage the practice, a desktop application for the frameworks has been developed. It can be installed on any computer, and utilized for information and data collection on particular processing lines. Furthermore, it aids the analysis of the collected information, and guide decision of the enterprise in question e.g., SEC, USD/output, NPV, and PBP are automatically evaluated on entering the required numbers. Indeed, the desire of every enterprise is to make steady progress, grow from one level to another, and both have to be measured periodically. The most common measure is usually profits, although profit levels alone may not tell the whole story about the processing performance. Therefore, the proposed frameworks call for in-depth assessment of resources from stage to stage, as well as suggesting possible options for improvement. In reality, it does not make sense to implement strategies meant to achieve resource use efficiency without plans to assess and evaluate system performance.

Ideally, performance evaluation and assessment should be done before coming up with resource use improvement strategy; it is a precondition for any future actions including EE and conservation. Similarly, the processing waste streams must be considered in order to minimize waste, but also seek alternative useful channels for them e.g. recycling and waste-to-energy techniques. This means that, the estimated quantity of waste generated per processing should be determined. Likewise, their state (e.g. solid or liquid) needs to be established as one of the first steps towards appropriate waste management. Indeed, management of the processing waste is very important in order to achieve sustainable processing and protection of the environment and ecosystems (Sinha, Sidhu, Barta, Wu, & Cano, 2012). Individual enterprises should take the initiatives towards resource efficiency and proper waste management. However, formal bodies such as USSIA for small-scale enterprises are handy in contributing to resource efficiency since they engage the enterprises and individuals on how to make their businesses more profitable. They engage them through training and seminars on business management, marketing, and branding. They also organize exhibitions where small-scale enterprises can showcase what they do, and in doing so attract a wider market as well as creating awareness among the public (USSIA, 2011). Equally, the GoU, through Uganda Revenue Authority (URA) and Ministry of Finance, Planning and Economic Development (MFPED) has put in place a number of incentives intended to promote business ideas in Uganda e.g. the exemption of taxes on renewable energy devices and liberalization of the economy (Read & Parton, 2009; URA, 2019). Due to such incentives, a lot of progress has been made (MFPED, 2016), but a lot more can be achieved if the enterprises take the lead since they fully understand their respective business requirements.

III) The energy use reduction concepts coming out of this research focused on replacement of inefficient cook stoves, staff awareness, energy education, and behavioral change. These were found more relevant as most of the enterprises investigated are small-scale, and tend to improvise on several occasions. They were also informed by the previous interventions e.g. the EE implemented by the GoU and its development partners. Therefore, energy use reduction approaches, which do not demand a lot of financial commitment, are likely to be accepted with ease. Regarding the improved stove adoption for example, those that are relatively cheap and involve user participation during construction might be more appealing since the approach empowers the users (Kees & Feldmann, 2011). Similarly, a number of potential alternative energy sources, which can be applied by the investigated enterprises exist. The most promising one is solar thermal since most of the processes are low temperature processes e.g. drying whose ideal drying temperature is between 40 ^{0}C and 65 ^{0}C (Akoy, 2014; Belessiotis & Delyannis, 2011). Munaanansi and winemaking involve a lot of heating, and juice making requires pasteurization, where solar thermal can be applied. Hybrid energy systems and renewable energy integration are possible since some of the enterprises are already using a combination of energy sources e.g. solar thermal, solar PV, and the grid. It remains to determine how these various energy sources interact, and the most optimal combinations. Simulations can be employed in the evaluation of the various possible combinations to guide further steps. These ideas are already emphasized in the evaluation frameworks. For renewable energy integration in particular, solar and biomass (using better conversion device) are good candidates for integration since they are readily available and solar component prices have significantly reduced over time. In fact, the prices of solar components especially solar panels are reported to have tremendously gone down from over USD 6 to less than USD 2 per Watt peak (W_p) within about a decade (Murphy, Twaha, & Murphy, 2014). Similar price reductions are reported in Kenya who is a close neighbor and business partner to Uganda, and part of the East African Community. In particular, it is reported that in 2007, a W_p cost about USD 6.7 in Kenya, but now (2020) costs less than a dollar (about 78 USD cents) (Zarembka, 2019). These are quite remarkable developments, and give a lot of hope for the future of renewables in East Africa, and Uganda in particular. Indeed, such developments play in the hands of energy users including the small-scale processors. There are driven by the deliberate move to promote renewables especially solar in Uganda, and the government intervention of tax exemptions on solar components, which is a very attractive incentive to those interested in solar application (MEMD, 2007; URA, 2019). It can therefore be argued with confidence that, the future of renewable energy integration into processing is bright, although it is still required to establish the appropriate level and stage of integration. Studies like this and collaborations are very relevant in the actualization of renewable energy application in processing.

