ANALYSIS OF ENERGY UTILIZATION AND RENEWABLE ENERGY POTENTIAL IN KTDA REGION TWO TEA FACTORIES IN KENYA

INOTI JOHN MWENDA

MASTER OF SCIENCE

(Energy Technology)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

2016

Analysis of energy utilization and renewable energy potential in KTDA region two tea factories in Kenya

Inoti John Mwenda

A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science Degree in Energy Technology of Jomo Kenyatta University of Agriculture and Technology

2016

DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other University.

Signature …………………….. Date ……………..……..

Inoti John Mwenda

This thesis has been submitted for examination with our approval as the University supervisors.

Signature …………………….. Date ……………..……..

Dr. Jeremiah K. Kiplagat

KPLC, Kenya

Signature …………………….. Date ……………..……..

Dr. Joseph N. Kamau

JKUAT, Kenya

DEDICATION

This work is dedicated to my parents, my dear wife Pamela, and my children, Whitney, Alfred and Reagan, due to their love and as an appreciation for their encouragement and sacrifices they made during my study period.

ACKNOWLEDGEMENTS

I would like to acknowledge my research university supervisors Dr Joseph. N. Kamau of Jomo Kenyatta University of Agriculture and Technology and Dr Jeremiah. K. Kiplagat of Institute of Energy Studies and Research, Kenya power and lighting company, for their professional guidance and encouragement throughout this research work. I would like to acknowledge Kenya tea development agency ltd for allowing me to conduct my survey at their factories.I also acknowledge my family and my parents, who have supported me unconditionally. It was through their support, encouragement and love that lead me to insist, to focus all the way until I achieve my target and dream.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

CHP	Combined Heat and Power
CTC	Cut Tear Curl
DNEP	Draft National Energy Policy
DNI	Direct Normal Irradiance
EDB	European Development Bank
IEA	International Energy agency
FIT	Feed In Tariff
GTIEA	Greening Tea Industry in East Africa
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KNBS	Kenya National Bureau of Statistics
KTDA	Kenya Tea Development Agency
LCOE	Levelized Cost of Energy
MJ/kg MT	Mega Joules per Kilograms Made Tea
MT	Made Tea
NREL	National Renewable Energy laboratory
NSWT	New South Wales Treasury
PWC	Price Water Coopers
REN	Renewable Energy Network
RET	Renewable Energy Technology
WEC	World Energy Council

ABSTRACT

High cost of energy is one of the major challenges facing tea sector in Kenya. In an effort to address that challenge, a study was conducted to determine energy indicator trends and indentify factors that affect energy indicators in nine tea factories in central Kenya. Energy consumption data for five years was collected and analyzed. Plant survey was carried out to establish sectional energy requirements for a tea factory. The potential of renewable energy utilization within a tea factory was also studied. Biodegradable waste thermal potential was estimated based on the quantity of waste produced while the monthly wind and solar data for Nyeri was sourced from Renewable Energy Technology (RET) screen 4 software data base. RET screen software was used to model and carry out financial analysis of the renewable resources indentified in the tea factories. The results of the study show energy intensities ranged from 32.40 MJ per kg Made Tea (MT) to 38.31 MJ per kg MT and cost intensities from USD 163.05 to 214.72 per ton of MT. Sectional electrical energy demand were 36.7 %, 21.4 %, 24.9 % and 17 % for withering, processing, drying and others respectively. Factors identified to affect energy indicator are on production volume, capacity utilization, climatic factors, operational factors, and cost of energy as well as type, quality and mode of fuel wood storage. The levelized cost of energy for Solar photovoltaic (PV), solar air heating, wind resource, combined heat and power were USD 469.63 per MWh, USD 182.89 per MWh, USD 45.11 per MWh and USD 72 per MWh respectively. The study shows opportunities for energy cost reduction through energy conservation and resource management exist as well as renewable energy utilization as a viable alternative source of energy for tea factories.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The Kenya's agricultural sector contributed about 25.3% of Gross Domestic Product (GDP), employed about 80 % of rural population and accounted for about 60 % of foreign earnings as well as 45 % of government revenue in the year 2013 (Price Water Coopers (PWC), 2014). Tea which was introduced in Kenya from India by a colonial settler in 1903 was first planted in Limuru before spreading to other parts of the country (Gesimba, Langat, Liu & Wolukau, 2005). Over the years the tea sector in Kenya has grown and currently employs 10 % of the Kenya population either directly or indirectly in addition to enhancing rural infrastructure and living standards of those living in tea growing areas (Kagira, Kimani & Kagwathii, 2012). Report by Tea board of Kenya (2014), shows that in 2013, tea contributed 11 % of the GDP in agriculture and 26 % of the foreign earnings that year. Therefore, the tea sector remains an important sector in Kenya's economy. However, tea sector faces a lot of challenges such as low market prices and high production cost due to the high cost of energy leading to low tea farmers earnings.

Currently, the aim of the Kenya government is to improve the living standards of her citizens and any step that can maximize tea farmers' returns compliments that goal. It was therefore necessary to explore measures that could reduce tea production cost without compromising on the quality of the product supplied to the market. Processing of tea involves; withering, cutting, fermentation, drying, grading, packing and dispatch. In withering, green leaves are loaded onto the withering beds, at a certain optimum loading rate. Draught is then forced onto the withering bed by a fan impeller coupled onto an electric motor. During withering, process air is passed through air to steam heat exchanger to raise its temperature while monitoring the dry bulb temperature after conditioning to avoid scorching the green leaves (Jayatunge, 1999).

After withering, the leaves are then macerated by rotor vane(s) and thereafter cut using the Cutting Tearing and Curling (CTC) machines. The CTC machines consist of pair of rollers, arranged in three sets with rollers rotating at different speeds in opposite direction. The cut withered tea leaves are fermented in Continuous Fermentation Unit (CFU) machines and fed into tea driers where moisture content is reduced to acceptable limits. Tea drying machines consist of drying chamber with different temperature zones. The drier has fans for blowing in air, dampers to control air flow rate, heat exchangers for conditioning drying air, plenum chamber, drying chamber, exhaust section and cyclones. Finally tea is graded, packed and dispatched to the market. Therefore, tea processing is an energy intensive process consuming either thermal or electrical energy or both energy sources.

1.2 Problem statement

The tea sector in Kenya faces energy related challenges like escalating energy costs, unreliable and poor quality power. Moreover the cost of energy is a major expense that determines the overall cost of production of tea. The returns to tea farmers depend on production cost and prevailing market price. Factories in the same region or localities have different energy intensities and hence different profit margins leading to variations in the final payment to tea farmers. Most of the tea factories have access to renewable energy resources such as solar, wind, biomass and biomass waste, which can provide cheap alternative sources of energy for driving some of the production processes. However, these resources have not been properly utilized and exploited due to lack of information. The aim of this study was to bridge that gap.

1.3 Purpose for the study

The research sought to analyze energy consumption trends and indicators in different tea factories with a view of determining potential for use of the available renewable energy resources. The study avails vital information that would guide investment decisions on energy conservation and utilization of renewable energy in tea factories in Kenya.

1.4 Research objectives

1.4.1 Main objective

To study the energy consumption trends and the potential use of renewable energy resources in tea factories in Kenya.

1.4.2 Specific objectives

1. To determine the energy intensity trends in different tea factories.

2. To determine the potential of different renewable energy sources available within a tea factory.

3. To calculate specific cost of energy from different renewable energy resources in the tea factory

1.5 Research questions

The following questions guided the study:-

1. How does energy consumption vary from one factory to another?

2. What were the renewable energy resources available in tea factories and their potential for use?

3. What is the specific cost of energy for different renewable energy conversion technologies?

1.6 Justification

The available conventional sources of energy are expensive, unreliable and at times of poor quality. According to Greening Tea Industry in East Africa (GTIEA) (2007), cost of energy in KTDA managed tea factories accounted for 30 % of total production cost with electricity cost alone being 17 % which translated into between USD 294,200 and USD 650,935 annually that was spent on electricity bills.

Furthermore, according to Kenyan Draft National Energy Policy (DNEP) (2014), there are no guidelines on how to promote use of renewable energy resources available in tea factories. Exploitation of these resources can improve energy mix; reduce cost of production and eventually improve shareholder returns. The study provides the necessary information that can be used by policy makers in charge of tea factories when developing business strategic plans especially on energy conservation, management and renewable energy exploitation. The other objective was to establish the energy consumption trends and compare the energy intensities of the selected tea factories located within the same geographical area.

1.7 Significance of the study

The information from the study will be very useful to policy makers' especially factory management and factory Board of Directors when making decisions on energy conservation, energy management and renewable energy investment. Other beneficiaries are statutory policy makers who are involved in the formulation of regulation in Kenya.

1.8 Scope of study

The study profiled energy demand, end use and established levelized cost of energy for renewable energy resources within smallholder tea sector factories.

CHAPTER TWO

LITERATURE REVIEW

2.1 Energy consumption trend in the world

Energy is a necessity for sustaining human lives. When energy cost increases more money is directed to purchase energy. Over a long period, fossil fuel has been the main source of energy mainly due to availability of conversion technologies which are considered cheaper than for renewable energy sources. In Africa, countries in the North depend heavily on oil and gas, South Africa depends on coal whereas the rest of Africa depends on biomass mainly for domestic use especially the rural population (Karekezi & Kithyoma, 2003). However, studies show fossil fuel consumption has negative environmental impacts hence; there has been a lot of interest in exploring and utilization of environmental friendly renewable energy resources (Simion, Blarke & Trifa, 2012). Projections by World Energy Council (2004) show world primary energy consumption will grow by 60 % by the year 2020. In 2008, Africa had the least generation capacity of 2.65 % in the world of which 30 % was generation by South Africa (Osieni, 2012). This indicates most African countries have low per capita energy consumption which affects development in the continent.

In Kenya, the Ministry of Energy (MOE) in 2011 reported that less than 15 % of the population was supplied with electricity and 48 % of the installed capacity was from hydropower, 37 % from thermal, 13 % geothermal, 2 % from both wind and cogeneration plants. Low per capita energy consumption and connection percentage implies more resources should be directed towards energy generation projects in Africa by the governments as well as private investors. In Kenya, energy sector like in most Africa countries is characterized by high dependency on biomass, frequent power outages; low access to energy and overreliance on hydropower and oil imports (Kimuyu, Mutua & Wainana, 2011).

Studies show, on average in Kenya tea factories receive electricity from the national grid 93 % of the time and the remainder generated by tea factories standby diesel generators World Energy Council, 2004 (Nordman, 2014). These power challenges resulted to a loss of about 9.5 % on production excluding the cost of damaged equipments, meaning losses are higher (Mwakubo, Mutua, Ikiara & Aligula, 2007). Considering the power supply challenges, unsupplied and growing population as well as economic growth then demand for electricity in Kenya remains high. In order to meet the demand, spur economic growth and fight poverty as well as attain vision 2030 Kenya should invest in renewable energy (Yuko, 2004).

Researchers have been focusing on renewable energy exploitation to meet the growing demand of energy and to reduce reliance on the expensive fossil fuels but studies show traditional power generators will still remain cheaper (World Energy Council (WEC, 2004). Most countries in the world have been formulating policies that promote investments in renewable energy. However, in East Africa there are minimal investments although the scenario could be different in future due to untapped renewable energy potential (Yuko, 2004). Kenya government recognized importance role renewable energy will play on her economy and introduced Feed in Tariffs (FiT) in 2008, which were reviewed once midterm to attract renewable energy investments by private firms (MOE, 2010).

Through Kenya National Draft Energy Policy (KNDEP, 2014), cross cutting issues hindering development and adoption of renewable energy were identified. These include lack of awareness and information, financing mechanisms, trained manpower for installations; designs not good for local conditions, lack of government policies and coordination. In Kenya, lack of information about renewable energy, has been singled out as a major obstacle, since renewable energy technologies are viewed by policy makers as new and traditional technologies are preferred even where alternatives exist (Yuko, 2004).

In order to promote renewable energy exploitation, the Ministry of Energy and Petroleum in Kenya financed feasibility studies for 10 small hydro projects in tea growing areas with cumulative power potential of 25 MW for KTDA to invest in addition to the two sites that were financed through GTIEA programme (Kirai & Shah, 2009). Tea factories in Eastern and Central Africa have shown a lot of interest to invest in renewable energy generation to reduce production cost and green house gas emissions (GTIEA, 2007). Energy cost accounted for about 30 % of production cost in KTDA managed tea factories (GTIEA, 2007) but the 30 % cost of energy compared well to tea factories in India (Environmental Management Centre, 2012). Although renewable energy does not guarantee 100 % reliability, firms should invest in them to supplement traditional sources of energy so as to achieve better productivity, economic growth and developments as well as improve social welfare of the citizens (Osieni, 2012). It was, important to avail information about renewable energy exploitation as a long term solution rather than short-term solutions like the expensive fuel oil.

2.2 Tea processing energy requirements

Tea processing involves; withering, rolling or cutting, fermentation, drying, grading, packing and dispatch. Tea processing is mainly a drying process that reduces moisture content from about 83 % to 3 % of the fresh harvested green leaves (School of Environment Resources Development, Asia Institute of Technology, 2002). Therefore, tea processing is an energy intensive process that requires both electrical and thermal energy at a ratio of 15:85 respectively (Baruah, Khare & Rao, 2012). In India, every kilogram of Made Tea (MT) required 3.5 to 6 kWh of thermal energy and 0.2 to 0.5 kWh of electrical energy (Kumar, Velan & Sivasubramanian, 2004). However, in Sri Lanka it ranged between 4.45 to 6.84 kWh/kg of MT and about 10 kWh/kg of MT in Vietnam (Baruah, Khare & Rao, 2012). In Sri Lanka the overall energy intensity was about 22.4 MJ/kg MT of which 95 % was thermal and the rest electricity (Jayah, Aye, Fuller & Stewart, 1999). A study by EMC in India found out fuel wood consumption to be 1.9 kg for every kg of MT compared to Tanzania of 3.6 kg for every kg made tea (Sheya & Mushi, 2000).

Studies show fuel wood ratio depends on the moisture content, fuel wood tree species and duration of storage after harvesting which should be six months minimum (Erkkila & Alakagas, 2008). Moisture content of fuel wood varies from 25 % to 45 % wet bulb (Jayah, Aye, Fuller & Stewart, 1999).

In Kenya, thermal energy for tea processing was derived from fuel wood and heavy fuel oil whereas electricity was sourced from the national grid and standby generator sets in case there is power interruption. In Kenya 70 % of the energy needs are derived from fuel wood (Githiomi & Oduor, 2012) compared to 92 % of final energy in neighboring Tanzania, and projections show fuel wood will be a major source of energy even in future (Sheya & Mushi, 2000).

Studies show firms in Africa, loose 77 hours of production time every month due to power quality factors (Osieni, 2012). In Kenya as per Kenya Institute for public Policy Research and analysis (KIPPRA) (2007), firms lose about 9.5 % of the total output due to power outages. As a result there is a lot of interest in energy efficiency and conservation so as to reduce cost of energy. There are several merits of using energy efficiently such as reduced investments in energy infrastructure, low dependency on expensive fuel oil, increased profits and environmental conservation.

Studies show in tea processing, electricity saving of about 23 % could be achieved by controlling air flow rates for withering fans to an average of 0.567 m^3 per minute per kg green leaves (Botheju, 2013). That was achieved by adjusting the withering fan pitch angles and loading density of 26.9 kg/m^2 of green leave (Botheju, 2013). Results from a study carried out in a broiler processing plant in Georgia and Alabama USA show energy consumption by a plant depends on plant location, climatic conditions, technical and engineering characteristics of the plant as well as operating procedures and practices employed (Jones & Lee,1978). However, energy indicators are also determined by type of energy source, production levels, production conditions and energy input (Jekayifa & Bamgoye, 2008) as well as quality and plant efficiency which depend on the equipment used (Kumar, Sujatha & Thyaragajan, 2012). Under-utilization of plant leads to energy loss since base load of energy remain the same irrespective of the quantity processed by the plant.

Further, another study found out that low machine efficiency and down time resulted to high energy use (CIPEC, 2006) implying Overall Equipment Effectiveness (OEE), a product of plant availability, quality and performance; indicate plant utilization levels compared to its optimum capacity measures plant performance and energy efficiency of the plant. It was established that the world class average overall equipment effectiveness for manufacturing plants is about 85 % (Glova, 2012). Energy conservation is hindered by lack of information and awareness, lack of co-ordination standards, lack of funds, research and development (SERD, 2002). Studies on energy consumption and energy indicator trends was carried out to avail information to guide in planning, monitoring energy use as well as energy conservation and management.

2.3 Renewable energy exploitation status

2.3.1 Overview of global renewable energy use

Renewable energy is the energy derived from natural resources like solar, wind, tides, geothermal, hydro and biomass. According to US department of renewable energy in the year 2012 alone, 23 % of the electricity generated globally was from renewable energy resources. The low renewable energy generation capacity was confirmed by another study carried out in Africa showing that although there are substantial renewable energy resources they remain unexploited, and they can play a major role to the continent’s energy sector when exploited (Karekezi & Kithyoma, 2003) especially for off grid electrification in rural areas of Africa (Kirchner & Salami, 2014). According to world energy council projections, by the year 2030 energy from renewable energy sources will have increased by 34 % with major contributors being wind and solar sources at 17 % and 16 % respectively. Twidell and Weir, (2006) argues for that to be realized, availability of renewable resource, end user requirements, environmental impacts and cost of energy should be taken into consideration when harnessing the resources. A study by Dale (2013) show wind being cheap to exploit followed by concentrated solar power and then solar photovoltaic.

However, in terms of growth according to Renewable Energy Network (REN), (2012), from the year 2006 through 2011, solar PV was the fastest growing technology followed by solar thermal and wind power. Therefore, renewable energy resource exploitation depends on its available potential, geographical location and market availability. In Kenya, tea factories have potential for renewable energy and no evaluation has been carried out. The present study aims at bridging the gap.

2.3.2 Biomass energy utilization

Biomass covers forestry grown agricultural crops, trees, plants, organic wastes, agricultural, agro industrial and domestic wastes (Balat & Aya, 2005). Unlike other renewable energy resources, biomass can produce heat, power, chemicals i.e. solids, gases and liquids and available continuously if harvested sustainably (Karekezi, Lata & Coelho, 2004). Utilization of biomass has several benefits like job creation, reliable source of energy, source of income and infrastructure development in rural areas (Gumartini, 2009). Studies show biomass consumption vary from country to country but higher in poor countries (Karekezi, Lata & Coelho, 2004) compared to developed countries where biomass accounted for about 35 % of primary national energy requirements (Balat & Ayar, 2005). However, in developing countries like in Asia (excluding China) and Africa, biomass consumption accounted for about 30 % and 48 % of world biomass consumption respectively (International Renewable Energy Agency (IRENA), 2012). In sub-Saharan Africa about 90 % to 98 % basic national energy needs are supplied by biomass (Idiata, Ebiogbe, Oriakhi & Lyalekhue, 2013).

In Kenya, fuel wood consumption levels were about 70 % of the total national energy needs (Githiomi & Oduor, 2012) and was inadequate since a deficit of 57 % existed (Mugo & Gathui, 2010). But Balat and Aya (2005), reports about 50 % of rural populations in Africa, depend on biomass as fuel source. However, biomass consumption in Kenya was lower compared to Ethiopia of 92 % of the energy needs (Guta, 2012). Studies show biomass combustion efficiencies in developed countries are better and regulated especially on emission standards which lacks in developing countries (Gumartini, 2009).

Projections show that in Kenya, fuel wood will be the main source of energy although policy formulation on its utilization remains a challenge despite its role in the economy (Githiomi & Oduor, 2012). This projection compare well with Gumartini (2009) which show that world annual fuel wood utilization by year 2020 will be about 2 billion m^3 of fuel wood annually.

Organic wastes defined by Kitani, Junbluth, Peart and Ramdani (1999) as materials from plants already collected with low or no value have uniform characteristics is another source of energy. However, its properties depend on the moisture content, quantity and seasonal availability. Wastes generated depend on product being processed and production technique employed (Ndubuisi, Uchechi & Ougeke, 2014). A study carried out in a tea factory in India found quantities of tea waste generated depends on leaves quality, withered leaves moisture content during processing and condition of the processing machinery (Environmental Management Centre (EMC), 2012). Another study found tea factories in the Eastern bloc of Turkey produced 20 % of the annual MT as wastes (Uzun, Apaydin, Ozbay & Putun, 2010). However, Manskar (2007) reports tea wastes from a tea factory as 2 % of the black tea produced of which 0.3 % of the wastes could be reused to produce by-products. Another study found total solid biodegradable waste produced from a tea factory in Kenya to be 0.01 % of the MT produced (Oirere, 2011). Although solid tea waste has high calorific value of 16.19 MJ/kg it remains un-utilized as a source of energy and little literature on tea waste gasification, pyrolysis and carbonization was available (Esin, Ates, Ozbay & Eren, 2010). Solid contents (dry matter) play a major role during biogas production, and more amount of water means less biogas production (Seadi, Rutz, Prassl, Kottner, Finsterwalder & Volk, 2008). According to EIA (2012), co-digestion of various feed stocks ensures stable process and can produce a balanced biogas. A study in Kenya recommended utilization of organic wastes by tea factories to reduce energy costs (Murunga, 2012). However, this study did not quantify bio-waste energy but established caloric values of sawdust, briquettes, tea fluff, wet manure and immature wood to be 25.03 kJ per g, 20.24 kJ per g, 21.67 kJ per g, 23.57 kJ per g and 21.35 kJ per g respectively.

However a study in United States by Stilwell, Hoppcock and Webbner, (2010) found energy from waste water accounted for 0.1 % to 0.3 % of the total energy consumption compared to high electricity consumption by those waste treatment plants.

There are several methods of extracting energy from biomass as pointed out by International Energy Agency like combined heat and power, a proven, cost effective and reliable technology (Heat, 2008). Studies show waste heat utilization through Combined Heat and Power (CHP) technologies, savings of 20 % and 40 % of electrical and heat energy for a tea factory respectively can be achieved (Rudramoorthy, Kumar, Velavan & Sivasubramarian, 2004). However, a study by Gao, Lamtrakul and Kristsanawonghong (2014), show 10 % to 20 % savings of the overall primary energy demand could be realized. The high energy savings can be attributed to the high efficiency of CHP of about 76.5 % compared to 60 % of the convectional plants (EIA, 2012). However, United States department of energy (1999) reported efficiencies above 90 %. The best technology for maximizing energy content extraction from biomass is through gasification (Muzee, 2012). Further, Humley *et al.*, (2014), found gasification efficiency to be greater than 17 % compared to electricity generation using anaerobic digester gas. Through gasification, specific fuel wood utilization for tea drying of 0.4 kg fuel wood /kg MT was achieved resulting overall fuel wood consumption reduction by more than 50 % (Rudramoorthy, Kumar, Velavan & Sivasubramarian, 2004).

There are several cogenerations technologies in the market such as steam turbines, gas turbines, combined gas or steam cycle and diesel engines. However, gas turbines are the most efficient because they produce more electricity per unit of fuel compared to say steam turbines (MoE, 2011) a fact confirmed by US Environmental Protection Agency study report of 2011 on CHP. Due to low electricity to steam ratio required for tea processing, steam turbine topping cycle which produces electricity first is better than bottom cycle which first produces thermal energy (Rudramoorthy Kumar, Velavan & Sivasubramarian, 2004).

A study by Rudramoorthy, Kumar, Velavan and Sivasubramarian *(*2004) shows, with a 4.5 ton/hour boilers operating at a pressure of 2.4 N/mm^2 and output temperature of 300 ^{0}C, 250 kVA of electricity can be generated but levelized cost of energy was not established which this study aimed to establish. But according to International Renewable Energy National Agency (IRENA), (2012), levelized cost of energy for biomass generated electricity ranged between USD 660 to 1860 per kWh at a capacity factor range of between 45 % to 65 % and plant availability of 85 % to 90 % with feedstock accounting for about 40 % to 50 % of that cost. But, US department of energy (1999) reports lower LCOE of USD 500 to 1000 per kWh for all CHP technologies except for fuel cell with capacity factors of 25 % to 70 % and better availability of 90 % to 98 %.

In western Kenya, sugar factories have CHP plants with a cumulative generation capacity of 36.4 MW (Yuko, 2004). In central part of Kenya, Bidco oil refineries in Thika too have a 2.2 MW CHP plant (Spenomatic, 2014).There was no CHP in small holder tea factories in Kenya, although the factories use fuel wood and are located in rural areas where biomass is available. The study aim was to establish viability of CHP to maximize on the energy resources available.