6.3 Recommendations

6.3.1 To the drying enterprises and stakeholders

Pineapple waste especially peels should be investigated for use as animal feeds since animals especially cattle were spotted by the researcher feeding on the raw peels dumped around in Kangulumira. In addition, there are reports that damaged pineapples, peels, and crowns are fed to animals especially cattle, horses, and pigs (Joy & Rashida, 2016; Tröger, 2019). Similar reports suggest the application of pineapple waste as fertilizers for soil amendment (Gowda et al., 2015; Ketnawa et al., 2012). However, such alternative applications are rarely exploited in Uganda. This could be due to lack of awareness or even lack of trust of what the animals would become in case there are fed on pineapple waste. In fact, related sentiments were raised to the researcher in Kangulumira where some farmers suggested that feeding cattle on pineapple peels reduces milk yield, although based on hearsay without scientific evidence. There is therefore need to further investigate and disseminate findings on the possibilities of using pineapple waste for animal feeds and as fertilizers in Uganda. In the opinion of the author of this document, these two options seem to be the most relevant ones for Uganda since animal feeds and fertilizers (especially organic ones) are becoming a necessity to most farmers (Katongole et al., 2012; Sunday & Ocen, 2015). If established as viable alternatives for Ugandan situation, the pineapple wastes will become free raw material for making animal feeds and fertilizers (for soil fertility enhancement) while offering alternative disposal mechanism. Similarly, possible business models and supply scenarios should be examined if the peels were to be supplied to munaanansi makers some of whom are currently sourcing peels from fresh pineapple markets, which might be unhygienic. It can be very interesting to know if a business may be established between munaanansi makers and pineapple peel generators.

Change of the electricity tariff plan from domestic to commercial by S01 is recommended so that time of use charge and associated benefits are exploited. In Uganda, UMEME, the main electricity distributor (UMEME, 2017b) under the oversight of Uganda Electricity Regulatory Authority (ERA) categories electricity consumers mainly into domestic, commercial, and industrial. They consequently apply "time of use tariff" to commercial and industrial consumers under three time brackets: peak (18:00-24:00), off-peak (24:00-06:00), and shoulder (06:00-18:00). The lowest tariff is associated with the off-peak period, but this ("time of use") does not apply to domestic consumers (ERA, 2017; UMEME, 2017a). To emphasize the tariff variations, the 2019 fourth quarter commercial and domestic tariffs (per kWh) are compared as an example. The commercial tariffs were: peak (UGX 863.6 ≈ USD 0.23), off-peak (UGX 408.6 ≈ USD 0.11), and shoulder (UGX 664.7 ≈ USD 0.18) while the domestic tariff for any units above the first 15 kWh during the same quarter was UGX 752.5 (USD 0.2) (ERA, 2019). Therefore, converting from domestic to commercial can encourage maximizing the off-peak period whose tariff (USD 0.11) is almost half the domestic one (USD 0.2) [Exchange rate on 25th Oct 2019: USD 1 ≈ UGX 3,718] (BOU, 2019a).

In fact, S01 has already applied (on recommendation by the researcher) for a three-phase connection as one of the first steps in transitioning from domestic to commercial tariff plan. This initiative can be coupled with change or improving working schedules so that peeling and slicing begins very early in the morning to enable switching on the drying system by 10 am. This will maximize both solar thermal and PV that are available at S01 especially in the current situation when it is still being billed as a domestic consumer. Where only solar energy is used e.g. at S03, reliable weather forecasts should be used to determine the daily and weekly weather conditions in order to avoid drying schedules on very bad weather days (e.g. cloudy or rainy days).

Better measurement and control mechanisms of temperatures in and at the drying chambers e.g. analogue temperature display units and control knobs, should be replaced with digital ones. The current analogue ones especially at S01 are generally difficult to set and read. Uniform distribution of temperatures in the chambers at S01 can be achieved by introducing fans (preferably solar powered) into the inlet to each of the chambers. Currently, only one circulation fan located in the diesel burner is used to force hot air to all the three chambers. Similarly, improvement of insulation of the hot air ducts and drying chambers so as to reduce heat loss and eventually the drying time is recommended. Most of the control valves and knobs should be considered for automation or semi-automation to limit human error and possibility of negligence. Replacement or improvement of the current biomass burners especially at S02 to minimize wastage of fuel (charcoal and firewood) is urgent. The current situation is nearly open burning, which leads to a lot of wastage of the biomass but also promoting "smoking" of the nearby environment and rooms. The designers and fabricators of the drying systems can take some of these recommendations into consideration when new orders are placed. The researcher interacted with the designers and fabricators of the existing systems at S01 and S02, and they are positive about such improvements. In effect, the supplier of the drying system at S01 has indicated that their planned grain dryer will take care of some of those recommendations especially automation or semi-automation. Additionally, the designers and fabricators continue to consult and engage with the researcher on particular issues and envisage some form of collaboration in future.

Routine maintenance of dryers and trays to ensure that they are kept in good shape and hygienic conditions should be encouraged and emphasized. This is likely to lead to quality dried products, reduced damage, and waste. Some dryers at S03 were observed having leaks through the transparent polythene cover which implied possible damage to the fruits especially when it rained.

Advanced and hybrid dryers seem to be more relevant today because they enable control and continuous drying irrespective of the weather conditions and time of the day. In relation to that, a biomass assisted solar dryer is currently (2020) being constructed for the cooperative in Kangulumira. It is said that the lead team is from Makerere University.

6.3.2 To Munaanansi, wine, and juice makers

Replace the three stone and traditional charcoal stoves with improved wood and charcoal stoves whose thermal efficiencies can be as high as 60% (MacCarty, Still, & Ogle, 2010). This is because the results revealed that the dominant fuel among the three pineapple processing categories (munaanansi, wine, and juice making) was biomass and the conversion devices were the three stone and traditional charcoal stoves. The conversion thermal efficiency for most traditional cook stoves is reported to be less than 30% with some reports of 10 – 17% for three stone stoves (SNV, 2015) suggesting a worse situation. The economic analysis performed based on munaanansi maker P01 yielded positive economic results supporting the replacement of such stoves. Therefore, processors in this situation are encouraged to adopt devices that are more efficient.

6.3.3 To the academic institutions

The academic institutions should develop capacity (especially equipment and human) for carrying out the evaluation and assessment of processing lines; it can involve the final year and masters' engineering students under the supervision of the experienced faculty. In collaboration, relevant simulations and optimization programs should be performed to inform the next steps in improving the studied processing lines. Such interactions with the private sector will enhance the already existing outreach programs in some institutions of higher learning, and reduce the would be costs if individual processors were to hire professionals to carry out the assessments. One of such initiatives is the institutional incubation center - Food Technology and Business Incubation Center (FTBIC) established under the School of Food Technology, Nutrition and Bioengineering at Makerere University. The center is in possession of the state-of-art machinery for food processing including those for fruit processing especially into juice (Lybbert, Diiro, Kawooya, & Wunsch-Vincent, 2018; Wamai, 2019). Small-scale enterprises and businesspersons are free to enter into agreement with the center and pay a lump sum amount in order to use the shared resources. FTBIC offers services such as product development, training in food processing, food analysis, technical support, marketing and business management, to mention a few. It also runs a mobile fruit processing unit on a truck with all necessary equipment to process fruits on farm (Lybbert et al., 2018; Wamai, 2019). Such arrangements are very relevant especially with SMEs who may not afford the investment capital and maintenance costs especially for machinery. It also ensures optimal use of the shared infrastructure. Therefore, other academic institutions should explore such approaches and create shared processing parks targeting low capital entrepreneurs. Similarly, human capacity can be developed by training of staff who run the processing lines through collaboration and staff exchanges.

6.4 Limitation and Future Research Areas

Some limitations of this research were identified during the discussion of the results and in the conclusion, but one of them is emphasized here:

I. The quality aspect of the final products such as dried pineapples, wines, and juices were not determined. It is possible; a lot of information and discussion points would have been raised based on quality aspect of the final product. It would probably be stimulating to relate energy consumption with the quality of the output, and pointers to good or bad practices during processing.

The following areas seem to be viable for future research although some of them have already been pointed out in other sections of the dissertation;

I. The net effect of solar thermal and solar PV on the drying process at S01 should be investigated. Currently (2020), there is no clear picture on their contribution to the total energy supplied because PV is directly hooked unto the grid and both take on the load interchangeably. Therefore, no information to suggest whether to advise other processors to adopt such energy systems. Such research effort should be combined with attempts to simulate the various energy supply scenarios discussed in this thesis. It would be very stimulating to visualize the interaction of the various energy sources and probably an indication of the best supply combination. Relatedly, the possibility of using non-concentrating solar thermal systems such as better flat-plate or evacuated tube collectors to supply the hot drying air needs further technical and economic assessment in the Ugandan situation. This might be a grey area to exploit since the hot air drying temperature in the drying chamber should never exceed 70 ^{0}C, implying that drying pineapples is a low temperature application suitable for solar thermal supply. However, a similar situation for S02 evaluated in this dissertation yielded negative economic results based on only direct benefits and under specific constraints. But different scenarios should be evaluated for low temperature solar heating. In fact, changing the cost of firewood at S02 (from USD 0.02/kg to USD 0.07/kg) gave positive economic results. Therefore, considering various scenarios under varying conditions is paramount. The evaluation can be extended to pasteurization of pineapple juice or even heating applications required during wine preparatory stages whose temperature requirement is less than 100 ^{0}C. Similarly, heating applications other than cooking using the traditional biogas stoves should be explored so as to establish the possibility of supplementing the existing heating needs e.g. among drying enterprises.

II. Determine the EE of biomass burners and traditional direct solar dryers fabricated locally in Uganda. All the biomass burners and solar dryers being used are locally fabricated with no or inadequate specifications, and therefore no basis for their performance evaluation and comparison. This should be done in cooperation with some of the popular fabricators in order to come up with some indicative energy efficiencies, which may guide further improvements. Final year engineering and Masters' students can be very helpful in this exercise for their own experience and academic knowledge contribution. In fact, the author interacted with one of the fabricators of biomass burners who clearly indicated that he has never attempted determining the efficiency of what he fabricates, and does not even know the procedure. Nevertheless, he would be willing to collaborate in order to find out the efficiency for further improvement and marketing strategy.

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Appendix A: Examples of Post-harvest Loss and Waste Reduction Interventions

Intervention	By	Food type	Actor (stage)	Year (period)	Effect(s)	Country (region)	Comment(s)	Source
Courtauld Commitment	Waste Resource Action Programme (WRAP)	Food and drink	Retailers and suppliers	2005-2010	1.2 million tons of food and packaging waste prevented	UK	Voluntary participation for resource efficiency	(Lipinski et al., 2013; WRAP, 2011b)
			Household	2007-2010	13% reduction			
			Manufacturers and retailers	2009-2011	8.8% reduction			
Three-month campaign to reduce food waste	Worcestershire County Council	All	Household	2011	Waste reduced by 14.7%	England	Best Waste Minimisation or Prevention Project 2011	(WRAP, 2011a)
Food donation	SecondBite		Farmers, retailers, community groups, and food banks	2012	Rescued and redirected 3,000 tons of fresh food	Australia	Collaboration and coordination very important	(Lipinski et al., 2013)
Low-cost storage techniques and handling practices	WRAP	-	Storage and handling	-	More than 60%	Benin, Cape Verde, India, and Rwanda	Need coordination of all stages	(Lipinski et al., 2013; WRAP, 2011b)
Zero energy cool chamber	Krishi Vagyan Kendra (KVK)	Various crops	Farmers – after harvesting	1997-2000	1,200 were reached,	India	Funds from National	(Lipinski et al., 2013)