2.3.3 Solar resource potential in Kenya

Kenya is located along the equator where there is adequate radiant energy from the sun which is the most important parameter when exploiting solar resource (Broesamle, Mannstein, Schillings & Trieb, 2001). Kenya receives adequate Direct Normal Irradiance (DNI) of 6 kWh per m^2 throughout the year and good for electricity generation and solar thermal applications (Ministry of Energy, 2011). However, the minimum DNI should be about 5 kWh per m^2 for solar concentrating system to be economically viable (Asian development bank, 2013). A minimum DNI of 4 kWh per m^2 is good for small PV installations and 5 kWh per m^2 for large installations like solar thermal plants (Hammar, 2011).

Figure 2-1 below shows annual direct normal solar radiation in various parts of Kenya.

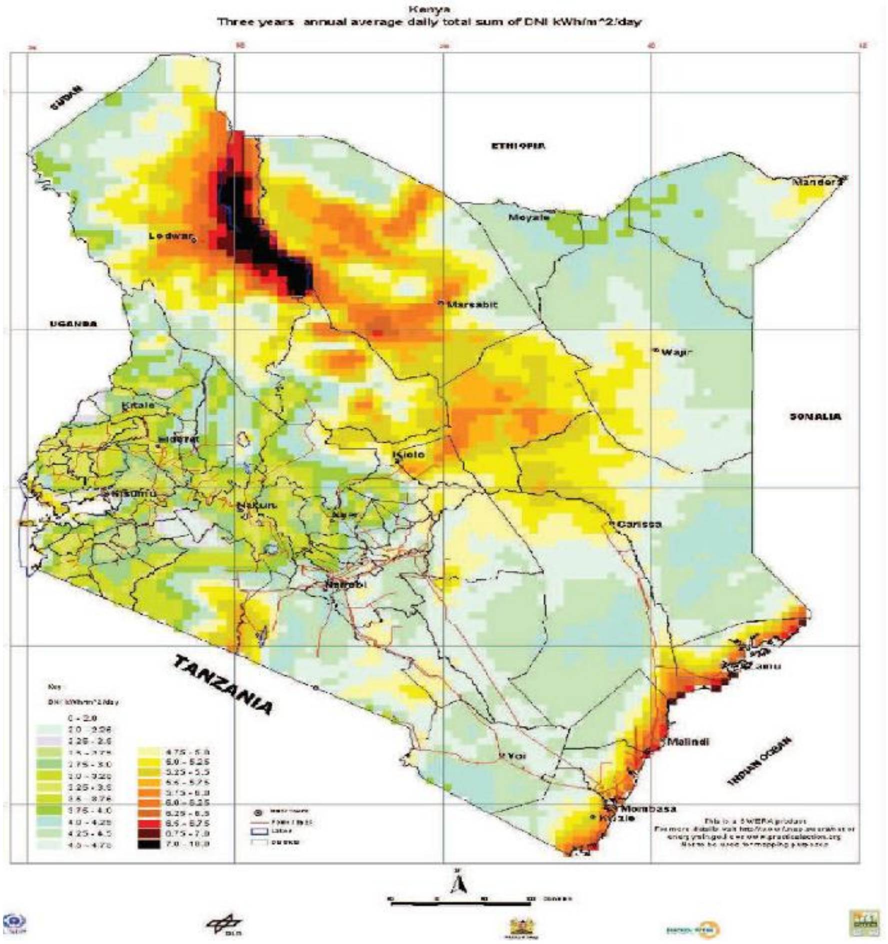


Figure 2-1 Annual direct normal solar radiation in various part of Kenya (Theuri & Hamlin, 2008)

2.3.3.1 Solar Photovoltaic (PV)

Solar PV uses photons from solar radiation to produce electricity which not only depend on intensity of radiation but duration of sunlight hours, prevailing weather conditions and storage capacity (Duffie & Bekham, 2013). The type of module affects electricity production because studies conducted in Serbia show CdTe solar modules to be the best for electrical energy generation but when leaked they are harmful to the environment (Chanel, Agrawal, Sanjay & Mathur, 2014).

However, multi-crystalline modules have better efficiencies of about 13 % to 13.5 % compared to thin film modules which have efficiency range of 6.5 % to 7 %; they require less space (Asian Development Bank, 2013) and degrade by 2 % per year (Chu & Mesein, 2011). Operation and maintenance costs for PV systems are 1 % of the initial costs and major cost of PV was the module which accounts for 50 % to 60 % of the system capital costs but vary from country to country depending on volume of sales, profit margins expected by dealers, maturity of the marketing infrastructure, duties, taxes and competition levels (Woodruff, 2007). Cost of PV module ranged between USD 0.75/W and USD1.1/W with capacity factor range of 10 % to 25 % (IRENA, 2012). That capacity factor compared well with 16.5 % to 26.1 % for a 5 MW PV plant in Iran and 27.6 % to 33.7 % for a 10MW PV plant in Egypt (Chanel, Agrawal, Sanjay & Mathur, 2014). Studies in Germany show there are higher capacity factors and that high solar irradiance results to lower Levelized Cost of Energy (LCOE) for solar PV (World Energy Council, 2013).

In Kenya, scanty information on PV for industrial application however, Uhuru farm, in Timau, 230 km north of Nairobi installed a 72 kW solar PV plant with the estimated return on investment of 5 years and Williamson tea estate in Kericho, Rift valley had commissioned Azimuth power to install 1 MW solar PV installation (Azimuth power, 2014). Other companies in Kenya that have shown interest to utilize solar energy are Sameer Africa a tyre manufacturing firm, cement manufacturer Bamburi, and snacks and spices manufacturer tropical heat which intends to supplement current sources of energy (Kenya Renewable Energy Association, 2013).

2.3.3.2 Solar thermal

Solar thermal technologies trap thermal energy from the sun, and concentrate it by solar collectors or mirrors to a fluid. The fluid which can be air or any other fluid absorbs that heat and transfers the heat to a point of use. Solar thermal collectors are categorized as low, medium, or high temperature collectors.

Examples of low temperature collectors are unglazed flat plate collectors used for swimming pool heating but can also be used as air collectors for agricultural low temperature applications such as crop drying. Medium-temperature collectors are flat-plate collectors, enclosed in an insulated case, with single or double glazing and used for heating water or air for residential and commercial use. The unglazed collector, solar pond, flat plate and evacuated collector can generate heat output temperature in the ranges of 40 ^{o}C to 60 ^{o}C, 60 ^{o}C to 90 ^{o}C, 60 ^{o}C to 80 ^{o}C and 200 ^{o}C to 500 ^{o}C respectively depending on solar radiation (Garud, 2008). High temperature collectors have absorber plates, heavy insulation, and enhanced temperature capabilities and have a sun-tracking system .They are good for steam generation for industrial applications and power generation. A study carried out by Alinta energy in 2014 in the port of Augusta found parabolic trough, power tower and linear Fresnel collectors technically viable. A parabolic trough can generate heat output in the temperature range of 100 ^{o}C to 500 ^{o}C, linear Fresnel 100^{o}C to 250^{o}C; parabolic concentrator range of 100 ^{o}C to 150 ^{o}C and parabolic dish collector can achieve temperature range of 300 ^{o}C to 1000 ^{o}C (Garud, 2008). These temperature ranges are within tea factory applications such as tea drying that require hot air within temperature range of 90 ^{o}C to 140 ^{o}C and 32 ^{o}C for tea withering (Palaniappan & Subramanian, 1998). Therefore, the temperature ranges by Garud (2008), show solar can be used for supplying hot air required for tea processing either partially or fully but that depends on cost. However, auxiliary air heating system was found necessary for supplementing solar air heating in order to produce high quality teas because of variability of solar radiation and steady uniform temperature required for tea drying process (Swaramoorthy, Mohamed & Galahiyawa, 2003). Studies show, solar air preheating systems are viable when supplementing the existing industrial heating systems although the percentage of the total process heat supplemented unlikely to be more than 30 % and viability of solar air heating depends on the cost of fuel being replaced (Rawlins & Ashcroft, 2013). In India, results from roof mounted solar air heaters which have been operational in some tea factories show with an average of five solar heating hours per day better specific fuel consumption from 0.932 to 0.71 kg per kg MT was achieved, a saving of 25 % on fuel (Palaniappan & Subramanian 1998).

However, savings of between 25 % to 34 % have been achieved (Swaramoorthy, Mohamed & Galahiyawa, 2003) and Rudramoothy, Kumar, Velavan and Sivasubramarian, (2004) argues 50 % fuel savings can be realized for every m^2 of solar collector preheating 160 kg/day of air to about 75^0 C on a sunny day. Parabolic dish was the best technology that was recommended by Asian development bank (2013), for Karnataka and Tamil Nadu small stand alone off grid power systems. Although small and standalone solar applications are cheaper for process energy requirements (VILAR(ED), 2012) they are uneconomical compared to large Concentrated Solar Power (CSP) plants of more than 10 MW in size due to economies of scale (Rawlins & Ashcroft , 2013). Cost breakdown for a parabolic trough as per United States department of energy (2011), was solar field 31 %, thermal storage 17 %, power plant 13 %, contingency 7 %, engineering, procurement and construction 12 % and land 3 %. Levelized cost of parabolic trough power plants, with thermal storage capacity of about 8 hrs at a direct radiation of 2,000 to 2,500 kWh per m^2 was 0.139 to 0.196 Euros/kWh in Germany (Kost *et al*., 2013). In California operation and maintenance (O&M) for concentrated solar power ranged USD 0.04/kWh to 0.025/kWh, insurance 0.5 % to 1 % of the capital cost and capacity factor of 18 % to 35 % (IRENA, 2012). This information on renewable energy lacks in tea factories in Kenya which this study aims to avail.

2.3.4 Wind resource potential in Kenya

Energy extracted from wind depends on the prevailing wind speeds and it involves installation of a wind turbine to converts the kinetic energy in the wind into useful energy either mechanical or electrical energy. Wind strength vary (Table 2-1) and an average value for a given location does not alone indicate the amount of energy that can be generated but that also depends on other factors like wind speed distribution, air density, rotor size and technical design of the turbine.

Table 2.1 Wind resource classification

Class Number	Description	Wind speed (m/s)	Wind power density (W/m^2)
1	Poor	0-4.5	0-90
2	Marginal	4.5-5.5	90-165
3	Moderate	5.5-6.5	165-275
4	Good	6.5-7.5	275-425
5	Very good	7.5-8.5	425-615
6	Excellent	>8.5	>615

Table 2.1 Shows wind resources classification (Nordman, 2014)

In Africa it has been a challenge when exploiting wind resource partly due to low wind speeds, lack of technical skills, lack of information and awareness (Karekezi & Kithyoma, 2003). Feasibility studies carried out in North Africa show wind energy as a good source of electricity but in East Africa little information was available on medium to large scale wind assessments (Nordman, 2014). In Kenya (Figure 2-2) the best wind potential areas are Marsabit, Samburu, parts of Laikipia, Nyeri, Ngong hills and Meru North (MoE, 2011) and similar results have been reported by Theuri and Hamlin (2008).

World wind energy association (2014), report shows about 73 % of Kenya total land area has wind speed of more than 6 m/s at a height of 100 m which includes 29 % of the tea factories in Kenya where wind resource can be exploited. For example Meru County has a power density of 355 W/m^2 at a wind speed of 6.3 m/s but has not been exploited due to wind turbines transportation challenges and limitation of selling electricity directly to consumers (Nordman, 2014). The cost breakdown by European wind association (2009) for a 2 MW wind turbine was 75.6 % turbine cost, 8.9 % grid connection, 6.5 % foundation, 3.9 % land rates, 1.5 % electrical installation, 1.2 % financial costs, 0.9 % road construction and 0.3 % control system.

Figure 2.2 shows wind power density at height of 50 m above ground level in Kenya

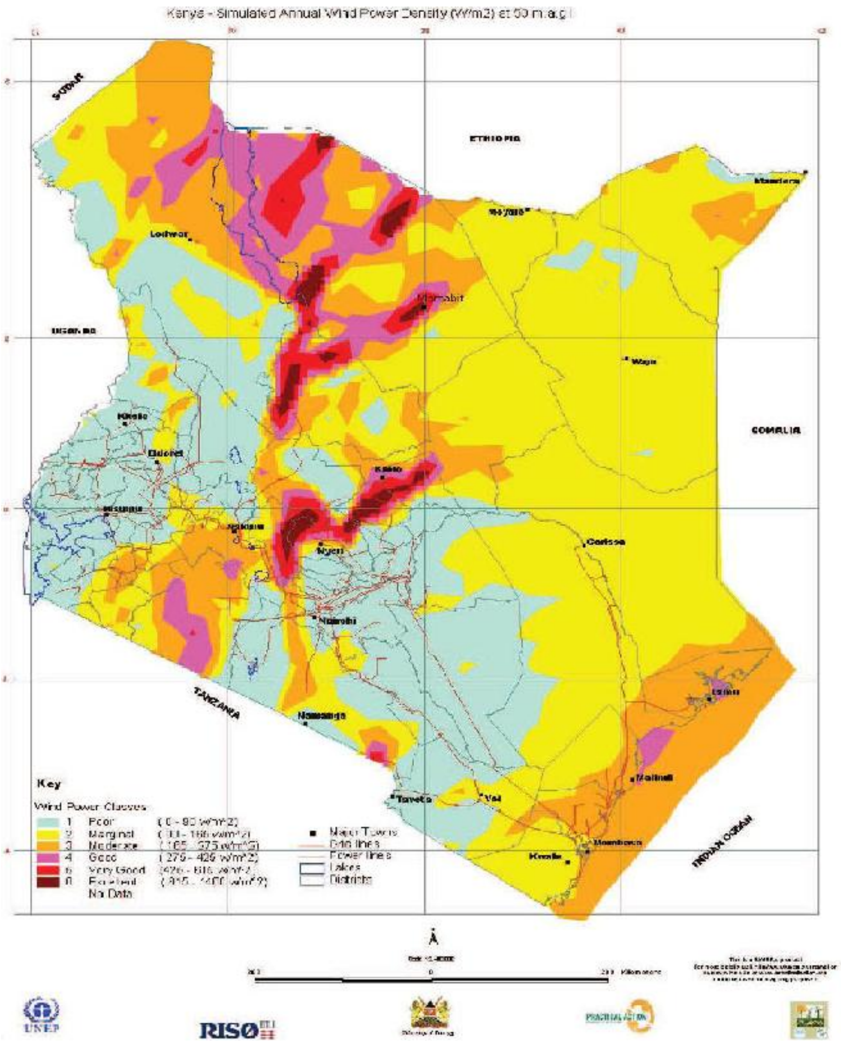


Figure 2.2 Wind power density at height of 50 m above ground level in Kenya (Theuri & Hamlin, 2008)

However, according to IRENA (2012), wind turbine alone accounted for 65 % to 84 % of the total costs, civil works 17 %, and grid connection 9 % to 14 % and construction cost 4 % to 16 %. Other costs such as roads, control systems accounted for 4 % to 10 % of the capital costs and operation and maintenance 20 % to 25 % of the levelized cost of energy (IRENA, 2012). However, Oileveira and Fernandes, (2011) reports operation and maintenance cost to be 5 % to 8 % of capital costs and 1 % to 2 % of other renewable technologies.

In Kenya, studies show cost of wind to be high compared to Europe due transportation and installation equipments cost (Economic consulting, 2012). Levelized cost of energy for Meru county turbine was estimated as USD 0.156/kWh which was below diesel and grid electricity of 0.202/kWh and USD 0.173/kWh respectively (Nordman, 2014) compared to a wind project in Nigeria of USD 0.493/kWh to USD 0.606/kWh at a capacity factor of 21 % to 28 % (Ahmed, Bello & Habou, 2013).

2.3.5 Renewable energy projects appraisal

A project is defined as the smallest, unique, separate planned investment financed that is implemented separately and utilizes scarce resources for a specific period of time to create socio-economic return of goods and services (Glendary, *et al.*, 2008). Therefore, projects should be evaluated because they utilize scarce resources and the resulting information assists during decision making (Oliveira & Fenandes, 2011) especially for forecasting purposes (Afonso & Cunha, 2009).

The two types of project appraisal are; economic appraisal which is more relevant for public funded projects and financial appraisal for commercial projects (Pierce, 2007). Renewable energy projects financial appraisal not only assists the investor to establish financial viability of the project but also strengthens lenders confidence that view renewable energy projects as risky ventures. Therefore, identification of all expenses and revenues related to projects lifetime should be established when carrying out project financial analysis. Renewable energy technologies costs comprise of investments costs, development costs, feedstock cost, operation and maintenance costs (Kirchner & Salami, 2014). When carrying out financial appraisal, rate of inflation is factored in the analysis because it affects project sustainability and economic viability of the project but interest rates, debt repayments, tax liabilities should be estimated at the time they are incurred whereas depreciation, should be ignored (Hubner, 2008). In capital investments, discounted cash flow methods are preferred rather than non discounted cash flow methods (Afonso & Cunha, 2009) and project(s) are considered viable when discounted benefits exceed discounted investment costs (Brzozowska, 2007).

Methods that are used to establish viability of a renewable energy project are life cycle costing, levelized cost (LCOE) method, and cost to benefit analysis method, internal rate of return, simple payback period and overall rate of return method. But according to Alinta Energy (2014), LCOE has been used by reputable bodies like IEA and National Renewable Energy Laboratory (NREL) to discount total life costs back to the base year so as to compare different renewable projects. According to world energy council (2013), LCOE is the revenue that the project should earn per MWh for that particular project to break even excluding subsidies, cost for connecting to the grid and any other support mechanism. LCOE of renewable energy technologies has been declining and as a result about 50 % of the new power generated worldwide was from renewable energy resources (IRENA, 2012). However, when calculating LCOE assumptions such as stable interest rates, exchange rates, electricity prices stability, no government incentives and taxes over the lifetime of the project are made (IEA, 2012) but subsidies and cost of grid connection should be excluded (World Energy Council, 2013). Further, according to IEA, (2012) contingency and scrap value used should be about 5 % and 20 % of the initial renewable installations investment respectively although no country has ever reported 20 % scrap value but 5 % of the construction cost used purposes of financial analysis. Competitiveness of any renewable energy projects depend on the specific investment, operating and maintenance costs, investment lifespan, renewable resource potential available, cost of feedstock’s and financing conditions (Kost *et al.*, 2013).Hydro power has been the cheapest renewable source of electricity with wind, biomass and geothermal electricity cost being below or same level with fossil fuel electricity but solar PV slightly above fossil fuel technologies (Kirchner and Salami, 2014). However, Woodruff, (2007) argues that there is no cheap renewable technology but the cost depends on local resource availability and conditions. Therefore, any renewable energy investor should carry out both pre-feasibility and full feasibility study to screen these projects and get an indication whether set objectives would be achieved since the cost of renewable energy depend on individual project and can change due to technological advancement and economies of scale (Oliveira & Fernandez, 2011).

Renewable energy investors face challenges like high cost of debt, high interest rates. For example cost of debt in India, was between 10 % to 14 % compared to 5 % to 7 % in United States and that debt cost depends on country perceived risks (Nelson, Shrimali, Goel, Konda & Kumar, 2012). According to Nelson, Shrimali, Goel, Konda and Kumar *(2012*), total finance cost of a project depends on cost and duration of debt, as well as return on equity by equity investors. In India renewable energy resources like wind and solar are adequate, construction, variable cost and labour costs are low but due to financing costs, renewable energy cost higher than in Germany and United states (Nelson Shrimali, Goel, Konda & Kumar*, 2012*). Another study by Allen consulting group in Australia (2013), cautions on financial analysis results which should not be taken to mean financial viability of a renewable project since a detailed resource assessment should be carried out. Ballantine, Galliers and Stray*, (*2012), indentified the challenges encountered when carrying out project financial appraisal as lack of right information, lack of knowledge and organizational problems. Therefore, the parameters that determine levelized cost of renewable energy are capital costs, including operation and maintenance costs resource available, technical factors such as characteristics of the wind turbine, debt duration, discount rates used and interest rates (IRENA, 2012).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study location

The study was undertaken in tea factories under Kenya Tea development agency in in Nyeri and part of Muranga Counties which had 9 factories. There are seven administrative regions in Kenya with a population of 54 tea factories but due to their geographical location and cost considerations, focus was mainly on region two. The administrative office of the region located in Othaya, Nyeri County which is 145 km from Nairobi the capital city of Kenya.

Table 3.1 shows the co-ordinates of the factories and their codes that were used in the study.

Table 3.1 Geographical location of the selected tea factories

No	Factory	Code	Latitude	Longitude
1	Githambo	F1	-00 43’ 44’’N	36053’36’’E
2	Kanyenyaini	F2	-00 40’ 46’’N	36054’56’’E
3	Gatunguru	F3	-00 38’ 19’’N	36054’2’’E
4	Kiru	F4	-00 37’ 11 N	36053’20’’E
5	Chinga	F5	-00 36’ 6’’ N	36053’50’’E
6	Iriaini	F6	000 32’ 39.3’’ S	36054’36’’E
7	Gitugi	F7	000 31’ 04’’ S	36052’29’’E
8	Gathuthi	F8	000 29’ 27’’ S	36053’38’’E
9	Ragati	F9	-00 23’ 29’’ N	370 9’ 33’’E

Figure 3.1 shows the study area map that indicates the location of the tea factories.

Figure 3.1 Study area map (Google Maps, 2015)

3.2 Research design

Five years processed tea data, electricity, fuel wood, fuel oil and diesel consumption including corresponding cost was obtained from 9-tea processing factories in Nyeri and part of Muranga County in central Kenya (Table 3.1). The period covered was from June 2009 to June 2014 on monthly basis. The data represented about 17 % of small scale holder tea factories operating in Kenya. Data on energy was converted to common energy units by using conversion coefficients from literature review. Data on factors that influence energy indicators among the factories was collected for analysis to study any relationship. Bio-degradable wastes data was collected from the sampled tea factories in that region and energy potential estimated. Wind and solar regime data was extracted from Renewable Energy Technology (RET) screen software data base and trended against monthly made tea volumes.

Plant survey to collect data for financial analysis was carried out at Iriaini tea Factory to estimate energy requirements for a tea factory. Primary data on factory end use thermal and electrical energy requirements was used to size and carry out the financial analysis of the renewable technologies. Financial and technical analysis assumptions were collected through literature review but the author made own assumptions (Appendix VI).

3.3 Sample design

For purposes of this study, due to financial considerations and time, convenience sampling was used to sample area of this study from the 7 regions under Kenya Tea Development Agency management. Iriaini Tea factory was selected for plant the survey, wind and solar resource assessment since the data from RET screen was for Nyeri county. Biodegradable primary data was collected from sampled tea factories.

3.4 Data collection method and procedure

Monthly made tea quantities, electricity, fuel wood, fuel oil and diesel consumption as well as cost secondary data was obtained from 9 tea factories in Nyeri and part of Muranga County in central Kenya. The period covered was 5 years from June 2009 up to June 2014 and all monthly energy consumption, cost of energy and production records for the period under study were complete. Data on factors considered to influence energy indicators was also collected from among the factories for analysis. Also primary data on bio-waste on weekly basis for the month of August 2014 was collected from sampled tea factories within the study area. Primary data on the various bio-wastes which included waste water (effluent) and sewage from staff houses was collected. Wind and solar irradiance data by American space agency NASA was obtained from RET screen version 4 software data base. Primary data was collected for sawdust wastes produced when billeting fuel wood. A plant survey was carried out to estimate the sectional energy requirement for a tea factory at Iriaini tea factory between 4th and 6th of September 2014. Cost of the viable technologies for purposes of carrying out financial analysis was sourced from a firm in India.

3.5 Data processing and analysis

Data was collected, coded, analyzed using Excel spreadsheet and RET screen version 4.0 software. Annual consumption for each source of energy was determined including percentage share for each source of energy as percentage of the total energy consumption and cost. Energy intensity and specific energy ratios were calculated to determine the energy utilization pattern for each factory. Also comparison was made between energy indicators and factors causing intensity variations. Bio waste data collected was also coded and analyzed using Excel spreadsheet. Energy potential for each bio-waste was determined including percentage contribution share of energy for each bio waste as percentage of the total thermal energy requirements using conversion factors from literature review. Sectional energy requirement was determined from the plant survey data collected. Wind and solar secondary data was analyzed by trending and comparing it with MT production levels on monthly basis. Renewable energy financial analysis was carried out using RET screen version 4 software and various assumptions were made (Appendix VI). All the data and results obtained was summarized and presented in form of tables and figures. The findings obtained were used to make conclusions and recommendation(s) about energy indicator trends, factors causing indicator variations and use of renewable energy resources available within tea factories in Kenya.

CHAPTER FOUR

RESEARCH RESULTS AND DISCUSSIONS

4.1 Energy consumption trends in tea factories

There are various sources of energy consumed by the tea factories such as fuel wood, fuel oil, diesel and electricity from the national grid. Also various sections within the tea factory have different energy requirements.