(ZECC) construction					awareness creation		Horticulture Board of India	
Product development	RELOAD Makerere University	Fruits and vegetables	Processing (value addition)	2013-2018	Products developed (pineapple wine, banana ketchup, banana yoghurt…)	Uganda	Marketing and standards validation	(RELOAD, 2017)
Zero Food Loss Initiative	World Food Programme (WFP)	Mainly grains	Farmers (after harvest)	2014-2015	Reduced losses to less than 2% from about 60%	Uganda	Funds from USAID, complexities of the chain, and collaborations	(Costa, 2015)
Field packing under thatched roof structure with concrete flooring	Not specified	Vegetables	Farmers (packaging)	-	Weight losses reduction from about 2.5% to 0.5%	Rwanda	Local materials e.g. wooden poles, thatched roof..	(Saran, Roy, & Kitinoja, 2010)
Small-Scale cold room equipped with CoolBot control unit	Not specified	Onions (perishables)	Farmers (storage after harvesting)	-	Losses reduced from 30% to 5%, market value improved from $0.5/kg to $2/kg	Ghana	Used with proper insulation, and onions sold 4 months after peak season	
"Purdue Improved Cowpea	Research Into Use (RIU)	Cowpeas	Farmers (storage)	2009	5-10% higher prices than peas stored traditionally	Nigeria	Limited availability	(Grace, Ugbe, & Sanni, 2012)

Storage" (PICS) bag								
Metal silos	FAO	Cereals	Farmer groups.	2012	300 metal silos distributed	Kenya	Funds by Sweden and Spain, upfront cost	(Lipinski et al., 2013)

Appendix B: Level of Biogas Utilization, Challenges, and Suggestions for Improved Performance

Region or country	Feedstock	Current level of use	Future potential	Challenges	Recommendations	Source of funds	Source
Central Uganda	Animal waste, crop and food material	Low (28.8%)		Limited feedstock Inability to maintain and repair the biogas plants	Improve management practices Consider socio-cultural factors	NGOs and government	(Lwiza, Mugisha, Walekhwa, Smith, & Balana, 2017)
SSA	Animal excreta, industrial and municipal wastes, weeds and agricultural residues	Low	High	Low income levels for individuals Low education levels Unreliable feedstock supply Poor maintenance and inexperience	Mobilize local and external funds Use of ready to use funds such as CDM[a] Formation of user and disseminator associations Promote multiple uses of biogas	NGOs (e.g., USAID, and African Biogas Initiative)	(Mwirigi et al., 2014)

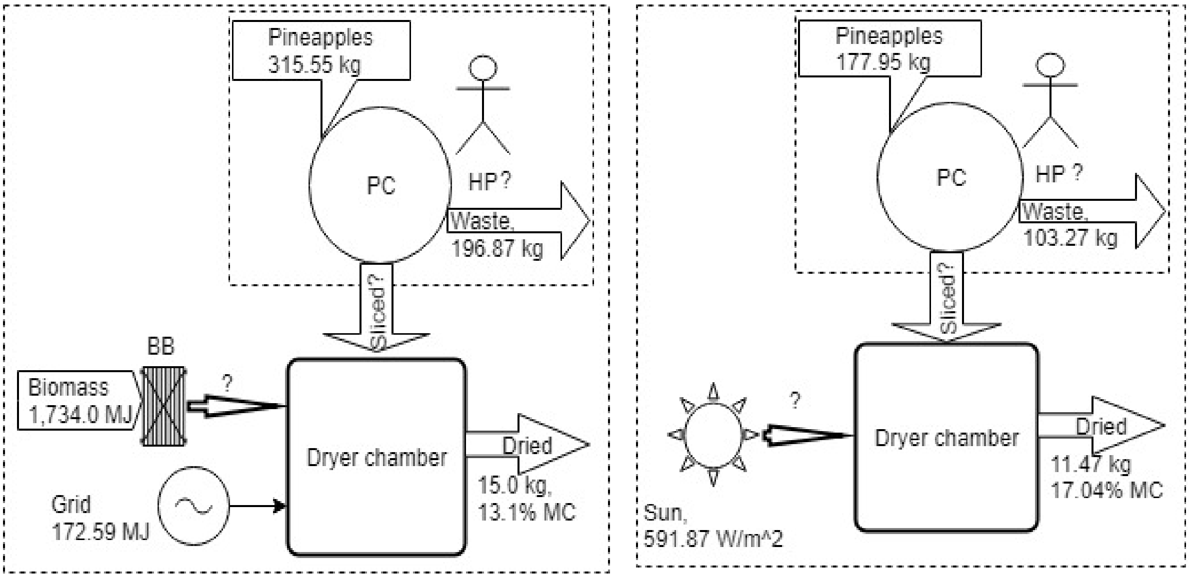
SSA	Livestock excreta Sometimes human waste	Low	High	Inadequate feedstock and finances, Balloon digesters vulnerable to damage Limited data availability	Form farmer co-operatives Collective participation of all stakeholders	NGOs (e.g., African Biogas Partnership Programme	(Orskov, Yongabi Anchang, Subedi, & Smith, 2014)
Uganda	Cow dung	Low	Viable and High	Initial capital, operating and maintenance costs Lack of information Technical and social challenges	Establish the economic feasibility Establish MFIs[b] specifically for the biogas financing Provide incentives	-	(P. Walekhwa, Lars, & Mugisha, 2014)
Uganda	Animal waste especially cow dung	Low	High	Socio-cultural, technical, financial and lack of awareness	Awareness campaigns Financial and non-financial incentives Provide low-cost credit, subsidies or financial aid	NGOs (e.g., HPI, ADRA, AMREF, Africa 2000 Network)	(P. N. Walekhwa, Mugisha, & Drake, 2009)
Zambia	Animal manure	Low	High	Lack of funding, policy, awareness, regulatory framework Inadequate expertise, high maintenance costs, and inadequate R & D	Address policy, awareness, and funding issues Promote co-digestion Promote R & D	Donors	(Shane, Gheewala, Kasali, & Cob, 2015)