4.1.1 Analysis of energy consumption in tea factories

Table 4.1 shows 5 years average energy consumption and energy indicators for the 9 selected tea factories. Energy data analysis for each year is presented in appendix I to V. For puposes of carrying out the analysis it was assumed that all electrical and thermal energy consumed goes directly to production. Therefore energy intensities indicated ignored any form of energy losses. To facilitate comparison the following conversion coefficients were used for the puposes of the analysis:

Electricity 1 kWh = 3.6 MJ, Fuel Oil (HFO) = 40.28 MJ/Litre, Diesel = 41.40 MJ/Litre, Wood 1 kg = 14.40 MJ (Engineering tool box, 2015). Density of wood was taken as 541 kg/m^3 giving 7790 MJ per m^3 of fuel wood. 1 USD equivalent to Ksh 85. Diesel and furnace oil was converted into the equivalent electricity and fuel wood respectively. From the analysis (Table 4.1) the average energy intensities ranged from 32.76 MJ/kg MT to 38.31 MJ/kg MT and average energy intensity was 34.87 MJ/kg MT. Cost intensity ranged from USD 163.05 per ton MT to USD 214.72 per ton MT with an average of USD 190.73 per ton MT. Other energy indicators like specific fuel wood ratio ranged between 0.384 per ton MT to 0.475 per ton MT per ton fuel wood and specific electricity ratio ranged 590.06 kWh per ton MT to 798.73 kWh per ton MT. The total specific thermal energy requirements in India and Sri-lanka ranged from 4.45 kWh/kg MT to 6.84 kWh/kg MT and about 10 kWh/kg MT in Vietnam and specific electricity ratio for these three regions ranged from 0.58 kWh/kg MT to 0.80 kWh/kg MT which compares well with study results (Baruah, Khare & Rao, 2012)

Table 4.1 Tea processing 5-Years average energy consumption analysis from July 2009 up to June 2014

Factory code	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual Made Tea ('000) (Ton)	4.14	4.00	3.76	3.98	3.43	3.09	2.62	3.09	3.20
Electricity energy (MJ) (%)	5.62	5.77	6.82	6.06	7.33	8.16	6.54	5.90	5.82
Diesel energy (MJ) (%)	1.02	1.22	1.06	0.61	0.76	0.43	0.62	0.58	0.81
Fuel wood energy (MJ) (%)	86.82	90.3	92.1	87.75	90.19	91.33	92.11	93.5	87.73
Fuel oil energy (MJ) (%)	6.55	2.69	0.00	5.58	1.71	0.08	0.73	0.00	5.64
Energy intensity (MJ/kg MT)	35.00	37.2	33.00	38.31	32.76	33.46	32.4	32.77	37.44
Cost intensity (USD/Ton MT)	193.4	191.0	185	214.7	201.0	172.5	179.3	163.1	206.7
Electricity ratio (kWh/ Ton MT)	645.0	723.0	722.0	709.9	736.7	798.7	644.6	590.1	689.6
Fuel wood ratio (Ton MT/Ton wood)	0.42	0.41	0.48	0.38	0.47	0.47	0.48	0.47	0.39

4.1.2 Energy types and proportions

Figure 4.1 shows the region average share of energy resources for tea manufacturing. The share of each source of energy varied from factory to factory whereby electricity, diesel, fuel wood and fuel oil ranged from 5.62 % to 8.16 %, 0.43 % to 1.22 %, 86.82 % to 93.52 % and 0 % to 6.55 % respectively.

The main sources of thermal energy were fuelwood and fuel oil which averaged 89.93 % and 2.88 % respectively for the period. Electricity sources were supplied by standby diesel generator(s) and electricity from the national grid which were 0.82 % and 6.37 % respectively. Therefore, energy proportion for tea processing in the area under study was 92.81 % thermal and 7.19 % electrical energy which compared well to 80 % to 85 % thermal energy supplied from fuel wood in Sri- Lanka, 15 % from fuel oil and 15 % to 20 % electricity from the grid (Jayah, Aye, Fuller & Stewart, 1999). The same study found out that in Vietnam, thermal energy consumption accounted for 80 % and electricity 20 %.

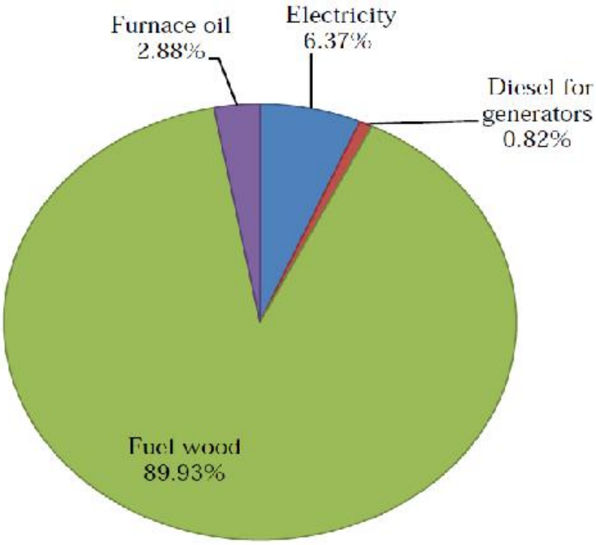


Figure 4.1 Proportions of different energy sources used in tea factories

The main source of energy for tea factories was fuel wood with a share of 89.32 % of the overall energy requirements compared to the national fuel wood contribution of 70 % (Githiomi & Oduor, 2012), 92 % in Tanzania (Sheya & Moshi, 2000) and 90 % to 98 % in africa (Idiata,Ebiogbe,Oriakhi & Lyalekhue, 2013). That large share of energy supplied by fuel wood shows when utilized efficiently the overall energy intensity achieved could be lower. According to economies of scale, the factory with the highest average production like F1 tea factory of 4,138.32 tons of processed tea should have the least energy and cost intensity compared to F7 tea factory whose production was the lowest at 2,624.61 tons of processed tea.

However that was not the case because the factory with the highest production had higher energy intensity at 35.0 MJ per kg MT compared to 32.4 MJ per kg MT for the tea factory which had the least production.

4.1.3 Tea processing energy cost analysis

Table 4.2 shows the average unit cost of energy over the period for various sources of energy. From Table 4.2, the cost of diesel consumed by standby generator was USD 0.09 kWh compared to electricity from the national grid of USD 0.15/kWh. Fuel oil was quite expensive at USD 0.05/kWh compared to fuel wood cost of USD 0.01/kWh which was 6.24 times more expensive than fuelwood. The high cost explains why most factories shifted from utilization of fuel oil to fuel wood as source of thermal energy (Figure 4.10).

Table 4.2 Average unit cost of energy used in tea processing from July 2009 up to June 2014

Energy source	Electricity	Fuel oil	Fuel wood	Diesel
Unit cost (USD/kWh)	0.15	0.05	0.01	0.09

Figure 4.2 shows fuel wood, electricity, diesel and fuel oil cost share as 37.84 %, 51.34 %, 3.95 % and 6.86 % respectively. It shows electricity from the national grid as the most expensive source of energy for a tea factories as shown in Table 4.2. Figure 4.1 shows electricity accounted for only 6.37 % of the total energy requirement during tea processing but 51.34 % of the overall energy cost (Figure 4.2) and 17 % of the total production cost (GTIEA, 2007). Therefore, main determinants of cost intensity achieved was electricity from the national grid and standby generators since unit cost per unit of energy from these sources was higher compared to the thermal energy sources. Any improvement in the specific electricity utilization can result to production cost reduction for a tea factory.

Figure 4.2 shows the average cost breakdown for each energy cost source

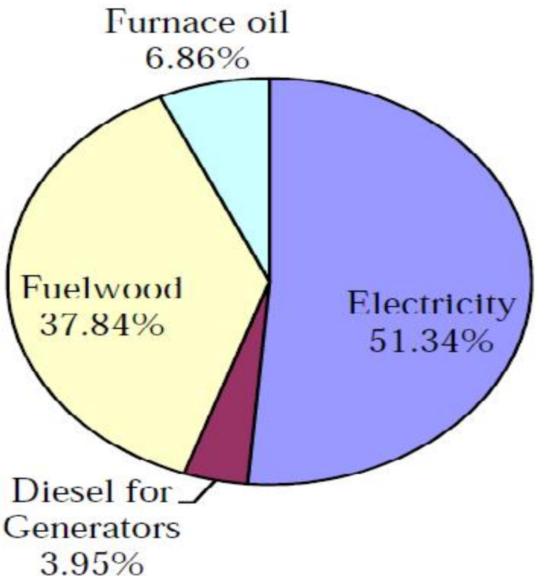


Figure 4.2 Proportion of energy cost by source in tea processing

4.1.4 Annual energy intensity trends for tea factories

Figure 4.3 shows 5-year's annual energy intensity for period from June 2009 to June 2014.

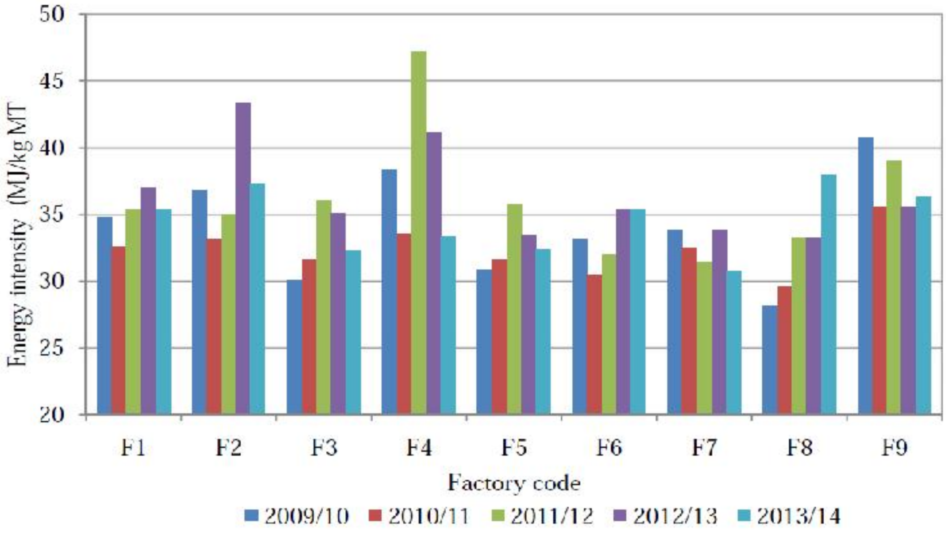


Figure 4.3 Annual energy intensity trends in tea factories

It shows factory F1, F2, F4 and F9 have higher energy intensities compared to the other factories. It shows energy intensities varied annually and from factory to another, although these factories are located within the similar geographical area.

4.1.5 Monthly energy intensity trends for tea factories

Figure 4.4 shows the average monthly energy intensity trends for the different tea factories. The factories exhibit increasing energy trends from January up to July and similarly from October to November.

The figure shows the average monthly energy intensity trends for the different tea factories.

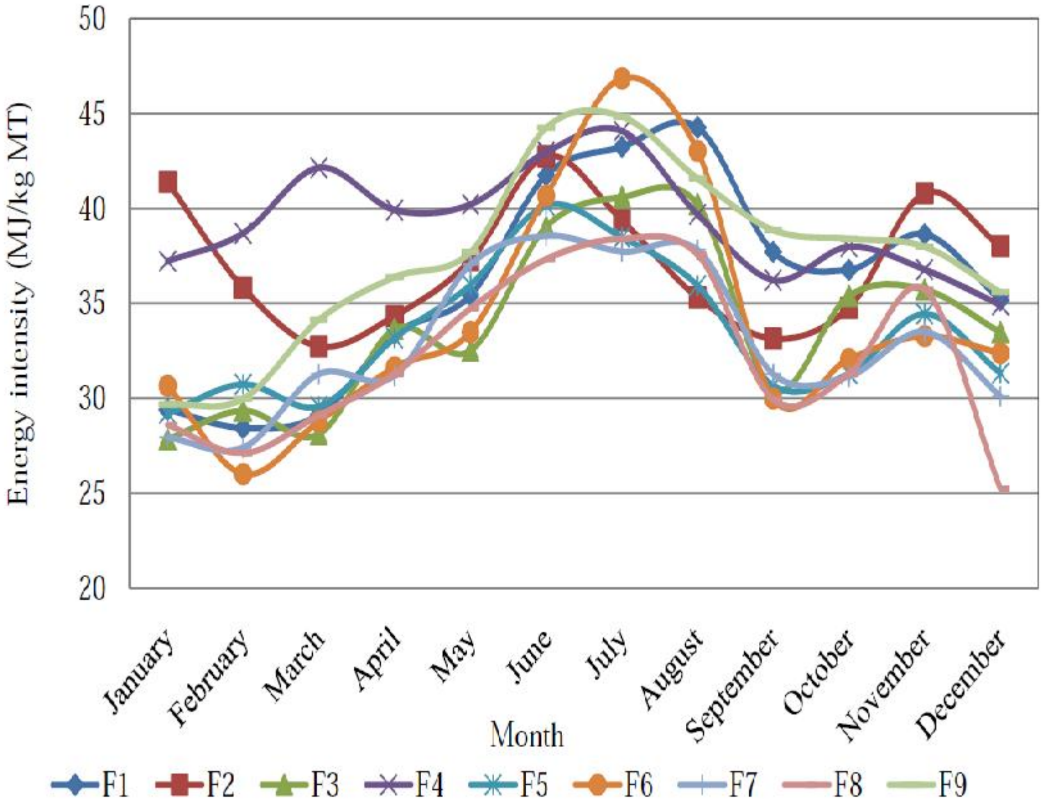


Figure 4.4 monthly energy intensity trends for the different tea factories

4.1.6 Seasonal specific energy ratio variations

Figure 4.5 shows monthly fuel wood and electricity specific energy ratio analysis over the 5 years period. It shows energy indicators vary from month to month and there was a pattern in some months over the period.Tea production depends on the prevailing weather and during low crop season the green leaves received for processing have little surface water. Like the months of August and September there was low thermal energy demand. Therefore,there was high electricty ratio during low crop season compared to fuel wood ratio because of the fixed electricity load independent of processing levels.

The Figure below shows monthly fuel wood and electricity specific energy ratio analysis a well as energy intensity over the 5 years period

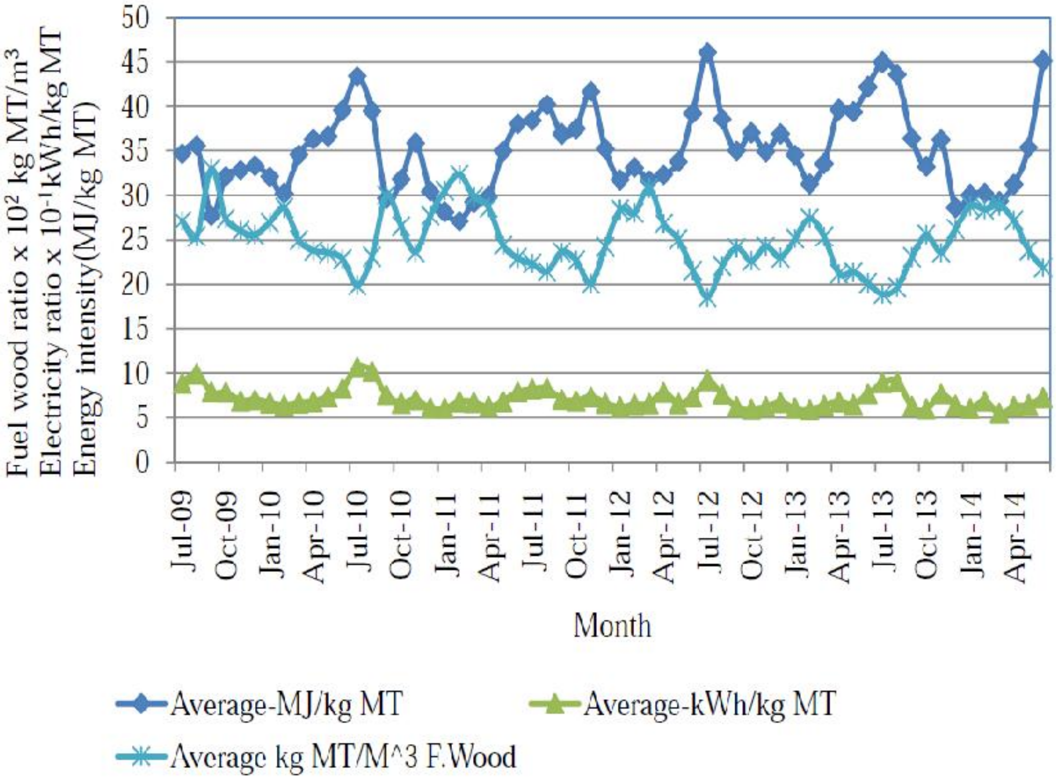


Figure 4.5 Monthly energy intensity trends in tea processing

4.2 Factors causing energy indicators variations

Energy indicators vary from factory to another as seen from the analysis in Figure 4.3, Figure 4.4 and Figure 4.5 considering that these tea factories are within a similar geographical area. Energy indicator variations can be attributed to the following factors:

4.2.1 Production volume

Figure 4.6 shows monthly variation between production and energy intensities for the period. The energy intensities varied with production volume and it's not constant throughout the year. It shows when production was very high the energy intensities were low which can be attributed to economies of scale.

The figure below shows the variation of production volume with energy intensity.

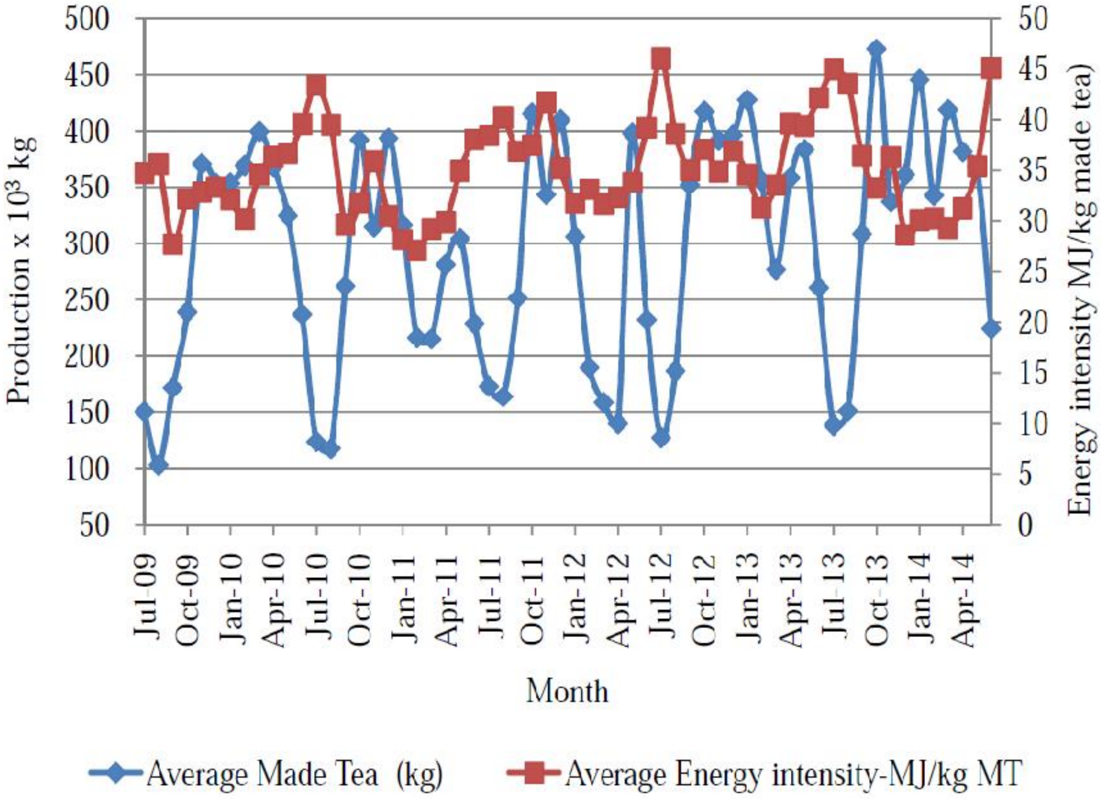


Figure 4.6 Variation of production volume with energy intensity

4.2.2 Climatic factors

Figure 4.7 shows the relationship between monthly ambient temperature, relative humidity (source; RET screen) and 5 years average monthly energy intensity during the study period. It shows that the energy intensities varied with relative humidity and air temparature. High relative humidity resulted to high energy intensities.

The ficure below shows the relationship between monthly ambient temperatures relative humidity

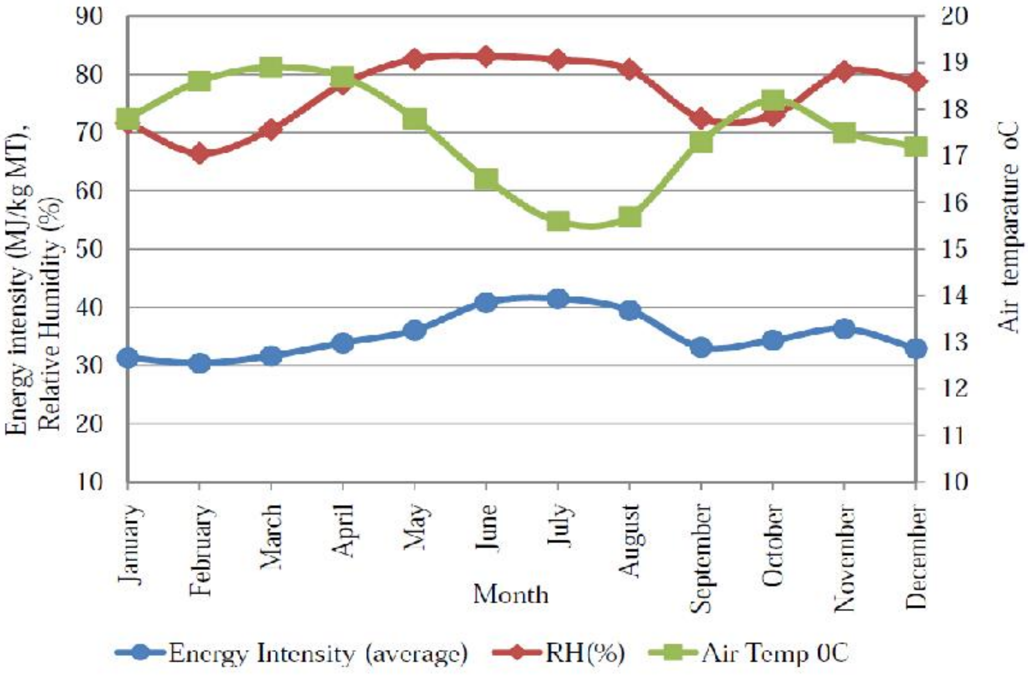


Figure 4.7 Variation of energy intensity with ambient conditions

4.2.3 Diesel consumed by standby generator

Figure 4.8 shows the relationship between electricity specific ratio and cummulative share of energy from diesel consumed by standby generators installed in the area of study. It shows that when the share of energy from diesel consumed by generators was high, the specific electricity ratio was high too. The monthly average power failure for the area of study was 41.1 hrs compared to Africas' average of 77 hrs per month. From the analysis diesel consumption accounted for 0.82 % of the factory energy requirements (Figure 4.1) and 3.95 % of the energy bill (Figure 4.2).