SSA	Agricultural residues, municipal wastes and industrial waste	Low uptake	Great potential	Political, social-cultural, financial, informational, institutional, technical, non-technical, and training	Establish national institutional framework, increase R & D Training and provide loans and subsidies	-	(Parawira, 2009)
Nigeria-SSA	Animal dung, household waste, agricultural and industrial wastes	Very little success	High	Lack of awareness on the benefits of biogas	Financial incentives Coordinated R & D Awareness and education	Government quota	(Akinbami, Ilori, Oyebisi, Akinwumi, & Adeoti, 2001)
Kenya	Animal manure (mainly cow dung)	Low	High	Selection of the most appropriate biogas plant design Sustainability not well documented	More research on selection criteria Information on sustainability	Biogas programme subsidies	(Nzila et al., 2012)
SSA	Any organic material	Limited uptake	Great	Cultural and social Financing Poor operation and maintenance	Funding Cost-sharing, regular user training and monitoring	NGOs and Government, e.g.,(UDBP subsidies)	(Smith, 2012)
Uganda	Animal waste especially cow and big dung	Low	High potential	Social-economic, low quality feedstock, high moisture content in the gas, and poor maintenance Poor structural designs	Sensitization Training of biogas digester owners Proper operation such as mixing ratios	NGOs (e.g., ADRA, AMREF, SSWARS, KULIKA), & Gov't	(Lutaaya, 2013)

SSA	Human, animal, and any organic waste	Limited uptake	Great	High costs, lack of construction materials, poor design and construction Lack of monitoring	Monitoring and follow-up Training Sustainable financing	NGOs	(Tumwesige et al., 2011)
Africa	Agricultural residues, forest residues, municipal wastes, animal, and human excreta	Low	High	Maintenance deficiency Lack of proper coordination of partnerships and NGOs Inadequate finances	Subsidize installation Coordination to avoid duplication of services and conflicts Awareness	NGOs (e.g., SNV, GIZ, HIVOS, WINROCK International)	(Mulinda, Hu, & Pan, 2013)

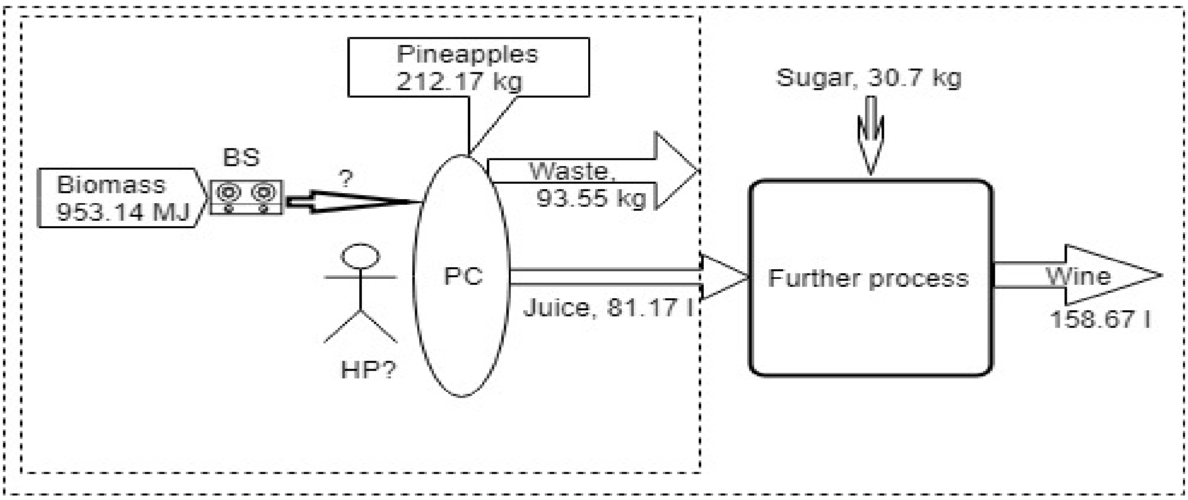
[a] CDM: Clean Development Mechanisms, [b] MFIs: Microfinance Institutions