Figure shows the variation of specific electricity with standby diesel consumption

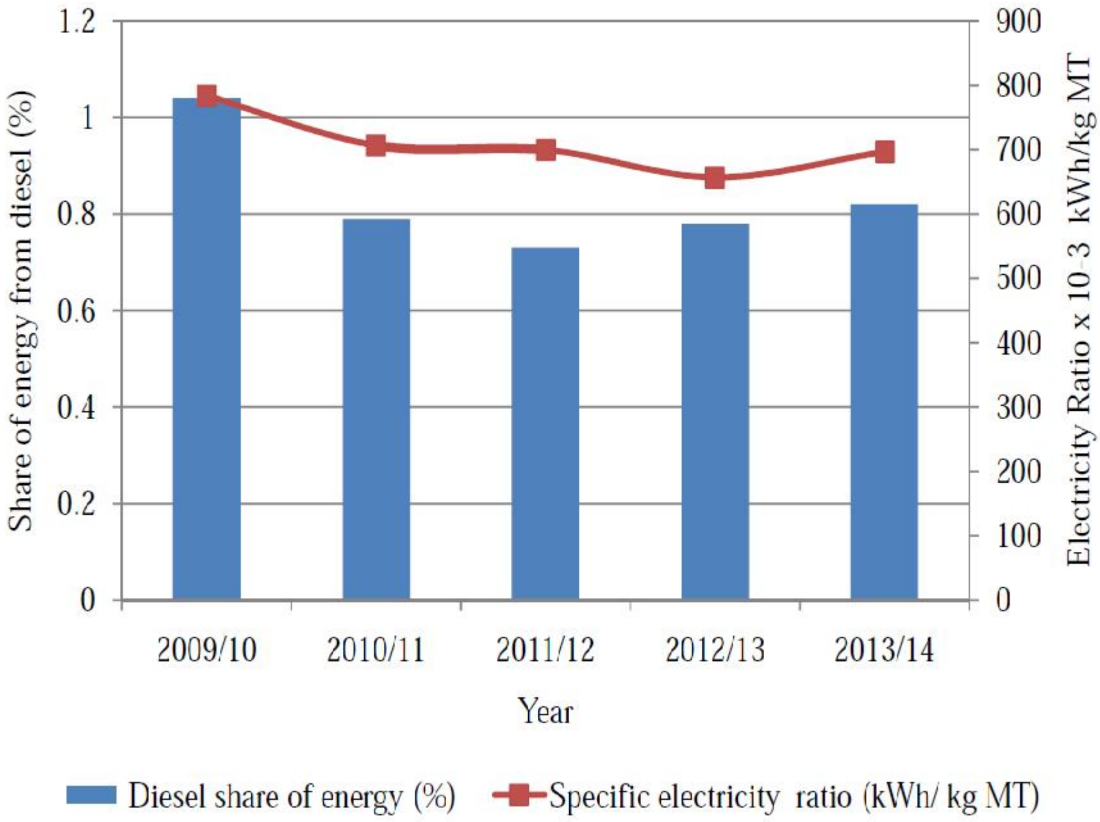


Figure 4.8 Variation of specific electricity with standby diesel consumption

Power failure(s) affect plant efficiency of a tea factory due to processing interruptions which prolongs processing hours eventually affecting energy indicators

4.2.4 Cost of different sources of energy in tea processing

Figure 4.9 shows five years fuel oil consumption and cost per litre trend of fuel oil. It shows the cost per litre of fuel oil increased from USD 0.46 to USD 0.83 in five years which was an increase of over 80.4 %. The figure also shows that as the price of fuel oil increased its consumption reduced from an average of 6.59 % to 1.21 % over the period and there was zero utilization in some months. This implies the high cost of fuel oil discouraged its consumption.

The figure below shows the trend of fuel consumption in the region and cost from July 2009 up to June 2014

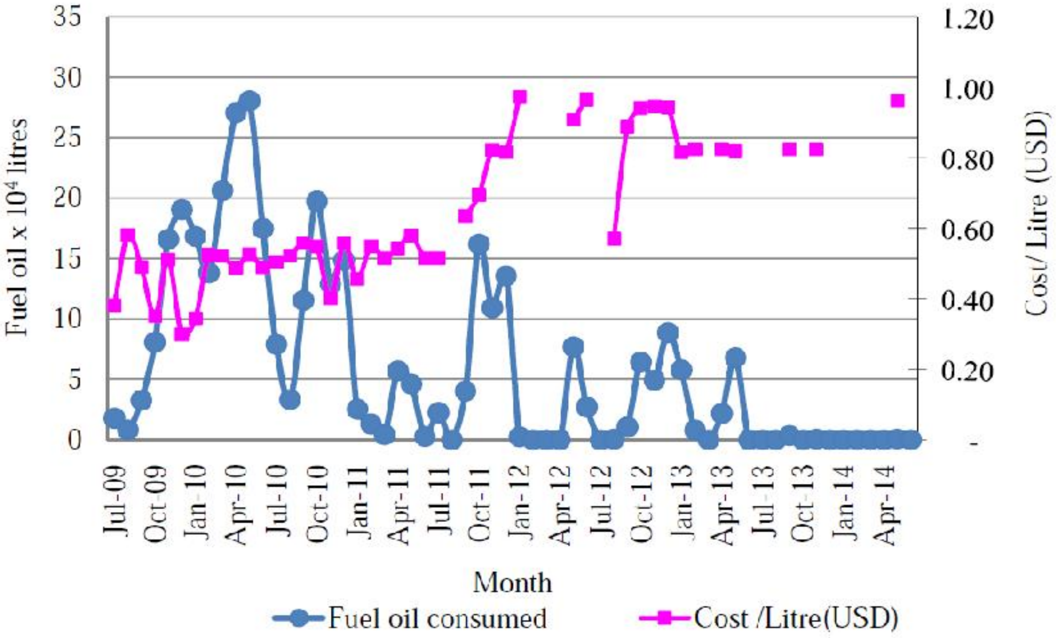


Figure 4.9 Variation of fuel oil consumption and fuel oil cost

Figure 4.10 shows analysis on fuel wood from July 2009 up to June 2014, which shows that fuel wood consumption and cost per ton increased gradually by 5.39 % and 7.18 % respectively. The increase in fuel wood consumption confirms that in future fuel wood will still be the main source of energy (Githiomi & Oduor, 2012). That increase in fuel wood cost can be explained by the law of supply and demand since factories shifted from fuel oil utilization which was 6.24 times more expensive to a cheaper source (Table 4.2). Fuel wood consumption accounted for about 90 % of the tea processing energy requirements. A similar case reflected in India and Sri Lanka where fuel wood was the main source of thermal energy (Baruah, Khare & Rao, 2012). It means that fuel wood impacts greatly on the energy intensities achieved by tea factories. Figure 4 .9 and Figure 4.10 shows energy cost being a major factor considered when determining the source of energy to use for tea processing. Fuel oil being 6.2 times more expensive than fuel wood (Table 4.2) implies its consumption results to higher cost intensity.

The figure shows the variation of the quantity of firewood consumption with price.

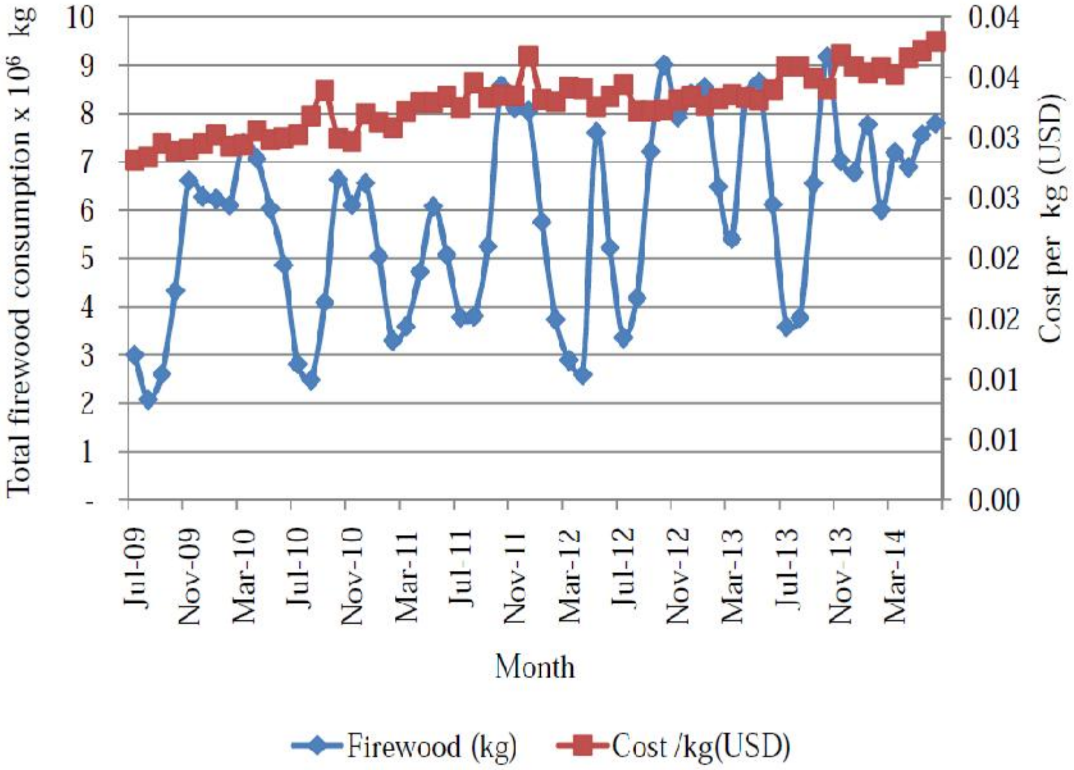


Figure 4.10 Variation of fuel wood consumption and cost

4.2.5Effect of operational factors on energy intensities in tea processing

Air flow rates data used for withering green leaves and the overall energy ratios of electricity were also analyzed for all the 9 factories (Figure 4.11). Figure 4.11 shows electricity ratio was affected by airflow rates used in withering green leaves during tea processing. Tea factories with high airflow rates had high electricity specific ratios. Studies have shown an average airflow rate of 0.01 m^3/s per kg green leaves as the optimum in Sri Lanka and power saving of 12 % to 32 % was achieved at a loading density of 26.90 kg/m^2 of green leaves by adjusting pitch angles of the withering fans (Botheju, 2013). The same study found at loading rate of 26.9 kg/m^2 and airflow rates of 0.011 m^3 /s per kg green leaves electricity specific ratio for withering of 0.24 kWh per kg MT was achieved (Botheju, 2013). Withering section energy utilization records for F2, F3 and F4 factories for different days selected for year 2011 to 2012 was analyzed as shown in Table 4.3.

Figure shows the variation of air flow rates with specific electricity ratio

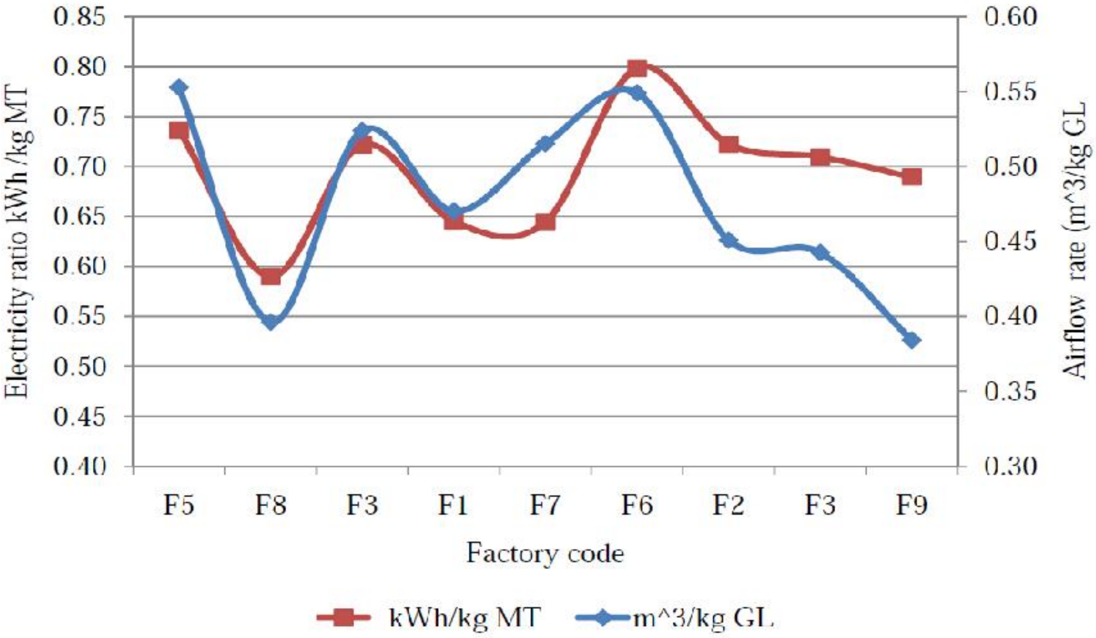


Figure 4.11 Variation of air flow rates with specific electricity ratio for different factories

From table 4.3, it was evident that when no steam was utilized for when withering green leaves , at a loading density range of 19.26 to 26.90 kg/m^2, the electricity specific ratio ranged from 0.26 kWh/kg MT to 0.93 kWh/kg MT. But with steam application at loading density range of 16.27 kg/m^2 to 26.90 kg/m^{2,} electricity specific ratio ranged from 0.26 to 0.73 kWh/kg of MT. These results show mode of operation of energy consuming equipments affects energy intensities. Therefore, the analysis show loading density, airflow rates and steam application duration during withering process affects specific electricity ratio. Therefore, low airflow rates and no steam utilization prolong withering time and when coupled with low loading rate results to higher specific electricity ratio leading to higher cost intensities.

Table 4.3 Variation of electricity ratio with loading density and steam application

Code	Parameter	No steam application				Steam application			
F2	Electricity ratio (kWh/kg MT)	0.26	0.93	0.27	0.31	0.72	0.63	0.73	0.32
	Loading density (kg/m^3)	24.42	21.95	16.6	17.8	16.57	16.57	16.57	24.42
F3	Electricity ratio (kWh/kg MT)	0.49	0.55	0.51	0.46	0.26	0.33	0.26	0.32
	Loading density (kg/m^3)	26.9	26.9	26.9	26.9	26.9	23.02	23.02	21.95
F4	Electricity ratio (kWh/kg MT)	0.76	0.81	0.76	0.74	0.44	0.56	0.68	0.32
	Loading density (kg/m^3)	19.26	19.26	19.3	19.3	19.26	19.26	19.26	21.95

4.2.6 Overall Equipment Effectiveness (OEE)

Figure 4.12 shows the overall equipment effectiveness and energy indicators relationship over the period for the 9 tea factories.

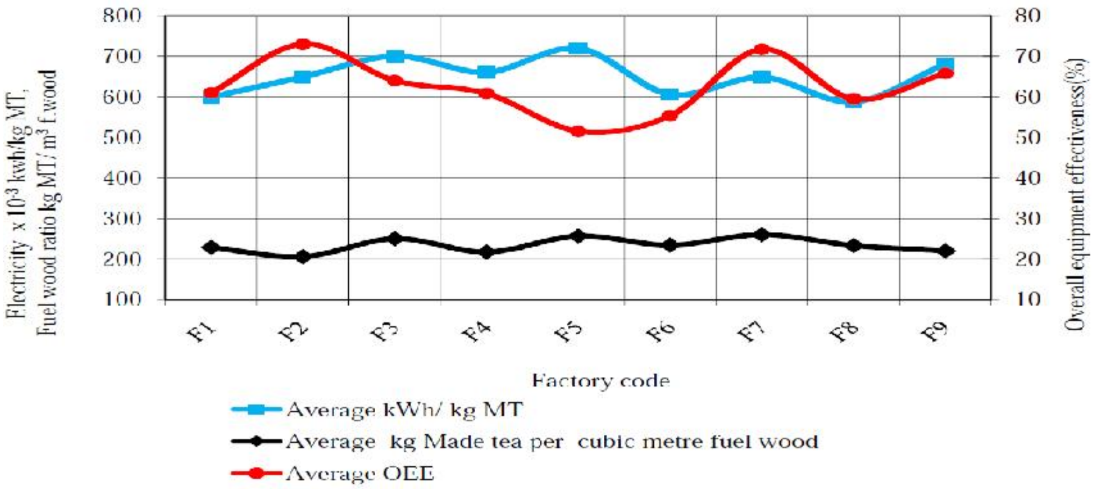


Figure 4.12 Variation of the specific energy ratios with OEE

It shows that low OEE results to high energy intensities. Low OEE prolongs production time resulting to lower production rates. The average OEE index for 9 tea factories of 62.6 % low compared to world class OEE index of 85 % (Glova, 2012). Study buy (Kumar,Sujatha & Thyragajan, 2012) and CIPEC (2006) show plant efficiency and down time respectively affect energy indicators. Tea factories can reduce energy cost intensity by matching production machinery to improve production rate and adopting high maintenance practices to reduce downtime.

4.2.7 Effect of conversion factor on energy specific ratio

Figure 4.13 shows the relationship between conversion factor and specific energy ratio which vary from factory to factory. From the analysis, low conversion factor results to low specific electricity ratio and high fuel wood ratio. It shows that when the weather was dry conversion factor was better and this is the period when leaves had less moisture content hence steam consumption lower over that period meaning low steam demand.

Conversion factor has an effect on the overall energy intensity, when it was high, energy intensities were low translating to low cost intensity.

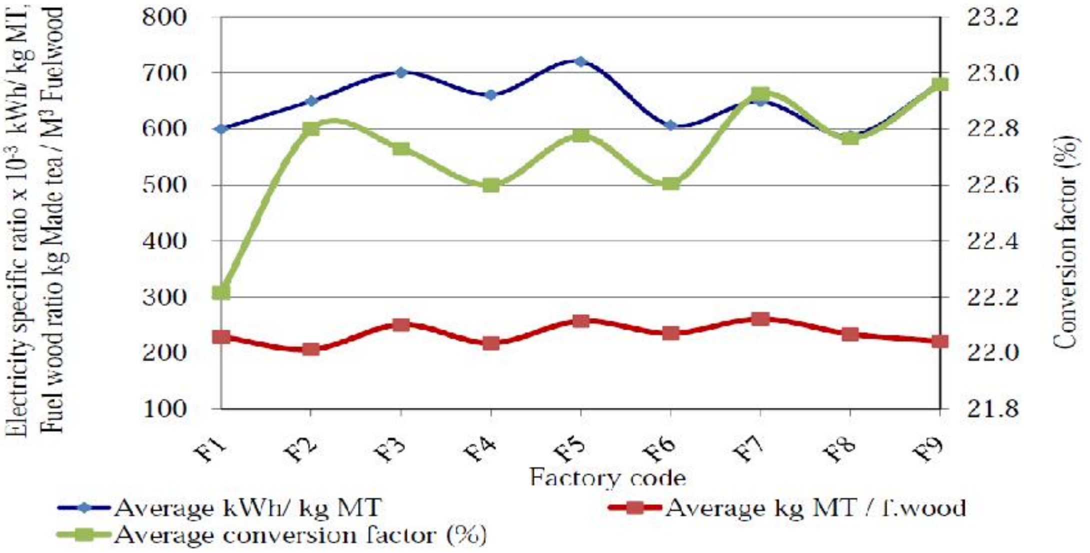


Figure 4.13 Relationship between conversion factor and specific energy ratio

4.2.8 Effect of firewood type and management on specific ratio

Figure 4.14 shows the relationship between firewood storage, fuel wood specific ratio and energy intensity.

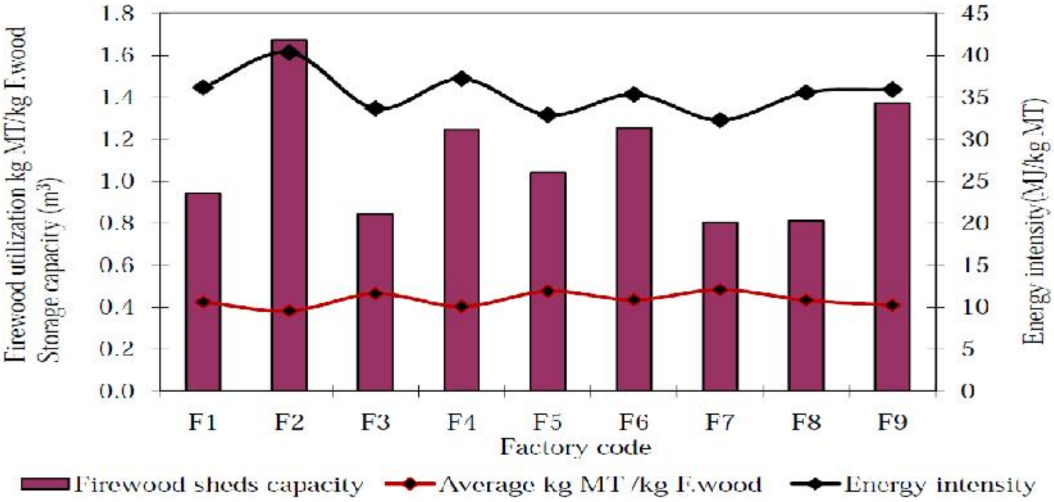


Figure 4.14 Relationship between firewood storage, fuel wood specific ratio and energy intensity

The figure shows that factories with the least storage capacity had high energy intensities. Inadequate storage compromises fuel wood quality especially during wet weather eventually affecting specific fuel wood ratio. Studies have shown for fuel wood to be well cured it must be stored for at least six months in an enclosed and well aerated place.

Data from July 2013 up to July 2014 from F3 which had separate records for different types of fuel wood consumed was selected and analyzed to establish the effect of fuel wood type on energy intensity (Figure 4.15). The figure shows that the type of fuel wood consumed affects specific fuel wood ratio. It shows when more softwood was consumed specific fuel wood ratio decreased and vice versa for hardwood. Therefore, different fuel wood types have different energy content which affects the overall energy intensity achieved.

The Figure shows a comparison between fuel wood type and specific fuel wood ratio

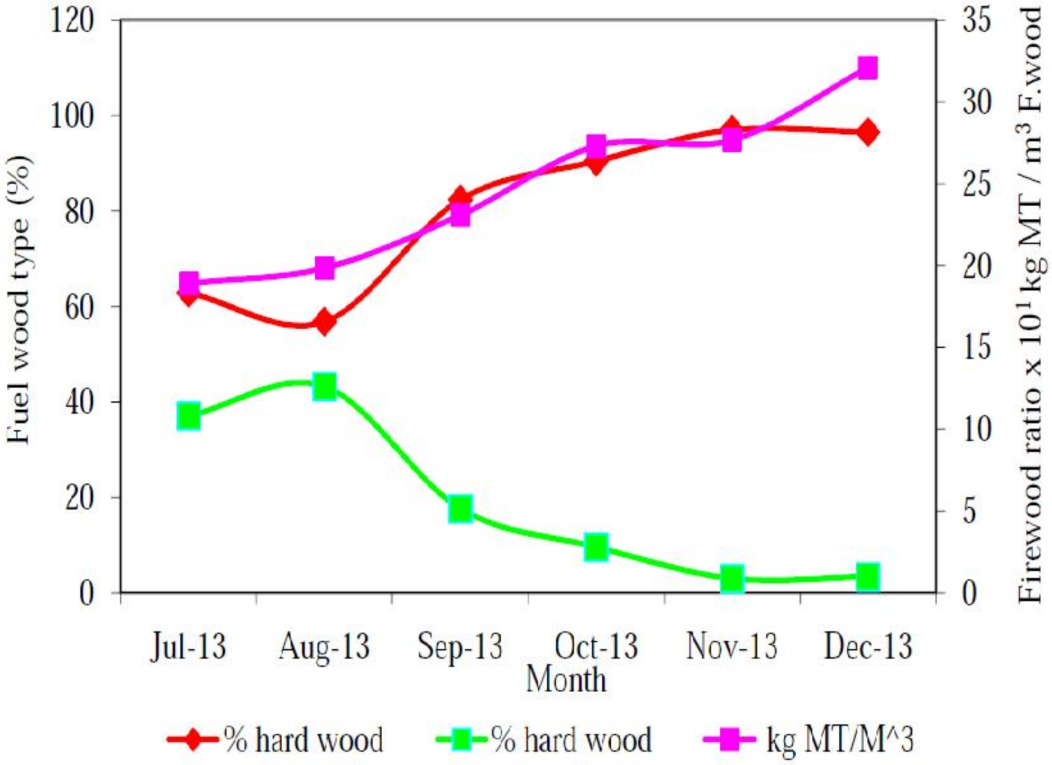


Figure 4.15 Comparison between fuel wood type and specific fuel wood ratio

Figure 4.16 shows analysis for data was collected from five factories F2, F3, F6, F7 and F9, based on their production levels, optimum fuel wood stocks to last for six months was estimated based on their specific fuel wood ratio. Figure 4.16 indicates shows as fuel wood stock levels decreased, fuel wood ratio reduced and energy intensity increased. It indicates on an average there was 10.15 % fuel wood deficit meaning fuel wood had inadequate time to cure. The factory with highest fuel wood deficit had high energy intensities. Therefore, from the analysis fuel wood storage capacity, type of fuel wood, stock levels all affect specific fuel wood ratio and eventually overall energy intensity achieved by that tea factory

Figure shows variation of energy intensity with fuel wood deficit

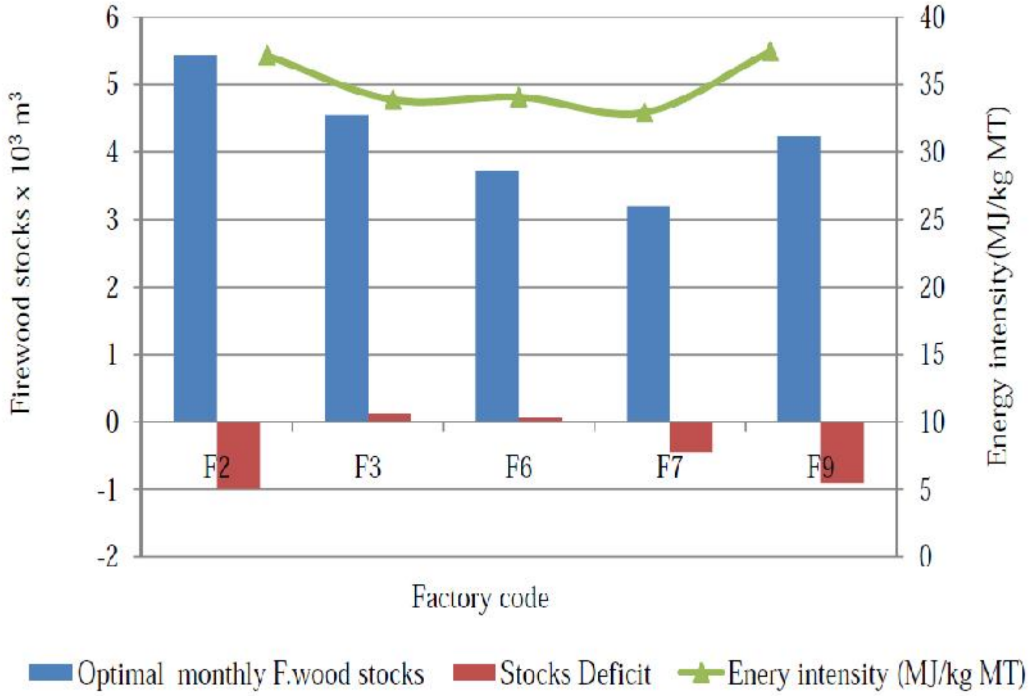


Figure 4.16 Variation of energy intensity with fuel wood deficit

4.3 Plant survey

During the day of plant survey a 4.5 ton wood Pac boiler, fuel wood fired of design operating pressure of 100 kPa was in operation. Fuel wood used to fire the boiler was about 0.3 m long. The moisture content of fuel wood measured with probe moisture tester was 23 % and feed water temperature was 80^{o} C.

4.3.1 Withering section energy requirement

Ultrasonic flow meter model No TDS 100H, (Appendix XVII b and c) was used to measure steam demand by measuring flow of makeup water into boiler (Appendix XVII a). The boiler generated 0.61 kg/s of steam on average at pressure of 800 kPa. There were 22 withering troughs which were in operation translating to steam requirement per withering trough of 0.03 kg/s at a reduced pressure of 450 kPa by a pressure reducing station.

Therefore, thermal energy requirement for withering in a tea factory depends on the number of withering troughs on use at any given time. Anemometer (Extech, model AN100) was used to measure air velocity that averaged 9.28 m/s. The cross sectional area of the fan casing was 0.98 m^2 giving an average air flow rate of 9.09 m^3/s. Taking a loading rate of 26.9 kg/m^2 (Botheju, 2013), and trough area of 31.23 m^2 translates to 0.01 m^3/s of air per kg green leaves which compare well with 0.01 m^3/s per kg (Botheju, 2013). Hannah, model H1 145 thermometer was used to measure ambient air temperature which was 15.0 ^{0}C and after preheating the temperature after the heat exchanger increased to 19.0 ^{0}C which was low compared to the optimal tea withering requirement of 35 ^{0}C (Palaniappan & Subramanian, 1998).

4.3.2 Drying thermal energy requirement

There were two fluidized bed tea drying (FBD) machines, (J.F McCloy model); in use during survey time of a design capacity of 0.17 kg/s MT and another 0.11 kg/s MT. The cumulative steam generated and consumed by the two driers was 5,238 kg for a period of 1.31 hours at generation pressure range of between 800 kPa to 900 kPa bars.

Fuel wood consumed by the boiler weighed 1,532 kg at moisture content of 20 %, drier combined throughput was 0.36 kg/s MT and moisture content of made tea was 3 %. From the survey measurements, 4.1 kg of steam was required to produce 1 kg of MT which compares well with a study in India that showed 4.473 kg of steam per kg of MT (Manskar, 2007) but 1.38 kg per kg MT in Sri Lanka which manufacture mainly orthodox teas (Barual, Khare & Rao, 2012). The specific thermal drying energy requirement of 4.76 kWh/kg of MT was within the range that was achieved by Indian tea factories of 3.5 kWh/kg of MT to 6.0 kWh per kg of MT (Kumar, Velavan & Sivasubramanian, 2004) but was higher than the minimum.

4.3.3 Tea processing thermal energy requirements

There were 68 withering troughs with combined stream load demand of 1.9 kg/s. The three FBD driers had a combined drying design capacity of 0.44 kg/s MT translating to 1.82 kg/s of steam.

Taking steam application for withering of 2 hours and drier operating time of 16 hours then, from the results thermal load ratio for drying and withering ignoring any losses was 93.88 % and 6.12 % respectively compared to 85 % to 15 % in India (Baruah, Khare, & Rao, 2012).

4.3.3 Sectional electricity load requirement in tea processing

The figure shows tea factory electricity load distribution

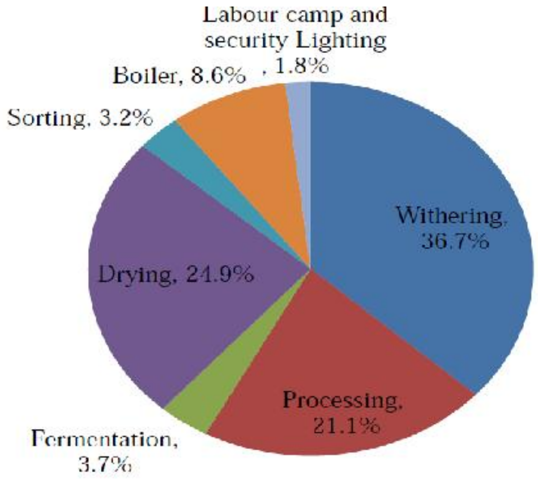


Figure 4.17 Electricity load distribution in a tea factory

The Figure shows sectional electrical energy requirements with highest section demand being withering, processing, and drying at 36.7 %, 21.4 %, 24.9 % compared to India 15.4 %, 45.32 %, and 35.5 % respectively (Manskar, 2007). Electrical demand for fermentation, sorting, and lighting were 3.7 %, 3.2 % and 1.2 % compared to 3 %, 2 % and 2 % respectively in India. However, in Sri Lanka which processes mainly orthodox teas which require tea leaves of lower moisture content, withering electrical energy requirements was about 55 % (Baruah, Khare & Rao, 2012). The maximum electrical load when all electrical facilities are operated in Iria-ini tea factory was 1025 kVA at power factor of 0.8. However, from secondary data analysis the actual maximum demand recorded was 600 kVA which indicates plant facilities were not operated all at once at any given time.

4.4 Renewable energy utilization potential in tea factories

Results from data analysis of the various renewable energy resources that were identified within tea factories are presented and their estimated energy potential.

4.4.1 Biomass utilization potential

Biomass sources identified in a tea factory were biodegradable wastes generated from factory operations and fuel wood if sustainable. Biodegradable wastes included tea waste, sawdust, sewage and waste water.

4.4.1.1 Tea waste

Table 4.4 shows monthly tea fluff and withering sweepings data for the period July 2013 to June 2014 analyzed ranged between 6,640.26 kg to 10,469.94 kg and 708.64 kg to 1,117.35 kg. That variation in tea waste generation was due to leaf quality, withered leaf moisture content during processing and condition of the machinery (EMC, 2012). Tea fluff ranged between 0.13 % to 0.22 % and withering sweepings 0.015 % to 0.54 %. A study in Sri Lanka in the year 2002, by School of Environment Resources and Development of Asia Institute of technology found 0.1 % of MT produced was tea waste and ranged from 2 % to 4 %. The results compared well with 2 % of tea solid wastes generated in India (Mansakar, 2007).

The quantity of tea wastes generated varied from factory to factory similarly energy potential. Therefore, taking the average withering sweepings and tea fluff of 0.027 % and 0.22 % of MT produced respectively and cumulative production MT for one year (July 2013 up to June 2014) and calorific value of tea waste as 16.2 MJ/kg (Esin, Ates, Ozbay & Eren, 2010), then estimated energy potential from tea waste by gasification range between 127,292 MJ to 183,984 MJ per annum representing 0.101 % to 0.125 % of annual thermal energy needs.

Table 4.4 shows the average tea fluff (Appendix XVII d) and withering sweepings generated

Table 4.4 Annual Tea waste quantity

Factory	**Fluff (kg)**	Withering sweepings (kg)
F1	**10,469.94**	1,117.35
F2	**10,111.82**	1,079.13
F3	**9,508.98**	1,014.79
F4	**10,063.75**	1,074.00
F5	**9,051.66**	965.99
F6	**7,808.72**	833.34
F7	**6,640.26**	708.64
F8	**7,814.38**	833.95
F9	**8,104.96**	1,117.35

.

4.4.1.2 Sawdust

The weight of a cubic metre of eucalyptus and pine was 608 kg and 556 kg respectively (Appendix XVII g). Fuel wood was billeted (Appendix XVII h) into three pieces of equal length, sawdust generated was 4.99 kg and 7.01 kg for eucalyptus and pine fuel wood respectively (Appendix XVII e). The results confirms another study carried out in Serbia by USAID, in 1999 where it was concluded residue sawdust produced depends on tree species and the results for hard broad leaves sawdust generated was 8 % and 7 % for soft broad leaves trees. The sawdust generated from this study of 1.04 % was within the range of 1 % to 3 % reported by another study in India (FAO, 1995). Therefore taking the average sawdust generated, fuel wood consumed from July 2013 up to June 2014 for the area of study, and calorific value of sawdust as 20 MJ/kg then sawdust energy potential range from 1.44 GJ to 2.68 GJ per annum which was 1.47 % to 1.68 % of the total annual thermal energy requirements for a tea factory.

4.4.1.3 Energy from sewage

Table 4.4 shows weekly volume of sewage discharged from factory F1 and F5 that were sampled for one month.

Table 4.5 Weekly sewage discharge

Factory	Week 1	Week 2	Week 3	Week 4
F1 (m^3)	356	289	429	397
F5 (m^3)	134	116	135	108
Daily average (m^3)	35.0	28.9	40.3	36.1

The Table shows the average volumes of sewage discharged ranged from 28.93 to 40.29 m^3 per day, varied weekly and from factory to factory Taking the volume of sewage generated from 2013 July up to 2014 June, sludge total volatile solids as 57.74 kg/m^3, biogas produced per m^3 of sewage as 0.525 m^3 /kg of volatile solids and methane content of the biogas as 65 % with heating value of 37.78 MJ/m^3 (Abeeku & Arthur, 2010), then annual thermal biogas energy potential from sewage ranges from 3,575 GJ to 5,626 GJ or 3.39 % of annual thermal energy requirement of tea factory.

4.4.1.4 Waste water

Table 4.6 shows the average daily waste water discharged after cleaning factory F1 and F5 that ranged from 16.42 to 21.40 m^3 per day and varied on weekly basis.

Table 4.6 Weekly waste water discharge

Factory	Week 1	Week 2	Week 3	Week 4	Daily average
F1 (m^3)	132	148	154	122.5	21.40
F5 (m^3)	112	106	109	100	16.42

Assuming waste water generated to be proportional to MT production then 1.40 M^3 and 1.33 m^3 waste water generated from F1 and F5 respectively. Therefore, the results compared well with those of a study carried out in tea factories in India which ranged from 0.11 per ton MT to 3.85 m^3 per ton MT (Mansakar, 2007).

The estimated energy potential from waste water was 19,637 MJ per year which was 0.01 % and compares well with a range of 0.1 % to 3 % (Stilwell, Hoppcok & Webber, 2010) of the annual thermal energy requirements. The low energy could be due to low solid levels in waste water.

4.4.1.5 Proportion of bio-energy potential by source

Figure 4.18 shows the estimated thermal energy from bio-waste found in a tea factory.

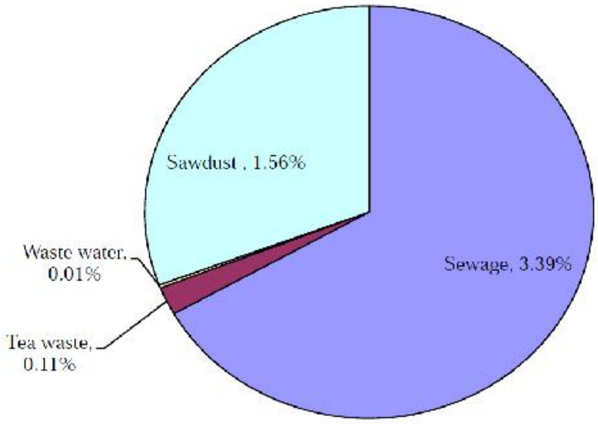


Figure 4.18 Proportion of bio-energy potential by source

It shows the main sources as sewage and sawdust at 3.39 % and 1.56 % of the total thermal energy respectively. The cumulative thermal energy potential from bio-wastes was 5.07 % of the total factory thermal energy requirements.

4.4.2 Solar and wind utilization potential

Figure 4.2 shows the main sources of electrical energy as that from the national grid or in-house diesel generators whereas thermal energy sources are fuel wood and fuel oil. The two sources demand depends on the volume of tea processed among other factors that affect energy indicators variations as was identified by this study. Therefore, understanding the relationship between production, wind speeds and solar irradiance was important for sizing of the renewable energy systems**.**

4.4.2.1 Solar irradiance

a)Average daily solar irradiance

Figure 4.19 shows the average daily direct normal solar irradiance trend for Nyeri County from RET screen data base as 5.78 kWh per m^2 per day which compares well with an average Direct Normal irradiance (DNI) of 6 kWh per m^2 per day by the MoE, Kenya (2011).

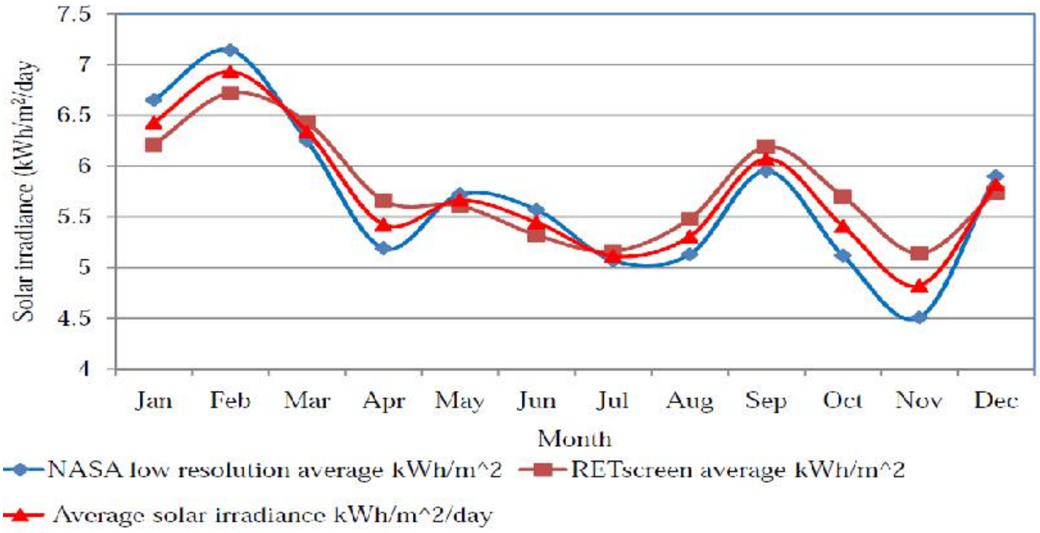


Figure 4.19; Monthly solar irradiance for Nyeri County

It shows the lowest irradiance recorded was in the month of November and was high in the months of February and then September. It shows solar radiation as a variable energy source which implies, solar energy can be used for supplementing existing energy sources of energy. The solar resource available in Nyeri County shows that potential for solar thermal and PV utilization exists. The solar resource is economically viable since Asian development bank (2013) recommends a minimum of DNI of 5 kWh per m^2 per day and the average was above apart from for the month of November. The figure indicates that when solar irradiance was low, average daily thermal load consumption was high and from earlier analysis over the same period (Figure 4.7) elecricty ratio was high compared to fuel wood ratio

b) Comparison between factory electrical load and solar irradiance

Figure 4.22 shows a comparison between factory electrical load and solar irradiance. From the figure there is close correlation between solar irradiance and average daily power consumption

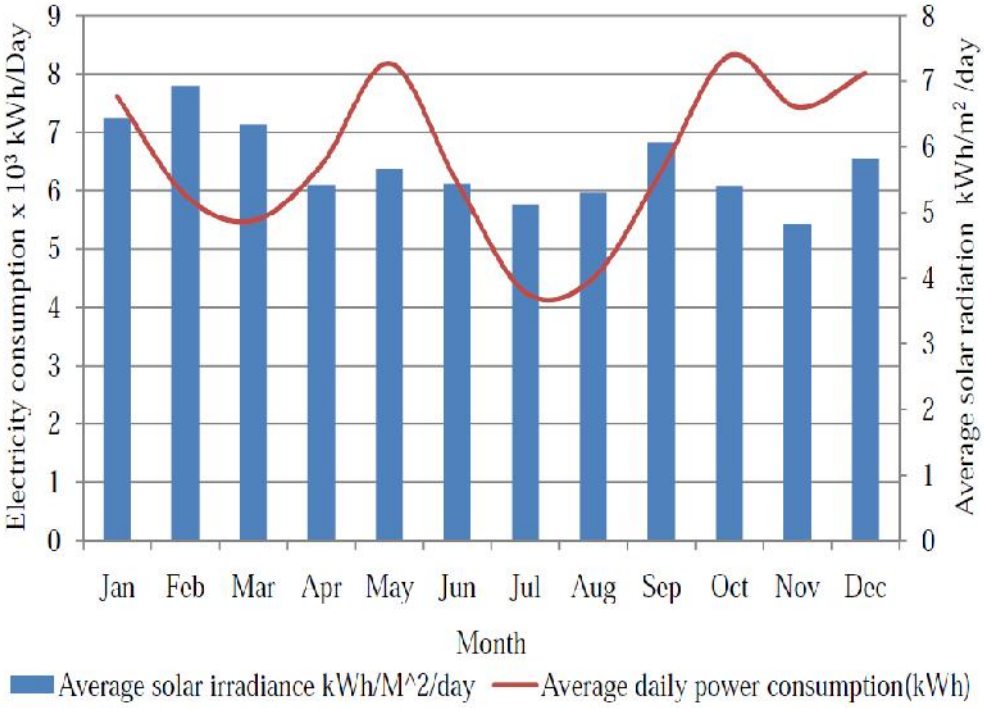


Figure 4.20 Comparison between factory electrical load and solar irradiance

It shows that when solar irradiance was high (February and March, September and December) electrical consumption was also high and when solar irradiance is low power consumption is also low. This is advantageous since the more the exploitation is closer to demand the more feasible and economical for the system.

4.4.2.2 Wind utilization potential

From wind map of Kenya wind potential for area of study range from 275 to 425 W/m^2 at height of 50 m above ground level (Figure 2.2).

a. Comparison between wind speed and production (MT)

Figure 4.23 shows wind speeds analysis at a height of 10 m with production levels. It shows that when wind speeds are high i.e. February to April and June to September production was low. The Figure shows during high peak seasons the wind speeds are high and low during low production season. This shows wind resource can be harnessed to supply or supplement the base electrical requirements making the investment economical.

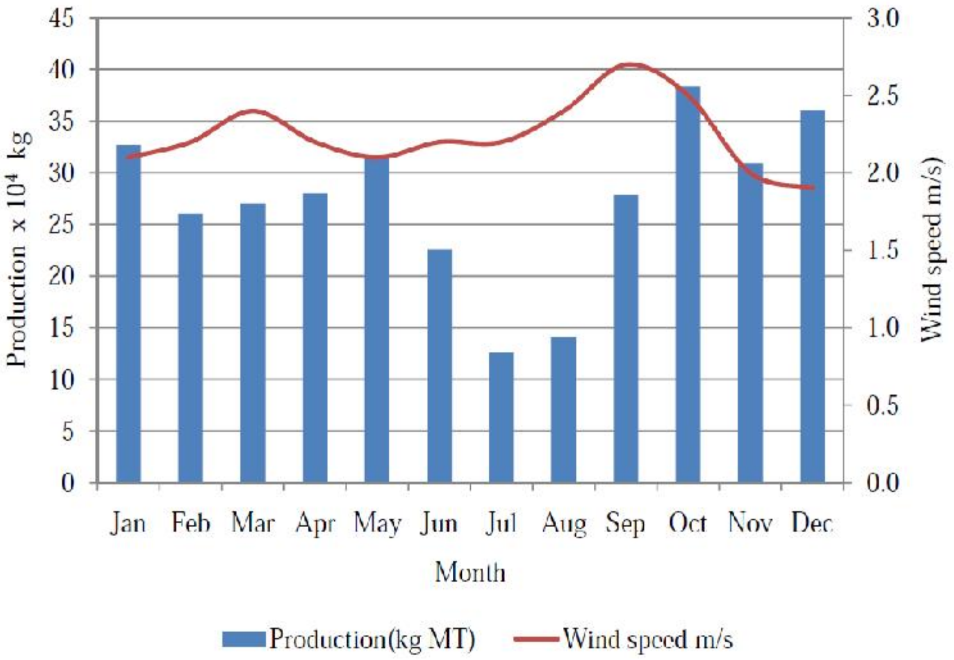


Figure 4.21 Comparison between wind speed and MT production

b. Comparison between electricity consumption and wind speed

Figure 4.24 shows a comparison between wind speeds at height of 10 m and electrical consumption. The Figure shows that when wind speeds are high electricity demand was low and varies from month to month.

Figure shows comparison between wind speeds with electrical consumption

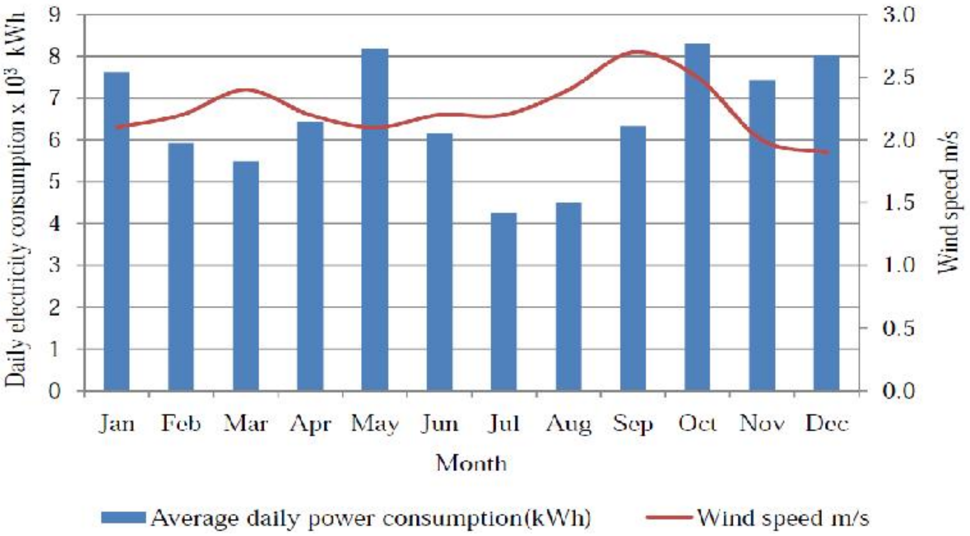


Figure 4.22 Comparison between wind speed and electrical consumption

Both Figure 4.23 and Figure 4.24 show there is relationship between production and electricity consumption in tea processing. This is an important factor that should be considered when carrying out sizing of a renewable project.

4.4 Renewable energy utilization financial analysis

Financial assumptions made for the purposes of carrying out the financial analysis were obtained from literature review sources as well as researcher assumptions. Results obtained from objective one and two of this study (Appendix V1) is also used for sizing the proposed system. The data was required as part of inputs into the RET screen software version 4 for purposes of carrying out energy modeling and financial analysis.

4.5.1 Solar Photovoltaic

The mono crystalline silicon solar panels were selected and resulting to area of 4,166.9 m^2 with an efficiency of 14.4 % at capacity factor of 13.68 % which was within capacity factor range of 10 % to 25 % (IRENA, 2012). The annual electricity delivered to the load with a one axis tracking was 726.83 MWh (Appendix VII).

The capital cost used was USD 2.0 Million for a 600 kW per day solar PV plant giving an equity payback period of 4.7 years, simple payback period of 9.0 years and cost ratio benefit of 13.18 (Appendix VIII). The resulting levelized cost of energy was USD 469.63/MWh at a capacity factor of 13.68 %. Although solar PV LCOE was higher compared to cost of electricity from the national grid of USD 150 per MWh it compared well with Western Europe and United States of USD 90 to 397 per MWh at a capacity factor of 18 % to 29 % and USD 139 to 449 per MWh at a capacity factor of 16 % to 27 % respectively with tracking (World energy council, 2013).