Appendix C: Other Material and Energy Flow Diagrams

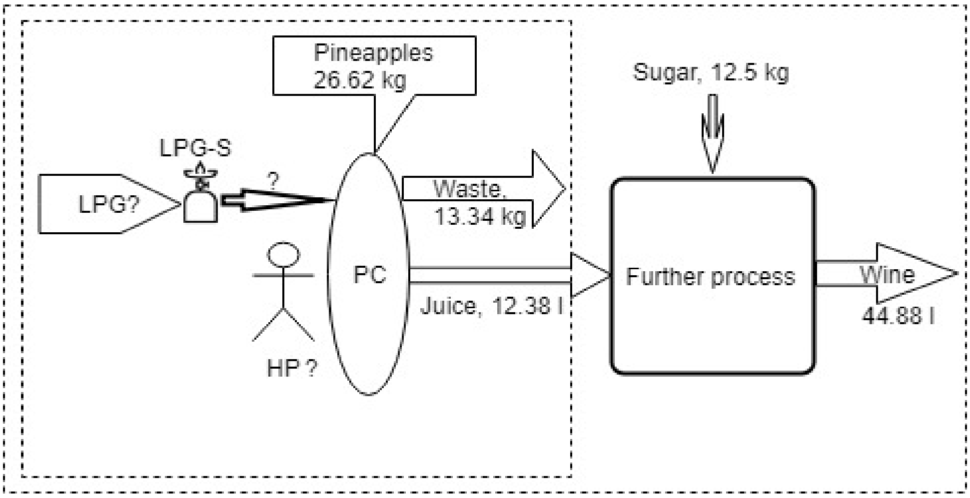


S02 *S03*

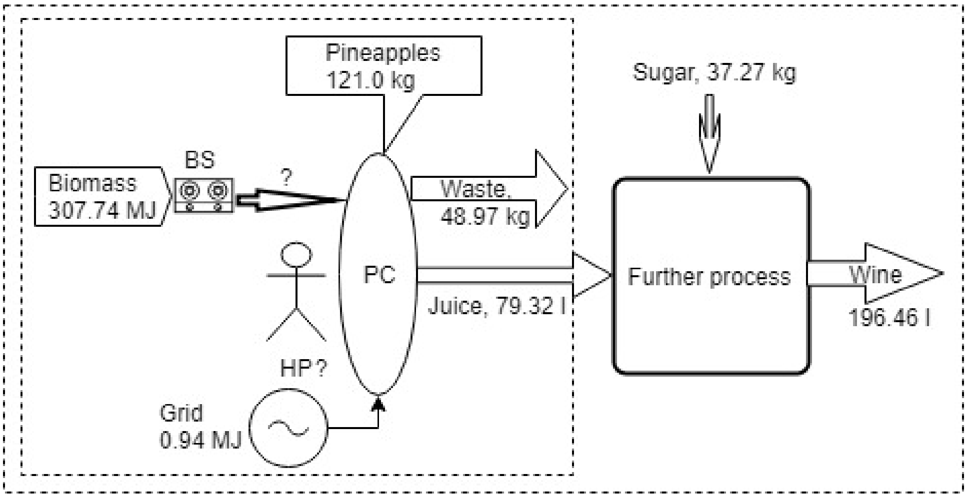
Material and Energy Flow Diagram at S02 and S03