4.5.2 Solar thermal

A transpired collector plate with one axis tracking could heat 18,500 m^3 of air per hour to a temperature of 145^0 C. The solar collector area was 30,912 m^2, heater fan flow rate was 36 m^3 per hour per m^2, efficiency of 16.9 %, absorptivity of 0.9 and performance factor of 1.0 (Appendix IX). The capital cost of the solar air heater was USD 12.0 Million. When displacing fuel oil with solar air preheating, equity and simple payback period was 5.3 years and 10 years respectively with a positive cost benefit ratio of 13.15 (Appendix X). Payback period results, compared well with a payback period of 3 years where fuel savings of 20 to 30 % for tea processing was realized (Palaniappan, 2009). The levelized cost of energy was USD 182.87 per MWh. However it was uneconomical when displacing cheap fuel wood, because equity payback period was high at 23.4 years with a negative net present value and cost benefit ratio of -1.33. The results show, fuel price being displaced has an impact on the levelized cost of energy (Rawlins & Ashcroft, 2013). The resulting LCOE when displacing fuel oil compared well with regions such as Spain, United States and Australia. In those regions LCOE for solar thermal ranged USD 109 to 239 per MWh at capacity factor range of 12 % to 21 %. Also it was USD 87 to 145 per MWh in India and China at capacity factor of 11 % to 20 % but without tracking and with tracking LCOE was USD 139 to 449 per MWh at a capacity factor of 16 % to 27% in United States (World energy council, 2013). Also, the results compared well with USD 194 per MWh for a solar parabolic trough (Lazard, 2014).

4.5.3 Wind

A power wind turbine rated 650 kW was selected and the cumulative losses assumed was 3.4 % with resulting capacity factor of 34.4 % (Appendix XI). The capital cost was USD 1 Million. From the financial analysis, equity and simple payback period was 2.3 years and 4.3 years respectively with a positive cost benefit ratio of 5.35 (Appendix XIII). The LCOE was USD 45.11 per MWh which compared well with USD 51 to 259 per MWh in Chile (Bloomberg, 2011) and other countries like United states where LCOE was USD 61 to 136 per MWh, India USD 47 to 113 per MWh and Europe of USD 71 to 117 per MWh (World energy council, 2013).

4.5.4 Combined heat and power

A 650 kW combined gas turbine cycle was selected with availability of 90 % which operated on multiple fuels of which 99 % fuel wood, 1 % from both biogas and tea waste combined (Appendix XIV and XV). The capital cost for the CHP (gasification plant) used was USD 4 Million. Equity payback and simple payback period was 3.7 years and 7.6 years respectively with a positive cost benefit ratio of 42.96 (Appendix XVI). The LCOE was USD 72 per MWh which compared well with gasification plants in United States and Western Europe of USD 50 to 140 per MWh at a capacity factor of 80 % (World Energy Council, 2013) and in Chile of USD 35 to 175 per MWh (Bloomberg, 2011).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter covers conclusions and recommendations, commencing with the energy indicator trends and factors causing energy indicator variations among tea factories. Also the section covers renewable energy resources identified complete with their potential and levelized cost of energy when exploiting those resources.

5.2 Conclusions

The study trended energy indicators and identified factors that cause energy indicator variations. Energy indicators vary from factory to factory and month to month. The ratio of thermal to electrical energy was 92.8:7.2 respectively. Average energy and cost intensities range from 32.40 MJ/kg MT to 38.31MJ/kg MT and USD 163.05 to 214.72 per ton of MT respectively. Also the average electricity and fuel wood ratio specific ratios ranged between 590.06 kWh per ton MT to 798.73 kWh per ton MT and 0.384 MT per ton to 0.746 MT per ton of fuel wood respectively. The estimated cumulative thermal energy potential from bio-wastes was 5.07 % of the total factory annual thermal energy requirements. Potential for solar and wind utilization exist but varies from month to month. The thermal load distribution for drying and withering ignoring energy losses was 93.88 % and 6.12% respectively. Also sectional electrical energy demand for withering, processing, and drying was 36.7 %, 21.4 %, 24.9 % respectively and others was 17%. The levelized cost for solar PV, solar air heating, CHP and wind was USD 469.63 per MWh, USD 182.87 per MWh, USD 72.00 per MWh and USD 45.11 per MWh respectively. The analysis s how solar air heating more economical when displacing fuel oil rather than fuel wood which was cheap.

The study shows energy intensities, specific energy ratios and cost intensity vary among tea factories. Energy indicator variations show potential for energy conservation and efficiency improvement exists in Kenyan tea factories. Factors that cause energy indicator variations include production levels, capacity utilization, environmental factors, energy source cost, type and quality of fuel wood and operation decisions. The results compared with those from previous studies in other industries and provide a good guidance when setting energy indicator targets, implementing, monitoring and evaluating energy efficiency programmes. There is renewable energy potential that can be utilized to supplement the existing sources of energy and is viable although levelized cost of energy vary from resource to another. However, cost of fuel being displaced determines LCOE of the renewable energy of that resource. The results of this study will assist during decision making process especially on energy conservation as well as energy management, renewable resource exploitation and further detailed investment studies.

5.3 Recommendations

1. Similar study should be conducted in other tea growing regions and other industries to compare the results
2. Experimental demonstration models to be conducted within tea factories for renewable options identified through this study.
3. A study to co-digest the feedstock found within a tea factory should be carried out to determine the actual thermal potential.
4. Further financial analysis by varying financial parameters and by sourcing prices from different technology suppliers on available renewable energy resources should be carried out to prepare a range of LCOE for the renewable resources within the tea factory in Kenya.

REFERENCES

Abeeku, H., & Arthur, R. (2010). Potential biogas production from sewage sludge: A case study of sewage treatment plant Kwame Nkurumah University of science and technology, Ghana. *International Journal of Energy and Environment, 1*(6). 1009-1016

Afonso, P., & Cunha, J. (2009). Determinants to the use of capital investments appraisal Methods: Evidence from the field, *The European Applied Business Research Conference (EABR),* Prague, 8-11 June, 2009. 2-5. Czech Republic.

Ahmed, A., Bello, A.A., & Habou, D. (2013). An investigation of wind energy in Nigeria. *International Journal of Energy and Power Engineering, 2*(5), 184-190.

Alinta Energy. (2014). Port *Augusta solar thermal generation feasibility study.* Persons Brinkerhoff Australia Pty limited. Retrieved from: https://alintaenergy.com.au/Alinta/media/Documents/2263503A-POW-RPT-001-RevD-Options-Study-Report.pdf

Allen Consulting Group. (2013). *Renewable Energy Opportunities for Decentralized Energy Master Plan: Renewable Energy, Financial and Economic analysis*. Sydney. Retrieved from.www.allenconsult.com.au.

Asian Development Bank. (2013). *Development of solar and wind power in Karnataka and Tamil-Nadu.* New Delhi: ADB.

Azimuth Power. (2014). *72 kW roof mounted solar installation provides power to the flower farm chillers room and bore pump*. Retrieved from. http://azimuthpower.com.

Balat, M., & Ayar, G. (2005). *Biomass energy use in the world: Use of biomass and potential trends.* London: Taylor and Francis. 931-939.

Ballantine, J.A., Galliers, R., & Stray, J. (2012).*The use and importance of financial appraisal techniques in the IS/IT investment decisions making process-recent UK evidence*. London: Taylor and Francis.

Baruah, B., Khare, P., & Rao, P. G. (2012). The energy utilization pattern in tea industries of NE India and environmental issues. *Two and a Bud, 59*(2). 9-13.

Bodík, I., Sedláček, S., Kubaská, M., & Hutňan, M. (2010). Perspectives of biogas production from restaurant waste on Slovak municipal wastewater treatment plants. *37th International Conference of SSCHE*, Tatransk´e Matliare, Slovakia.1120.

Botheju, W.S. (2013). *Strategic Cost Management in Black Tea Processing*. Tea research Institute, Sri Lanka. Retrieved from. http:/www.tri.lk

Broesamle, H., Mannstein, H., Schillings, C., & Trieb, F. (2011). Assessment of solar electricity potentials in North Africa based on satellite data and a geographical information system. *Solar Energy, 70*(1).1-12.

Brzozowska, K. (2007). Cost-benefit analysis in public project appraisal. *Engineering Economics, 3*(53).78-83.

Canadian Industry Program for Energy conservation. (2006). *Benchmarking Energy Use in Canadian Pulp and Paper Mills*. Retrieved from: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee

Chanel, M., Agrawal, G.D., Sanjay, M., & Mathur, A. (2014). Techno-economic analysis of solar PV power plant for garment zone of Jaipur city. *Case Study in Thermal Engineering, 2*(2014). 1-7.

Chu,Y., & Mesein, P.(2011). *Review and comparison of different solar energy technologies*, Retrieved from.www.geni.org.

Dale, M. (2013). A comparative analysis of energy costs of PV, CSP and wind electricity generation technologies. *Applied Sciences Journal 3*(2).325-337.

Divya, S., Samata, T., Das, S., Ghosh, A. K., Mitra, A., & Ghosh, B.C. (2012). Development of customerized trough to study withering tea leaves. *Two Leaf and Bud, 59*(2). 143-147.

Duffie, A. J., & Bekham, A.W. (2013). *Solar Engineering of Thermal Processes*, (4th ed.), John Wiley and Sons

Economic Consulting Associates. (2012). *Technical and Economical Study for Development of Small Scale Grid Connected Renewable Energy in Kenya*. Retrieved from:http://www.renewableenergy.go.ke/asset_uplds/files/ECA%20Final%20Report%20Kenya%20Small%20Scale%20Renewables.pdf.

Engineering tool box. (2015).*The engineering tool box*. Retrieved from: http://www.engineering toolbox.com/energy-content-d_868.html

Environmental Management Centre. (EMC). (2012). Process *document on energy conservation in small holder sector tea processing units in India.* Environmental Management Centre LLP, Mumbai. 17-32.

Erkkila, A., & Alakagas, E. (2008). *Manual for Firewood Production*. Retrieved from: http://www.biomasstradecentre2.eu .

Esin, A.V., Ates, F., Ozbay, N., & Eren, A. P. (2010). Synthetic fuel production from tea waste: Characterization of bio-oil and bio-char. *Fuel, 89*(2010).176-184.

Fischer, E., Schmidt, T., Höra, S., Giersdorf, J., Stinner, W., & Scholwin,F. (2010). *Agro-industrial biogas in Kenya; Potentials, Estimates for Tariffs, Policy and Business Recommendations*, German Biomass Research Centre.

Food and Agricultural Organization. (1995). *Proceedings of the International Workshop on Biomass Briquetting.* 3rd - 6th April, 1995. New Delhi: FAO

Gao, W., Iamtrakul, P., & Kristsanawonghong, S. (2014). Feasibility study of optimal sizing of micro-cogeneration system for convenience stores in Bangkok. *Energy and Power Engineering*. 69-81. Retrieved from: http://www.scirp.org/journal/epe

Garud, S. (2008). Solar thermal technologies for industrial applications-India experience. *Global Renewable Energy Forum*, 18th -21st May, 2008. Rio de Janairo

Gesimba, R. M., Langat, M.C., Liu, G., & Wolukau, J.N. (2005). The Tea Industry in Kenya: The challenges and positive developments. *Asian Journal of Applied Sciences*, *5*(2). 334-336.

Githiomi, J. K., & Oduor, N. (2012). Strategies for sustainable wood fuel production in Kenya. *International Journal of Applied Science and Technology, 10*(2). 21-24.

Glendary, G., Shukla, G.P., Thane, J., Kapoor, J., Maitra, A., & Voetsch, R. (2008).*USAID/India reform project compendium with practitioners guide,* State Fiscal Management reform.

Glova, J. (2012). Overall Equipment and Energy Effectiveness as One Key Performance Indicator in Manufacturing. Faculty of Economics, Technical University of Kosice Retrieved from: http://www.sjf.tuke.sk/transferinovacii/pages/archiv/transfer/24-2012

Green Tea Industry in East Africa. (2007). *Small Hydro Scoping Study Kenya*. Retrieved from: http://www.eatta.com.

Gumartini, T. (2009). *Biomass Energy in Asia-Pacific Region: Current Status, Trends and Future Setting*. Working Paper No APFSOS II/WP/2009/26, Food and Agricultural Organization, regional office for Asia and Pacific, Bangkok.

Gupta, S.P., & Gupta M, P. (2009). *Business Statistics.* (15th Ed.). New Delhi: Sultan Chand & Sons.

Guta, D. D. (2012). Assessment of biomass fuel resource potential and utilization in Ethiopia: Sourcing strategies for renewable energy, *International Journal of Renewable Energy Research, 2*(1).132-139

Hammar, L. (2011). *Wind and Solar Energy Resources in Tanzania and Mozambique.* Chammers, University of science and technology, Gothenburg, Sweden.

Herout, M., Malaťák, J., Kučera, L., & Dlabaja, T. (2011). Biogas composition depending on the type of plant biomass used. *Research in Agricultural Engineering Journal, 57*(4).137-143.

Hubner, D. (2008). *Guide to Cost Benefit Analysis of Investment Projects*. European Commission, Directorate regional policy. Retrieved from: http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf

Humley, P.G.N., Dotli, F.R., Prieto, L.A., Braun, J.R., Cath,Y.T., & Porter, M.J. (2014).Techno economic analysis of waste water sludge gasification: A decentralized urban perspective . *Bio-Resource Technology, 161* (2014). 385-394.

Idiata, J.D., Ebiogbe, M., Oriakhi, H., & Lyalekhue, L. (2013). Wood fuel usage and the challenge on the environment. *International Journal of Engineering Sciences, 2*(4).110-114.

Heat, C. (2008). Power. Evaluating the benefits of greater global investment. *France, Paris: International Energy Agency*.

International Renewable Energy Agency.(2012). Renewable Energy Technologies Cost Analysis Series. Retried from: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf

Jayah, H. T., Aye, U.L., Fuller, R.J., & Stewart, F.D. (1999). *Wood Gasifiers for Drying Tea in Sri Lanka.* Melbourne,: International Technologies Centre,

Jayatunge, P .G. N. (1999). *Engineering aspects of Tea Processing*. (2nd Ed.). National Institute of Plantation Management, Sri Lanka.

Jekayifa, O. S., & Bamgoye, L. A.(2008). Energy use analysis of selected palm kernel oil mills in south western Nigeria. *Science Direct Energy, 33*(1).81-90.

Jones, B.H Jr., & Lee, R.S. (1978). Factors influencing energy consumption and costs in a broiler processing plants in the south. *Southern Journal of Agricultural Economics, 10*(2). 63-68.

Kagira, E. K., Kimani, S.W., & Kagwathii, S. G. (2012). Sustainable methods of addressing challenges facing small holder tea sector in Kenya: A Supply Chain Management Approach. *Journal of Management and Sustainability, 2*(2).3-5.

Karekezi, S., & Kithyoma, W. (2003). Renewable energy in Africa: prospects and limits. *Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative*. 2-4 June. Novetel, Dakar. Senegal.

Karekezi, S., Lata, K., & Coelho, S.T. (2004). Traditional Biomass Energy: Improving its use and moving to modern energy use. *International Conference for Renewable Energies*.1–9. Bonn, Germany.

Kenya Institute for Public Policy Research and Analysis. (2007). Strategies *for Securing Energy Supply in Kenya*. Policy brief No 7/2007

Kenya renewable energy association. (2013). *Energy Digest.* Issue 1 June – July 2013, Kenya

Kimuyu, P., Mutua, J., & Wainaina, J. (2011). *Role of Renewable Energy in Promoting Inclusive and Sustainable Development in Kenya*. In: Draft European Report on Development Background Paper

Kirai, P., & Shah, B. (2009). *Target market analysis: Kenya's small hydro energy market*. Project development programme East Africa, German Federal Ministry of Economics and Technology.

Kirchner, R., & Salami, A. (2014).Promoting a low cost energy future in Africa. *Africa Journal of Environment Science and Technology, 8*(2). 91-98.

Kitani,O., Jungbluth,T., Peart, R.M., & Ramdani, A.B. (1999). *CIGR Handbook of Agricultural Engineering: Energy and Biomass Engineering.* Volume V, American Society of Agricultural Engineers.

Koneswaramoothy, S., Mohamed, Z., & Galahitiyawa, G. (2004). Developing and evaluating solar energy techniques for tea drying. *Journal of National Science Foundation Sri Lanka, 32* (1&2). 49-60.

Kost, C., Mayer, N. J., Thomsen, J., Hartmann N., Senkpiel, C., Philips, S., Nold, S., Lude, S., Noha, S., & Schlegl, T. (2013). *Levelized Cost of Electricity: Renewable Energy Technologies*, Fraunhofer institute for solar energy systems ISE, Germany.

Kothari, C.R. (1985). *Research Methodology: Methods and Techniques*. (2nd rev. ed.). New Age International Publishers, New Delhi.

Kristen, A., & Margolis, R. (2011). *2010 Solar Technologies Market Report.* Washington, DC: United States Department of Energy.

Kumar, S.P.C., Velavan, R., & Sivasubramanian, S. (2004). *Innovative Measures for Energy Management in Tea Industry*. Energy Engineering Division, Department of Mechanical Engineering PSG College of Technology, Coimbatore. Retrieved from: http://www.faculty.ait.asia/visu/SMI_Roadmap/Publications/Conf_Work_Smnr

Kumar,S. J., Sujatha, G., & Thyaragajan, D. (2012). Assessment of overall equipment effectiveness efficiency and energy consumption of breakfast cereal. *International Journal of Applied Engineering and Technology, 2*(2).39-48.

Laderach, P., Eitzinger, A., Quiroga, A., Pantoja, A., & Gordon, J. (2011). *Future Climate Scenarios for Kenya Tea Growing Areas.* International Centre of Tropical Agriculture, Cali, Colombia.

Lazard. (2014). *Lazard's Levelized Cost of Energy Analysis-Version 8.* Retrieved from: http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf.

Manskar, M.J. (2007).*Comprehensive Industry Document on Tea Processing Industry*. New Delhi: Central pollution control board,

Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2009). *Wind Energy Explained: Theory, Design and Application.* (2nd Ed.), New York: John Wiley & sons.

Ministry of energy and petroleum, Kenya. (2014). Draft *National Energy Policy*. 47-62. Retrieved from: http://www.kengen.co.ke.

Ministry of Energy, Kenya. (2010). Feed in Tariff Policy for Wind, Small Hydro, Biomass, Geothermal, Biogas and Solar.

Ministry of Energy, Kenya. (2011) *Updated Least Cost Power Development Plan* Study Period: 2011-2031, Kenya.

Monroy, L., Mulinge,W., & Witwer, M. (2012). *Analysis of Incentives and Disincentives for Tea in Kenya: Technical Note Series. MAFAP, FAO, Rome.* Retrieved from: http://www.fao.org .

Mugo, F., & Gathui, T. (2010). *Biomass Energy use in Kenya.* A background paper prepared for the International Institute for Environment and Development for an international ESPA workshop on biomass energy, 19-21 October 2010, Parliament House Hotel, Edinburgh.

Murunga, I.R. (2012). *An Efficient and Cleaner Production System for Tea Processing Industry in Kenya*: *A Case of Mudete Tea Factory in Kenya*. MSc Thesis, University of Nairobi, Kenya.

Muzee, K. (2012). *Biomass Gasification*: *The East Africa study*. Practical Action Consulting. Retrieved from: http://r4d.dfid.gov.uk/PDF/Outputs/PISCES/04398-PAC-Biomass-Gasification.pdf.

Mwakubo, S., Mutua, J., Ikiara, M., & Aligula, E. (2007). *Strategies of Securing Energy Supply in Kenya.* KIPPRA policies brief No 6/2007.1-4.

Ndubuisi, I .T., Uchechi, E., & Ougeke, C.(2014). Waste to wealth value recovery from agro processing wastes using biotechnology. *British Biotechnology Journal, 4*(4). 418-481.

Nelson, D., Shrimali, G., Goel, S., Konda, C., & Kumar, R. (2012). *Meeting India's Renewable Energy Targets: the Financing Challenge-Climate Policy Initiative*. Retrieved from: www.climatepolicyinitiative.org.

Nordman, E.E. (2014). Energy Transitions in Kenya's Tea sector: A wind energy assessment. *Renewable Energy, 68*(2014).505-514.

Nyaga, E.K. & Doppler, W. (2009).Use of dynamic models to access impact of changing tea prices on family income of small holder in Kenya. *Journal of Applied Sciences, 9*(9). 1647-1657.

Oirere, B.S. (2011). *Assessment of Waste Management Structures for Tea Factories in Kenya: A Case Study of Nyasiongo Tea Factory*. MSc Thesis, University of Nairobi, Kenya.

Oloiveira, S.W., & Fernandes, J. A. (2011). Economic feasibility applied to wind energy projects*, International Journal of Emerging Science 1*(4).659-681.

Osieni, M.O. (2012). *Power Outages and Costs of Unsupplied Electricity: Evidence from Back up Generation among Firms in Africa.* PhD Thesis, Judge Business School, University of Cambridge, UK. 9-32. Retrieved from: http://www.usaee.org/usaee2012/submissions/OnlineProceedings

Oyedepo, O.S., & Oladele, A.T. (2013). Energy audit of manufacturing and processing industries in Nigeria: A Case study of food processing industry and distillation and bottling company. *American Journal of Energy Research, 1*(3).36-44.

Ozturk, K.H. (2005). Energy usage and cost in textile industry: A case study for Turkey. *Energy, 30* (13). 2424-2446.

Palaniapan, C. (2009). Perspectives of solar food processing in India. *International Solar Food Processing Conference.* 14th to 16th January, Indore, India.

Palaniappan, C., & Subramanian, V.S. (1998). Economics of solar air heating in south Indian tea factories. *Solar Energy, 63*(1).31-37.

Parikka, M. (2004). Global biomass fuel resources. *Biomass and Bio-Energy, 27*(6). 613-620.

Pierce, J. (2007). *Commercial Policy Framework Guidelines for Financial Appraisal.* Office of financial management, policy guideline paper. New South Wales Treasury. 5-11.

Price Water Coopers. (2014*). A Brief Overview of the Agricultural Sector in Kenya*. Retrieved from: http://www.pwc.com.

Ramde,W. E., Azoumah, Y., Rungundu, A., & Tapsoba, G. (2011). Solar thermal plants in West Africa: Site selection and potential assessment. *Conference proceedings held* on 4th to 8th April, 2011. Ouagadougou, Cameroon.

Rawlins, J., & Ashcroft, M. (2013). *A Review of Current Activity and Potential to Accelerate Deployment of Small Scale CS*. Retrieved from: https://docs.google.com/file/d/0B2recxHj7XBvV3o0R3Z0dHAyLUk/edit?pli

Renewable Energy Network. (2012). *Renewable 2012, Global Status Report.* Retrieved from: http://www.ren21.net/Portals/0/documents/activities/gsr/GSR2012_low%20res_FINAL.pdft.

Rudramoorthy, R., Kumar, C.P, Velavan, R., & Sivasubramarian, S. (2004). *Innovative Measures for Energy Management in Tea Industry*. Energy Engineering Division, Department of Mechanical Engineering, PSG College of Technology, Coimbatore. Retrieved from: http://www.iea.org/publications/freepublications/publication/projected_costs.pdf

Salvadores, S.M., & Keppler, H.J. (2010). *Projected Costs of Generating Electricity*. International Energy Agency publication.

School of Environment Resources and Development. (2002). *Small and medium scale industries in Asia: Energy and Environment.* Asian Institute of Technology.

Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., & Volk, S. R. (2008). *Biogas Handbook.* University of Southern Denmark, Denmark.

Sheya, S.M., & Mushi, S.J. (2000). The state of renewable energy harnessing in Tanzania. *Applied Energy, 65* (1- 4).257-271.

Simion, V.C., Blarke, B.M., & Trifa, V. (2012). Techno-economic optimization of a sustainable energy system for a 100% renewable smart house. *2nd International Conference on Quality and Innovation in Engineering and Management.* 22nd to 24th November, 2012. Cluj-Napoca, Romania.

Spenomatic (K) Ltd. (2014). *Turnkey solutions: case study 2.2 MW power plant at BIDCO.* Retrieved from: http://www.spenomatic.net/index.php/product-lines/co-generation-plants

Stillwell, S. A., Hoppcock, C.D., & Webber, E. M.(2010). Energy recovery from waste water treatment plants in the United States. *Sustainability, 2*(4).945-962.