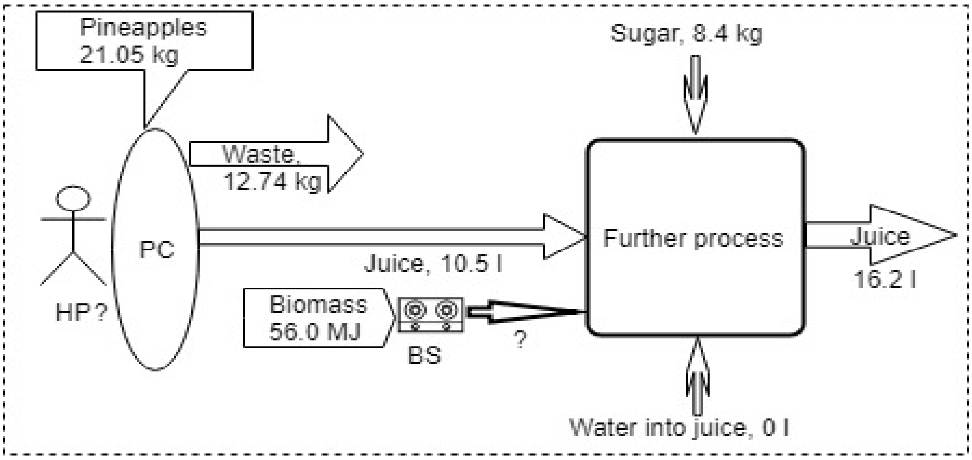
Material and Energy Flow Diagram at W01



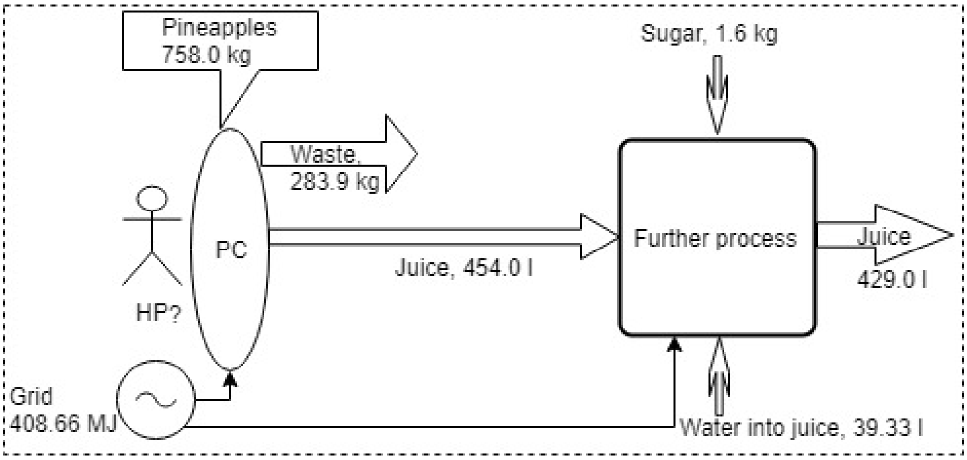
Material and Energy Flow Diagram at W02



Material and Energy Flow Diagram at W04

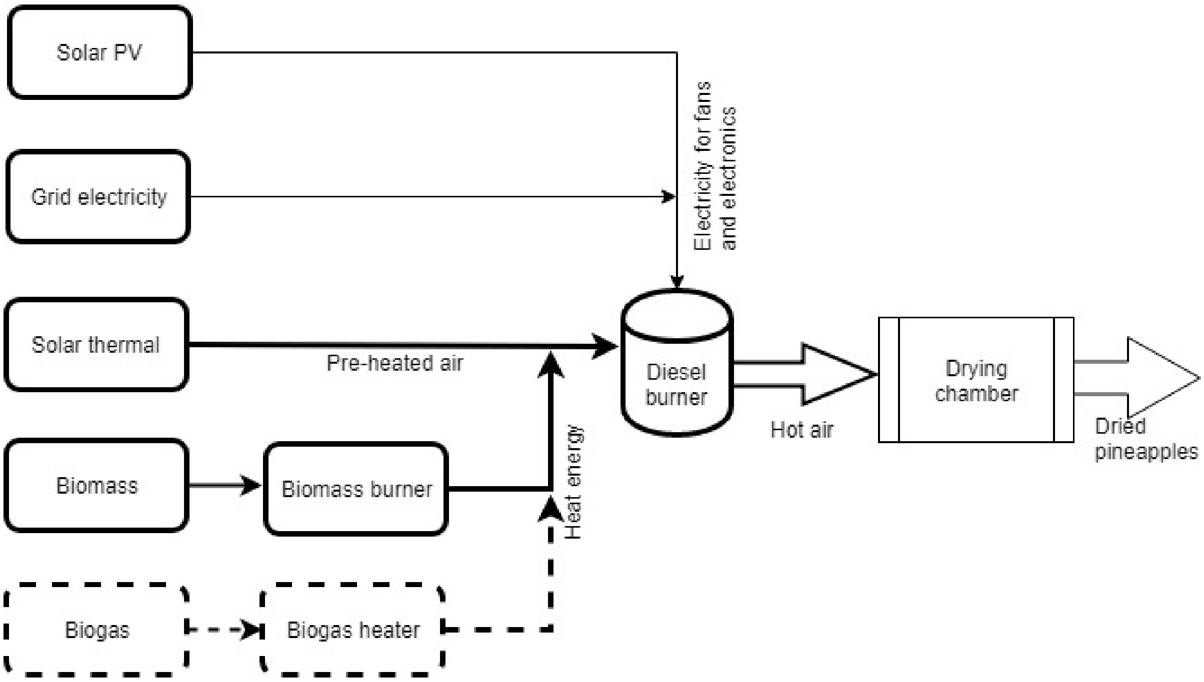


Material and Energy Flow Diagram at J01

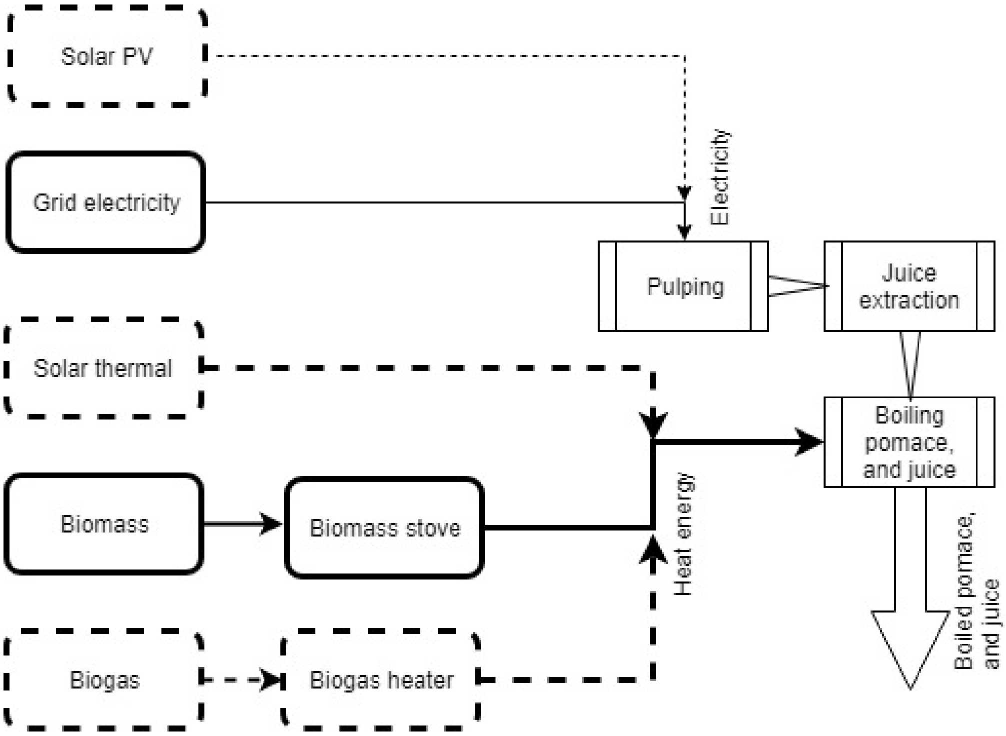


Material and Energy Flow Diagram at J02

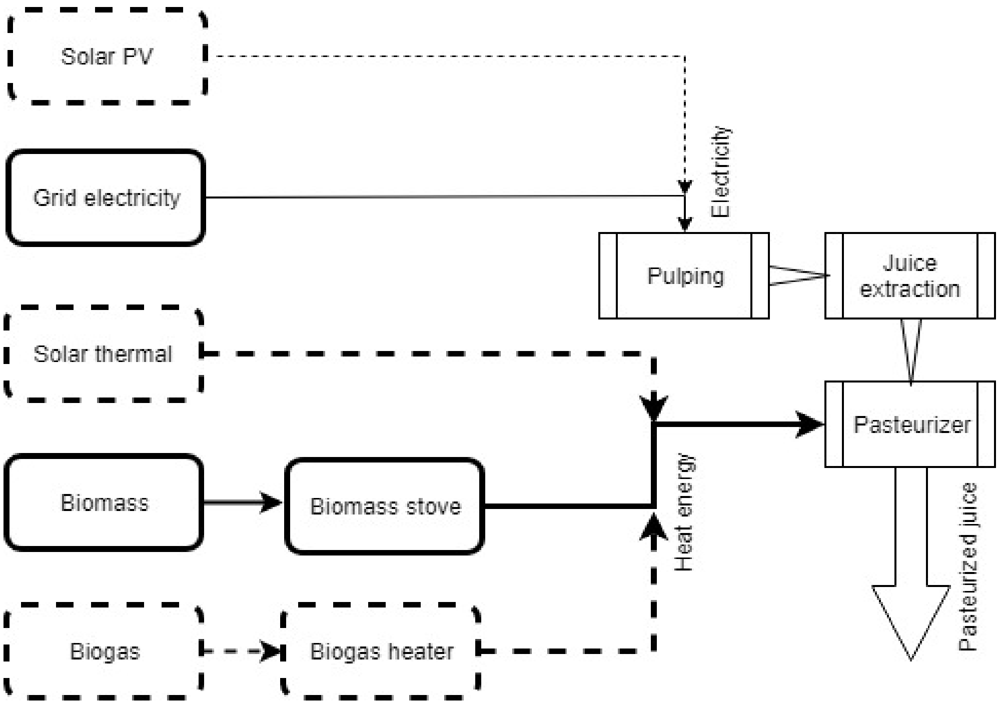
Appendix D: Other Possible Energy Integration and Hybrid System Diagrams



Possible Energy Integration and Hybrid System at S01



Possible Energy Integration and Hybrid System at W01



Possible Energy Integration and Hybrid System at J03

Appendix E: Some Pictures of the Measuring Equipment