Swaramoorthy, S., Mohamed, Z. M. T., & Galahiyawa, G. (2003). Developing and evaluating solar energy techniques for tea drying. *Journal of National Science Foundation* Sri Lanka, *32*(1 & 2).49-60.

Tea Board of Kenya. (2014). *About Kenya Tea.* Retrieved from: http://www.teaboard.or.ke.

Theuri, D., & Hamlin, T. (2008). Solar and Wind Energy Resource Assessment Project, Kenya country report. Retrieved from: http://en.openei.org/datasets/files/864/pub/kenya_swera-country_reportsmall.pdf

Twidell, J., & Weir, T. (2006). *Renewable Energy Resources.* (2nd ed.). London: Taylor and Francis.

United States Agency for International Development. No date. *Feasibility Study on Fuel Wood Waste Utilization in Serbia.* Retrieved from: http://pdf.usaid.gov/pdf_docs/PNADS215.pdf *:*

United States Department of Energy, Office of industrial technologies. (1999). *Review of combined heat and power technologies.* Retrieved from: http://www.distributed-generation.com/Library/CHP.pdf

United States Department of Energy. (2012). *Renewable Energy data book.* Retrieved from: http://www.nrel.gov/docs/fy14osti/60197.pdf .

United States Environmental Protection Agency. (2011). Opportunities for Combined Heat and Power at Waste Water Treatment Facilities: Market Analysis and Lessons from the Field. Retrieved from: http://www.epa.gov/chp/documents/wwtf_opportunities.pdf.

Uzun, B. B., Apaydin-Varal, E., Ozbay, N., & Putun, E. A. (2010). Synthetic fuel production from tea waste: Characterization of bio- oil and bio char. *Fuel, 8*.176-184.

VILAR(ED). (2012). *Renewable Energy in Western Africa, Situation, Experiences and Tendencies.* ECOWAS centre for renewable energy and energy efficiency. Retrieved from *http://www.ecreee.org/sites/default/files/renewable_energy_in_west_africa_0*

Woodruff, A. (2007). An Economic Assessment of Renewable Energy Options for Rural Electrification in Pacific Island Countries. Retrieved from:http:// www.sopac.org .

World Energy Council. (2004). *Renewable Energy Projects Handbook*. World Energy Council.

World Energy Council. (2013). *World energy perspective: Cost of every technologies*. World energy council, London.

World Wind Energy Association. (2014). *Wind Energy around the World.* Quarterly bulletin, issue 2. June 2014

Wright, G.D., Dey, K.P., & Brammer, J. (2010). A Barrier and Techno-Economic Analysis of Small Scale Biomass Combined Heat and Power (Bchp) Schemes in the UK. Aston Business School, Aston University, Birmingham, United Kingdom.

APPENDICES

Appendix I:Energy Data Year 2009/2010

Item description	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual MT ('000 tons)	4.27	4.35	3.84	3.62	3.46	3.00	2.42	2.74	3.25
Electricity energy (%)	6.16	6.32	7.02	6.37	7.78	14.06	6.30	6.61	5.68
Diesel energy (%)	0.93	1.53	1.39	0.91	0.95	0.76	0.79	0.76	1.00
Fuel wood energy (%)	75.25	82.83	91.59	83.80	88.18	85.18	91.62	92.63	84.25
Furnace oil energy (%)	17.66	9.32	0.00	8.92	3.08	0.00	1.29	0.00	9.08
Energy intensity (MJ/KG MT)	34.76	36.84	30.08	38.28	30.84	33.18	33.84	28.17	40.76
Energy cost ('000USD)	731.84	733.85	451.93	622.21	462.89	357.48	300.96	274.23	574.7
Cost intensity (USD/TON MT)	171.47	168.79	117.68	171.93	133.92	119.17	124.35	100.21	177.0
Electricity Ratio (KWH/ ton MT)	684.22	803.06	702.92	773.92	748.45	1365.75	666.49	577.18	756.0
F.W ratio (Tons MT/TON F.Wood)	0.384	0.391	0.524	0.376	0.498	0.510	0.453	0.553	0.350

Appendix II: Energy data year 2010/2011

Item description	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual MT ('000 tons)	4.07	3.82	3.41	3.85	3.08	2.68	2.29	2.58	2.70
Electricity energy (%)	6.62	7.44	7.66	6.92	7.69	8.74	6.24	6.58	5.63
Diesel energy (%)	0.93	0.92	1.21	0.62	0.61	0.78	0.74	0.71	0.52
Fuel wood energy (%)	82.56	87.63	91.14	84.68	88.58	90.47	91.84	92.71	91.66
Furnace oil energy (%)	9.89	4.00	0.00	7.77	3.11	0.00	1.18	0.00	2.19
Energy intensity(MJ/KG MT)	32.6	33.18	31.63	33.53	31.6	30.52	32.5	29.57	35.57
Energy cost ('000USD)	785.66	681.93	605.20	760.27	612.55	481.93	383.44	387.25	431.57
Cost intensity (USD/TON MT)	193.06	178.58	177.61	197.47	198.9	179.89	167.56	150.07	159.72
Electricity Ratio (KWH/ ton MT)	683.37	770.76	778.62	702.48	729.15	807.54	629.53	599.14	607.65
F.W ratio (Tons MT/TON F. Wood)	0.439	0.457	0.500	0.434	0.484	0.522	0.472	0.526	0.424

Appendix III: Energy data Year 2011/12

Item description	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual MT ('000 tons)	4.09	3.94	3.91	4.16	3.62	3.33	2.76	3.59	3.61
Electricity energy (%)	4.57	4.13	6.29	5.40	6.75	6.39	6.13	5.62	6.12
Diesel energy (%)	1.37	1.29	0.76	0.42	0.65	0.14	0.32	0.52	0.92
Fuel wood energy (%)	94.02	94.57	92.95	89.93	92.60	93.47	93.48	93.85	87.17
Furnace oil energy (%)	0.05	0.00	0.00	4.25	0.00	0.00	0.07	0.00	5.79
Energy intensity(MJ/KG MT)	36.98	43.39	35.09	41.12	33.39	35.31	33.82	33.25	35.54
Energy cost ('000USD)	760.90	837.26	735.60	1010.39	707.71	586.94	523.71	628.72	859.46
Cost intensity (USD/TON MT)	185.98	212.75	187.98	242.93	195.68	176.03	189.52	174.92	238.14
Electricity Ratio (kWh/ ton MT)	606.57	650.27	685.44	663.6	684.82	640.07	605.03	566.47	692.49
F.W (Tons MT/TON F. Wood)	0.415	0.352	0.442	0.359	0.467	0.437	0.456	0.462	0.415

Appendix IV: Energy data year 2012/13

Item description	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual MT ('000 tons)	4.79	4.43	4.32	4.79	3.85	3.51	3.05	3.44	3.32
Electricity energy (%)	5.07	5.22	6.84	6.46	7.40	5.59	7.42	5.36	5.96
Diesel energy (%)	0.97	1.05	1.15	0.65	0.98	0.24	0.68	0.44	0.68
Fuel wood energy (%)	93.92	93.73	92.01	88.34	91.62	94.17	91.83	94.21	87.19
Furnace oil energy (%)	0.04	0.00	0.00	4.55	0.00	0.00	0.07	0.00	6.17
Energy intensity(MJ/KG MT)	35.37	37.28	32.26	33.33	32.43	35.39	30.75	37.9	36.33
Energy cost ('000USD)	893.37	923.47	947.47	924.90	865.99	670.14	638.94	672.39	682.94
Cost intensity (USD/TON MT)	186.49	208.51	219.15	192.89	224.74	190.89	209.68	195.35	205.86
Electricity Ratio (kWh/ ton MT)	593.21	648.75	715.83	658.52	754.89	573.14	691.77	609.9	670.04
F.W(Tons MT/TON F. Wood)	0.434	0.413	0.486	0.447	0.486	0.433	0.51	0.404	0.403

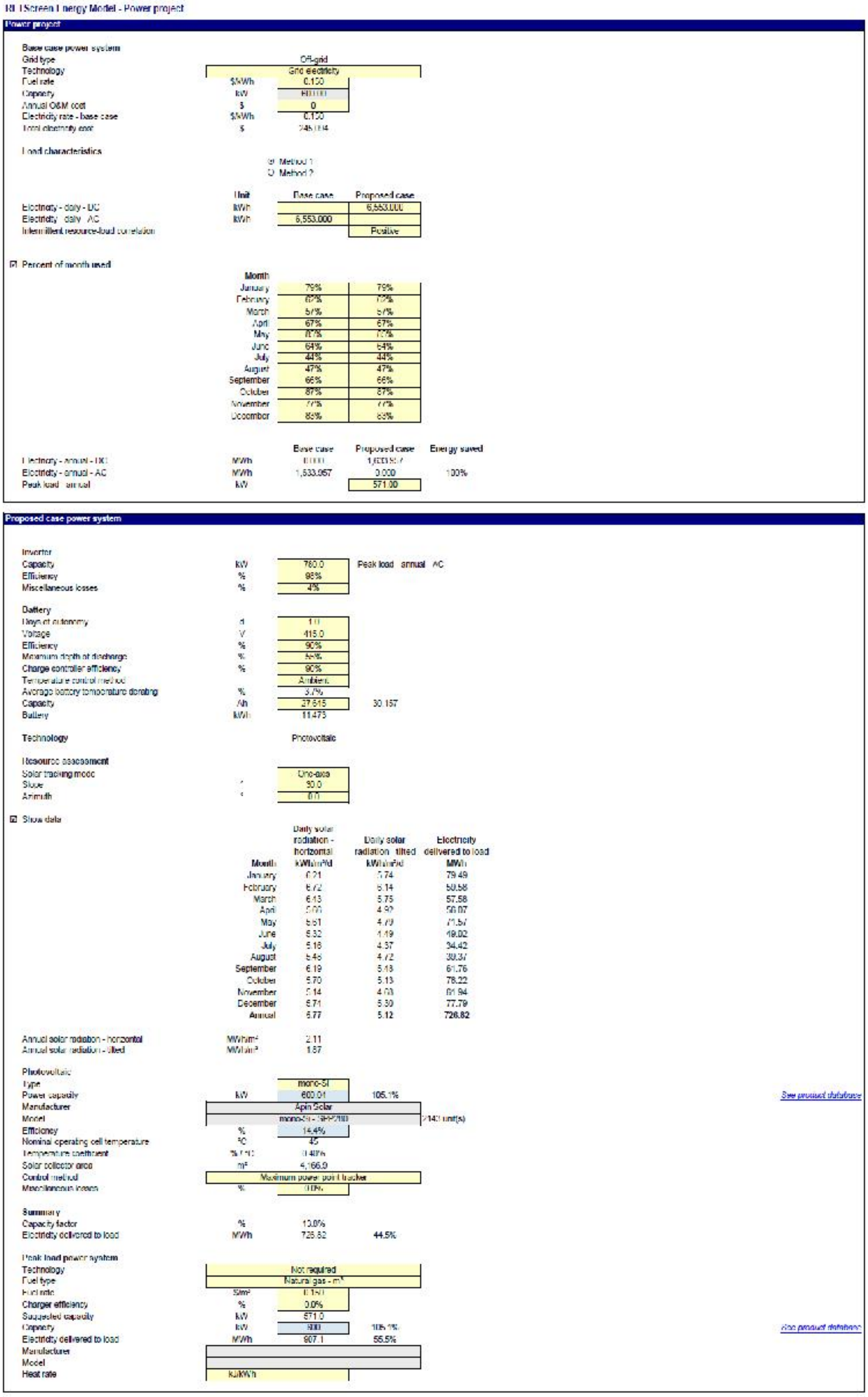
Appendix V: Energy data 2013/2014

Item description	F1	F2	F3	F4	F5	F6	F7	F8	F9
Annual MT ('000 tons)	4.79	4.43	4.32	4.79	3.85	3.51	3.05	3.44	3.32
Electricity energy (%)	5.07	5.22	6.84	6.46	7.40	5.59	7.42	5.36	5.96
Diesel energy (%)	0.97	1.05	1.15	0.65	0.98	0.24	0.68	0.44	0.68
Fuel wood energy (%)	93.92	93.73	92.01	88.34	91.62	94.17	91.83	94.21	87.19
Furnace oil energy (%)	0.04	0.00	0.00	4.55	0.00	0.00	0.07	0.00	6.17
Energy intensity(MJ/KG MT)	35.37	37.28	32.26	33.33	32.43	35.39	30.75	37.9	36.33
Energy cost ('000USD)	893.37	923.47	947.47	924.90	865.99	670.14	638.94	672.39	682.94
Cost intensity (USD/TON MT)	186.49	208.51	219.15	192.89	224.74	190.89	209.68	195.35	205.86
Electricity Ratio (kWh/ ton MT)	593.21	648.75	715.83	658.52	754.89	573.14	691.77	609.9	670.04
F.W(Tons MT/TON F. Wood)	0.434	0.413	0.486	0.447	0.486	0.433	0.51	0.404	0.403

Appendix VI: Technical and financial assumptions

No	Description	Technology /item	Value	Source
1	Availability	CHP	90%	Wright et., al
		Wind	20 years	
2	Life span	Solar PV and CSP	25 years	IRENA ,2012
		CHP	40 years	
3	Construction period	Solar PV ,Solar thermal and wind	12 months	Lazard ,2014
		CHP	36 months	
4	Insurance	Wind, Solar PV,CSP and CHP	0.5% capital investment	IRENA ,2012
	Contingency	Wind, Solar PV,CSP and CHP	5 % of capital investment	EIA, 2010
5	Scrap value	Wind	10 % capital investment	Ahmed et., al 2013
		Solar PV,CSP and CHP	5 % capital investment	IRENA, 2012
6	Fuel	Heat rate	14,200 Btu/KWh	Lazard, 2014
7	Temperature	Condensate inlet temperature	80 degrees	Own
		Air temperature range	35^0 C to 145^oC	Own
8	Rate	Fuel escalation rate	16.80%	Own
9	Solar installation	Slope	30	Jayakumar, 2009
		Azimuth	0	Yu et al
		Inverter efficiency	85%	
10	Financial	Discount rate	12%	Own
		Interest rate	6%	Own
		Inflation rate	5.70%	KNBS, 2013
		Debt ratio	65%	Own
		Loan term	8 years	Own
		Depreciation	Not considered	Own
11	Cost	Electricity	USD 0.15/KWh	Own
		Fuel oil	USD 0.0512/KWh	
		Fuel wood	USD 0.0082/KWh	
12	Others	Government incentives	None	Own
		Interest and exchange rates	Stable	

Appendix VII: Solar PV energy model



RETScreen Energy Model - Power project

Power project

Base case power system

Grid type		Off-grid	
Technology		Grid electricity	
Fuel rate	$/kWh	0.150	
Capacity	kW	[illegible]	
Annual O&M cost	$	0	
Electricity rate - base case	$/kWh	0.150	
Total electricity cost	$	245,094	

Load characteristics

● Method 1
○ Method 2

	Unit	Base case	Proposed case
Electricity - daily - DC	kWh		6,553.000
Electricity - daily - AC	kWh	6,553.000	
Intermittent resource-load correlation			Positive

☑ Percent of month used

Month		
January	79%	79%
February	67%	67%
March	57%	57%
April	67%	67%
May	77%	77%
June	64%	64%
July	44%	44%
August	47%	47%
September	66%	66%
October	87%	87%
November	77%	77%
December	85%	85%

		Base case	Proposed case	Energy saved
Electricity - annual - DC	MWh	0.000	1,633.957	
Electricity - annual - AC	MWh	1,633.957	0.000	100%
Peak load - annual	kW		571.00	

Proposed case power system

Inverter

Capacity	kW	760.0	Peak load - annual - AC
Efficiency	%	95%	
Miscellaneous losses	%	4%	

Battery

Days of autonomy	d	1.0	
Voltage	V	415.0	
Efficiency	%	90%	
Maximum depth of discharge	%	55%	
Charge controller efficiency	%	90%	
Temperature control method		Ambient	
Average battery temperature derating	%	3.7%	
Capacity	Ah	27,615	30,157
Battery	kWh	11,475	

Technology — Photovoltaic

Resource assessment

Solar tracking mode		One-axis
Slope	°	90.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity delivered to load MWh
January	6.21	5.74	79.49
February	6.72	6.14	59.58
March	6.13	5.75	57.58
April	5.66	4.92	56.07
May	5.51	4.79	71.57
June	5.32	4.19	49.02
July	5.16	4.37	34.42
August	5.46	4.72	39.37
September	6.19	5.18	61.76
October	5.70	5.13	78.22
November	5.14	4.63	61.94
December	5.71	5.30	77.79
Annual	5.77	5.12	726.82

Annual solar radiation - horizontal	MWh/m²	2.11
Annual solar radiation - tilted	MWh/m²	1.87

Photovoltaic

Type		mono-Si		
Power capacity	kW	600.01	105.1%	See product database
Manufacturer		Apin Solar		
Model		mono-Si - [illegible]	2143 unit(s)	
Efficiency	%	14.4%		
Nominal operating cell temperature	°C	45		
Temperature coefficient	% / °C	0.40%		
Solar collector area	m²	4,166.9		
Control method		Maximum power point tracker		
Miscellaneous losses	%	0.0%		

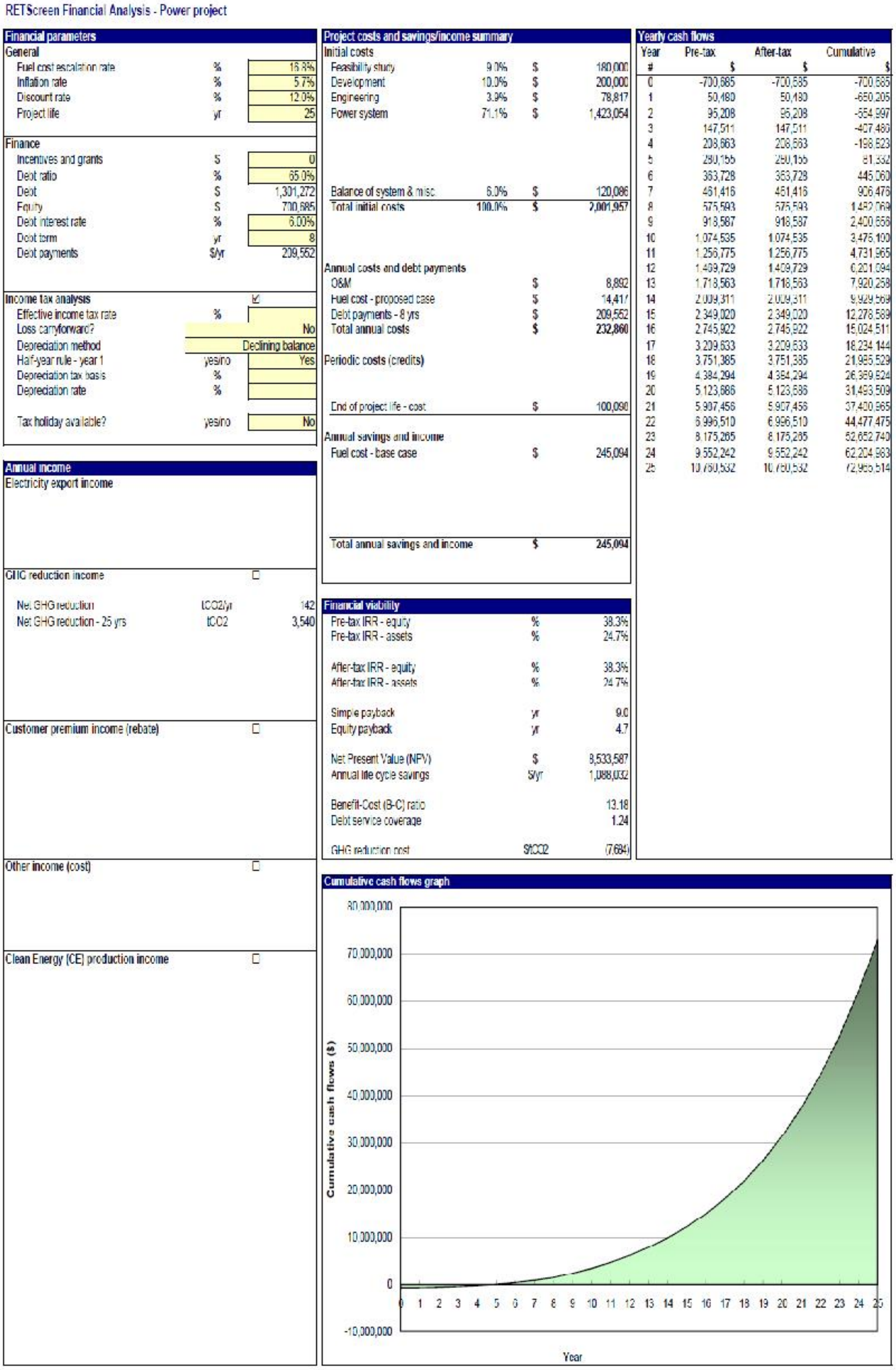
Summary

Capacity factor	%	13.8%	
Electricity delivered to load	MWh	726.82	44.5%

Peak load power system

Technology		Not required		
Fuel type		Natural gas - m³		
Fuel rate	$/m³	0.150		
Charger efficiency	%	0.0%		
Suggested capacity	kW	571.0		
Capacity	kW	600	105.1%	See product database
Electricity delivered to load	MWh	907.1	55.5%	
Manufacturer				
Model				
Heat rate	kJ/kWh			

Appendix VIII: Solar PV financial analysis



RETScreen Financial Analysis - Power project

Financial parameters

General

Fuel cost escalation rate	%	16.8%
Inflation rate	%	5.7%
Discount rate	%	12.0%
Project life	yr	25

Finance

Incentives and grants	$	0
Debt ratio	%	65.0%
Debt	$	1,301,272
Equity	$	700,685
Debt interest rate	%	6.00%
Debt term	yr	8
Debt payments	$/yr	209,552

Income tax analysis ☑

Effective income tax rate	%	
Loss carryforward?		No
Depreciation method		Declining balance
Half-year rule - year 1	yes/no	Yes
Depreciation tax basis	%	
Depreciation rate	%	
Tax holiday available?	yes/no	No

Annual income

Electricity export income

GHG reduction income ☐

Net GHG reduction	tCO2/yr	142
Net GHG reduction - 25 yrs	tCO2	3,540

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs

Feasibility study	9.0%	$	180,000
Development	10.0%	$	200,000
Engineering	3.9%	$	78,817
Power system	71.1%	$	1,423,054
Balance of system & misc.	6.0%	$	120,086
Total initial costs	100.0%	$	2,001,957

Annual costs and debt payments

O&M	$	8,892
Fuel cost - proposed case	$	14,417
Debt payments - 8 yrs	$	209,552
Total annual costs	$	232,860

Periodic costs (credits)