pH meter

MC meter

Wooden Mortar and pestle

Temp gun

Scale: max 600 g

DDS228 EE meter

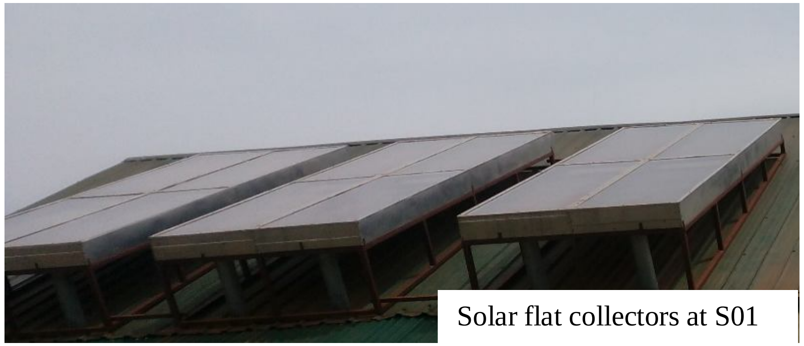
Logger 4000

Irradiance meter

Scale: max 40 kg

B1500D scale

Appendix F: Other Related Pictures



Solar flat collectors at S01

Solar PV collectors at S01

Advanced hybrid dryer

Diesel burner connected to hot air ducts

Dried pineapples on trays

Trolley loaded with trays

Sacs of charcoal

Fresh pineapples before peeling

Fresh pineapples after peeling and slicing

Bottled wine

Bottled juice

Filtering munaanansi

Filtered munaanansi cooling

Packaged for distribution

Packaged munaanansi under refrigeration

Author – Emmanuel Wokulira Miyingo