End of project life - cost	$	100,090

Annual savings and income

Fuel cost - base case	$	245,094
Total annual savings and income	$	245,094

Financial viability

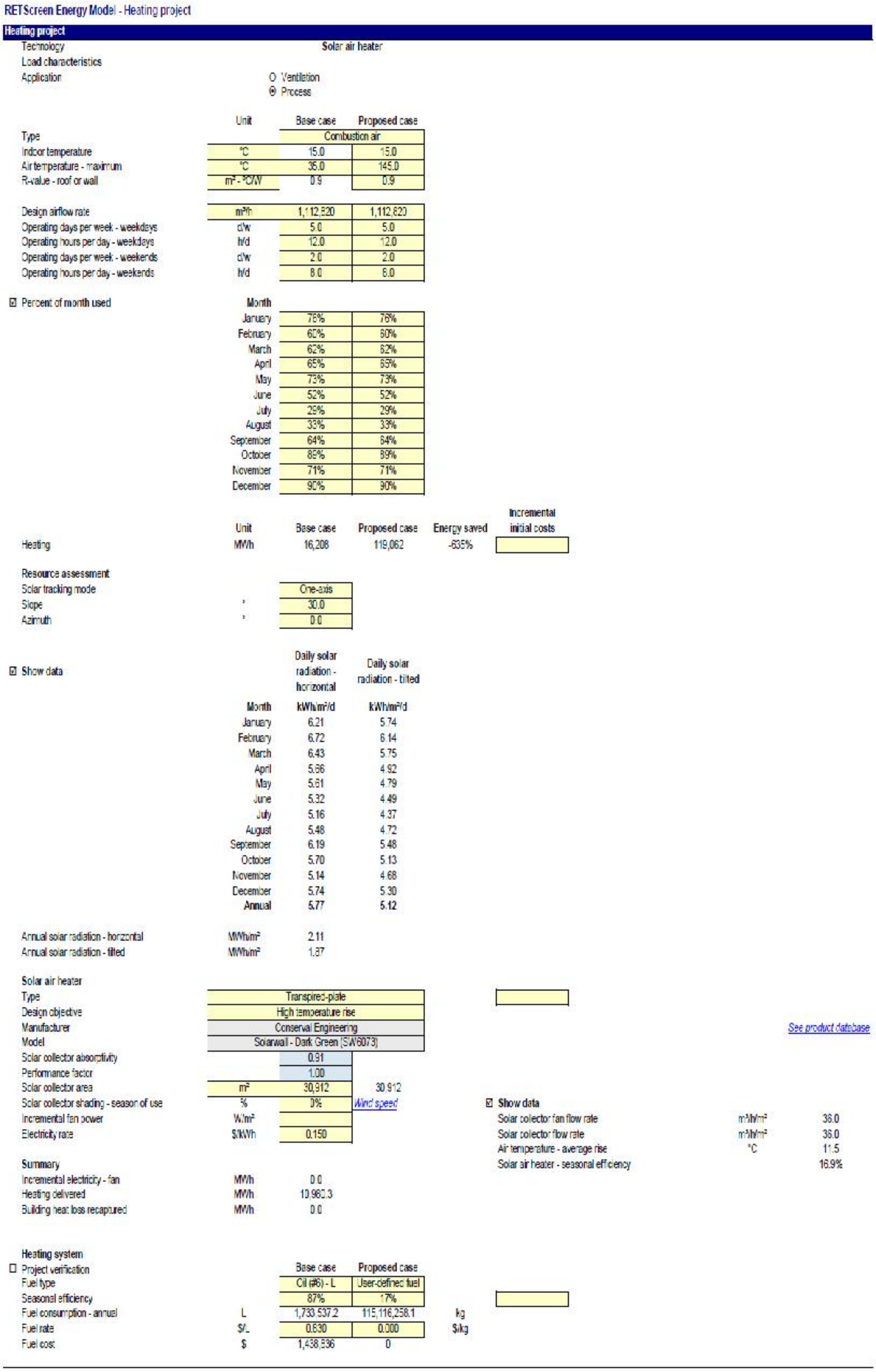
Pre-tax IRR - equity	%	38.3%
Pre-tax IRR - assets	%	24.7%
After-tax IRR - equity	%	38.3%
After-tax IRR - assets	%	24.7%
Simple payback	yr	9.0
Equity payback	yr	4.7
Net Present Value (NPV)	$	8,533,587
Annual life cycle savings	$/yr	1,088,032
Benefit-Cost (B-C) ratio		13.18
Debt service coverage		1.24
GHG reduction cost	$/tCO2	(7,684)

Yearly cash flows

Year \#	Pre-tax $	After-tax $	Cumulative $
0	-700,685	-700,685	-700,685
1	50,480	50,480	-650,205
2	95,208	95,208	-554,997
3	147,511	147,511	-407,486
4	208,663	208,663	-198,823
5	280,155	280,155	81,332
6	363,728	363,728	445,060
7	461,416	461,416	906,476
8	575,593	575,593	1,482,069
9	918,587	918,587	2,400,656
10	1,074,535	1,074,535	3,475,190
11	1,256,775	1,256,775	4,731,965
12	1,469,729	1,469,729	6,201,694
13	1,718,563	1,718,563	7,920,258
14	2,009,311	2,009,311	9,929,569
15	2,349,020	2,349,020	12,278,589
16	2,745,922	2,745,922	15,024,511
17	3,209,633	3,209,633	18,234,144
18	3,751,385	3,751,385	21,985,529
19	4,384,294	4,384,294	26,369,824
20	5,123,686	5,123,686	31,493,509
21	5,907,456	5,907,456	37,400,965
22	6,996,510	6,996,510	44,477,475
23	8,175,265	8,175,265	52,652,740
24	9,552,242	9,552,242	62,204,983
25	10,760,532	10,760,532	72,965,514

Cumulative cash flows graph

Appendix IX: Solar thermal energy Model



RETScreen Energy Model - Heating project

Heating project

Technology		**Solar air heater**	
Load characteristics			
Application		○ Ventilation ● Process	

	Unit	Base case	Proposed case
Type		Combustion air	
Indoor temperature	°C	15.0	15.0
Air temperature - maximum	°C	35.0	145.0
R-value - roof or wall	m² - °C/W	0.9	0.9
Design airflow rate	m³/h	1,112,820	1,112,820
Operating days per week - weekdays	d/w	5.0	5.0
Operating hours per day - weekdays	h/d	12.0	12.0
Operating days per week - weekends	d/w	2.0	2.0
Operating hours per day - weekends	h/d	8.0	6.0

☒ Percent of month used	Month		
	January	76%	76%
	February	60%	60%
	March	62%	62%
	April	65%	65%
	May	73%	73%
	June	52%	52%
	July	29%	29%
	August	33%	33%
	September	64%	64%
	October	89%	89%
	November	71%	71%
	December	90%	90%

	Unit	Base case	Proposed case	Energy saved	Incremental initial costs
Heating	MWh	16,208	119,062	-635%	

Resource assessment		
Solar tracking mode		One-axis
Slope	°	30.0
Azimuth	°	0.0

☒ Show data	Month	Daily solar radiation - horizontal	Daily solar radiation - tilted
		kWh/m²/d	kWh/m²/d
	January	6.21	5.74
	February	6.72	6.14
	March	6.43	5.75
	April	5.66	4.92
	May	5.61	4.79
	June	5.32	4.49
	July	5.16	4.37
	August	5.48	4.72
	September	6.19	5.48
	October	5.70	5.13
	November	5.14	4.68
	December	5.74	5.30
	Annual	**5.77**	**5.12**

Annual solar radiation - horizontal	MWh/m²	2.11
Annual solar radiation - tilted	MWh/m²	1.87

Solar air heater			
Type		Transpired-plate	
Design objective		High temperature rise	
Manufacturer		Conserval Engineering	
Model		Solarwall - Dark Green (SW6073)	
Solar collector absorptivity		0.91	
Performance factor		1.00	
Solar collector area	m²	30,912	30,912
Solar collector shading - season of use	%	0%	*Wind speed*
Incremental fan power	W/m²		
Electricity rate	$/kWh	0.150	

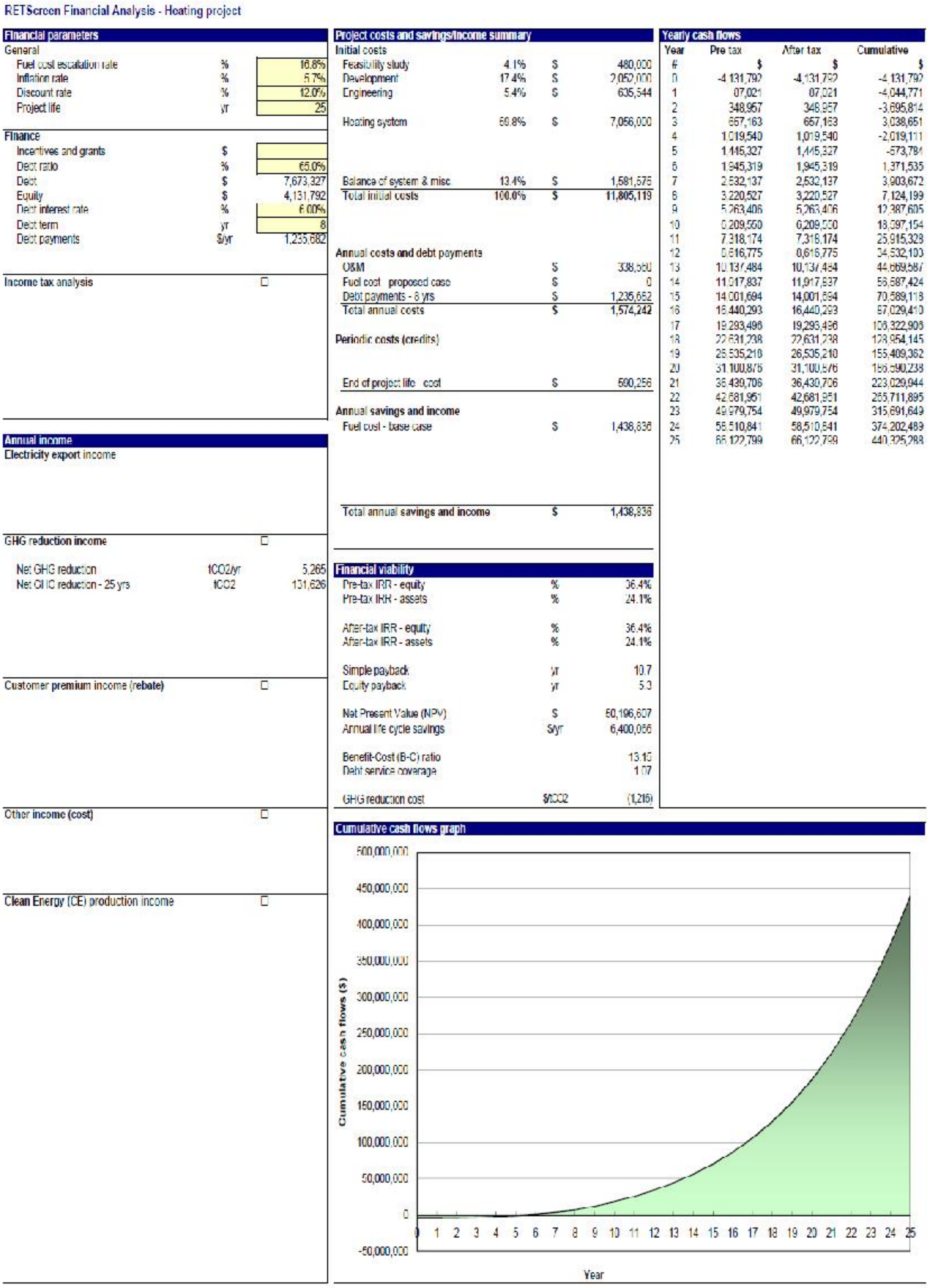
See product database

☒ **Show data**		
Solar collector fan flow rate	m³/h/m²	36.0
Solar collector flow rate	m³/h/m²	36.0
Air temperature - average rise	°C	11.5
Solar air heater - seasonal efficiency		16.9%

Summary		
Incremental electricity - fan	MWh	0.0
Heating delivered	MWh	10,960.3
Building heat loss recaptured	MWh	0.0

Heating system				
☐ Project verification		Base case	Proposed case	
Fuel type		Oil (#6) - L	User-defined fuel	
Seasonal efficiency		87%	17%	
Fuel consumption - annual	L	1,733,537.2	115,116,258.1	kg
Fuel rate	$/L	0.630	0.000	$/kg
Fuel cost	$	1,438,836	0	

Appendix X: Solar Thermal Financial analysis



RETScreen Financial Analysis - Heating project

Financial parameters

General		
Fuel cost escalation rate	%	16.8%
Inflation rate	%	5.7%
Discount rate	%	12.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	65.0%
Debt	$	7,673,327
Equity	$	4,131,792
Debt interest rate	%	6.00%
Debt term	yr	8
Debt payments	$/yr	1,235,682
Income tax analysis	☐	

Annual income

Electricity export income		
GHG reduction income	☐	
Net GHG reduction	tCO2/yr	5,265
Net GHG reduction - 25 yrs	tCO2	131,626
Customer premium income (rebate)	☐	
Other income (cost)	☐	
Clean Energy (CE) production income	☐	

Project costs and savings/income summary

Initial costs			
Feasibility study	4.1%	$	480,000
Development	17.4%	$	2,052,000
Engineering	5.4%	$	635,544
Heating system	59.8%	$	7,056,000
Balance of system & misc	13.4%	$	1,581,575
Total initial costs	100.0%	$	11,805,119
Annual costs and debt payments			
O&M		$	338,560
Fuel cost - proposed case		$	0
Debt payments - 8 yrs		$	1,235,682
Total annual costs		$	1,574,242
Periodic costs (credits)			
End of project life - cost		$	590,256
Annual savings and income			
Fuel cost - base case		$	1,438,836
Total annual savings and income		$	1,438,836

Financial viability

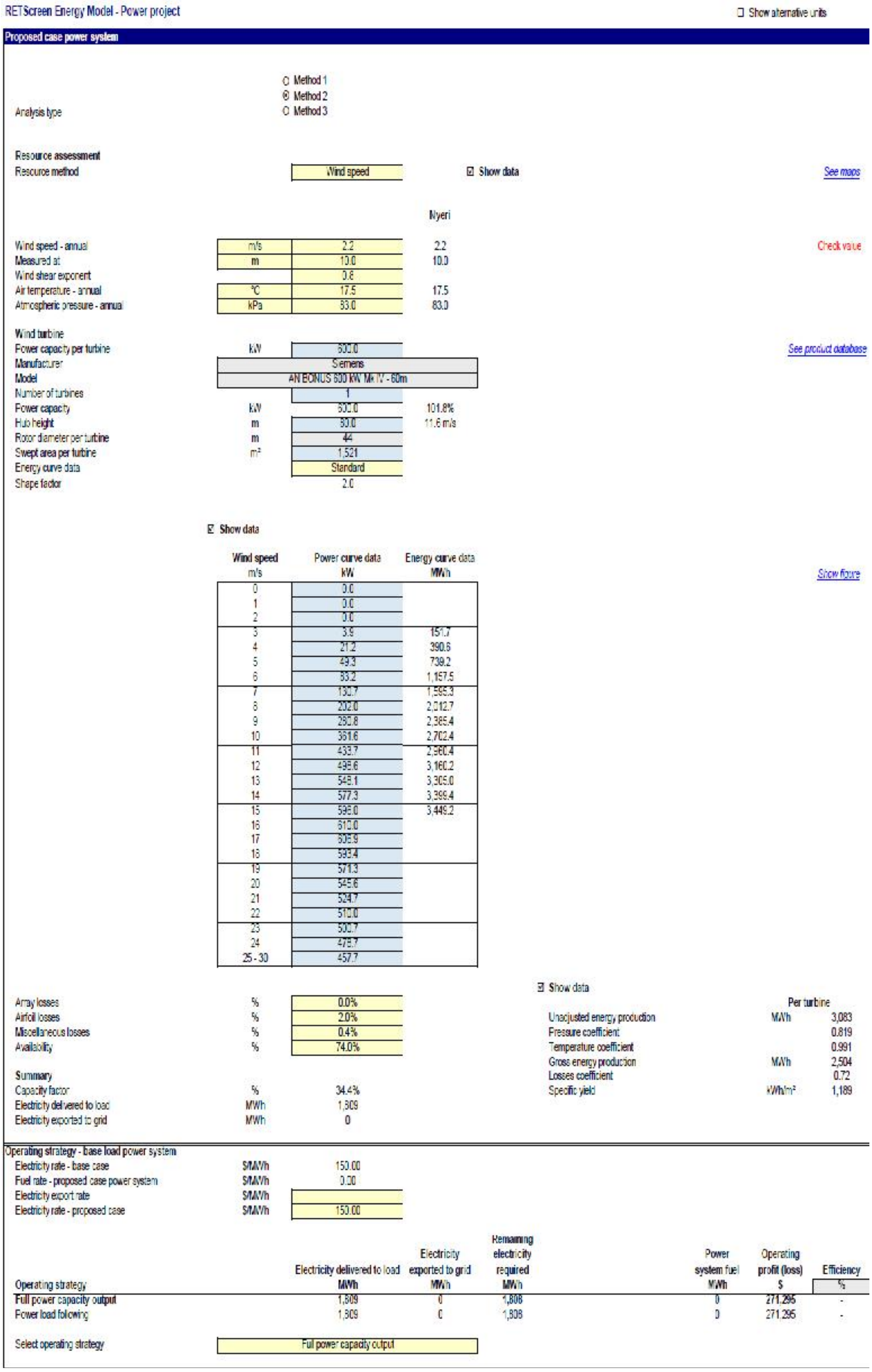
Pre-tax IRR - equity	%	36.4%
Pre-tax IRR - assets	%	24.1%
After-tax IRR - equity	%	36.4%
After-tax IRR - assets	%	24.1%
Simple payback	yr	10.7
Equity payback	yr	5.3
Net Present Value (NPV)	$	50,196,607
Annual life cycle savings	$/yr	6,400,066
Benefit-Cost (B-C) ratio		13.15
Debt service coverage		1.07
GHG reduction cost	$/tCO2	(1,216)

Yearly cash flows

Year #	Pre tax $	After tax $	Cumulative $
0	-4,131,792	-4,131,792	-4,131,792
1	87,021	87,021	-4,044,771
2	348,957	348,957	-3,695,814
3	657,163	657,163	-3,038,651
4	1,019,540	1,019,540	-2,019,111
5	1,445,327	1,445,327	-573,784
6	1,945,319	1,945,319	1,371,535
7	2,532,137	2,532,137	3,903,672
8	3,220,527	3,220,527	7,124,199
9	5,263,406	5,263,406	12,387,605
10	6,209,550	6,209,550	18,597,154
11	7,318,174	7,318,174	25,915,328
12	8,616,775	8,616,775	34,532,103
13	10,137,484	10,137,484	44,669,587
14	11,917,837	11,917,837	56,587,424
15	14,001,694	14,001,694	70,589,118
16	16,440,293	16,440,293	87,029,410
17	19,293,496	19,293,496	106,322,906
18	22,631,238	22,631,238	128,954,145
19	26,535,217	26,535,217	155,489,362
20	31,100,876	31,100,876	186,590,238
21	36,439,706	36,439,706	223,029,944
22	42,681,951	42,681,951	265,711,895
23	49,979,754	49,979,754	315,691,649
24	58,510,841	58,510,841	374,202,489
25	66,122,799	66,122,799	440,325,288

Cumulative cash flows graph

Appendix XI: Wind Energy model



RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Analysis type

○ Method 1
● Method 2
○ Method 3

Resource assessment

Resource method		Wind speed	☑ Show data	See maps
			Nyeri	
Wind speed - annual	m/s	2.2	2.2	Check value
Measured at	m	10.0	10.0	
Wind shear exponent		0.8		
Air temperature - annual	°C	17.5	17.5	
Atmospheric pressure - annual	kPa	83.0	83.0	

Wind turbine

Power capacity per turbine	kW	600.0		See product database
Manufacturer		Siemens		
Model		AN BONUS 600 kW Mk IV - 60m		
Number of turbines		1		
Power capacity	kW	600.0	101.8%	
Hub height	m	80.0	11.6 m/s	
Rotor diameter per turbine	m	44		
Swept area per turbine	m²	1,521		
Energy curve data		Standard		
Shape factor		2.0		

☑ Show data

Show figure

Wind speed m/s	Power curve data kW	Energy curve data MWh
0	0.0	
1	0.0	
2	0.0	
3	3.9	151.7
4	21.2	390.6
5	49.3	739.2
6	83.2	1,157.5
7	130.7	1,595.3
8	202.0	2,012.7
9	280.8	2,385.4
10	361.6	2,702.4
11	433.7	2,960.4
12	498.6	3,160.2
13	548.1	3,305.0
14	577.3	3,399.4
15	596.0	3,449.2
16	610.0	
17	606.9	
18	593.4	
19	571.3	
20	545.6	
21	524.7	
22	510.0	
23	500.7	
24	478.7	
25 - 30	457.7	

Array losses	%	0.0%
Airfoil losses	%	2.0%
Miscellaneous losses	%	0.4%
Availability	%	74.0%

Summary

Capacity factor	%	34.4%
Electricity delivered to load	MWh	1,809
Electricity exported to grid	MWh	0

☑ Show data

		Per turbine
Unadjusted energy production	MWh	3,083
Pressure coefficient		0.819
Temperature coefficient		0.991
Gross energy production	MWh	2,504
Losses coefficient		0.72
Specific yield	kWh/m²	1,189

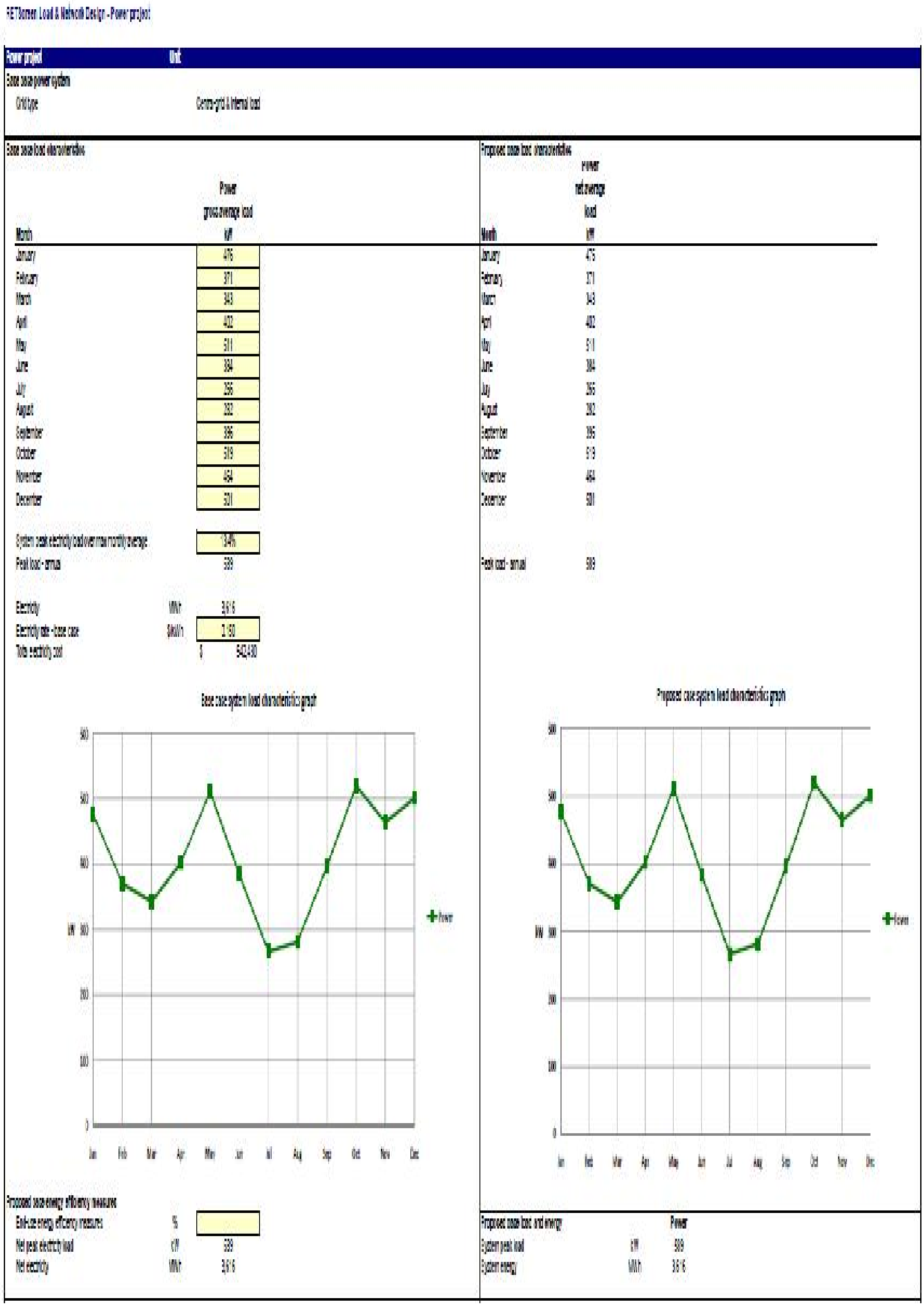
Operating strategy - base load power system

Electricity rate - base case	$/MWh	150.00
Fuel rate - proposed case power system	$/MWh	0.00
Electricity export rate	$/MWh	
Electricity rate - proposed case	$/MWh	150.00

Operating strategy	**Electricity delivered to load** **MWh**	Electricity exported to grid MWh	**Remaining electricity required** **MWh**	Power system fuel MWh	**Operating profit (loss)** **$**	**Efficiency** %
Full power capacity output	1,809	0	1,808	0	271,295	-
Power load following	1,809	0	1,808	0	271,295	-

Select operating strategy: Full power capacity output

Appendix XII: Wind load design



RETScreen Load & Network Design - Power project

Power project	Unit	
Base case power system		
Grid type		Central-grid & internal load

Base case load characteristics

Month	Power gross average load kW
January	476
February	371
March	343
April	402
May	511
June	384
July	266
August	282
September	396
October	519
November	464
December	501

System peak electricity load over max monthly average		104%
Peak load - annual		539
Electricity	MWh	3,616
Electricity rate - base case	$/MWh	150
Total electricity cost	$	542,480

Proposed case load characteristics

Month	Power net average load kW
January	476
February	371
March	343
April	402
May	511
June	384
July	266
August	282
September	396
October	519
November	464
December	501

Peak load - annual	539

Base case system load characteristics graph

Proposed case system load characteristics graph

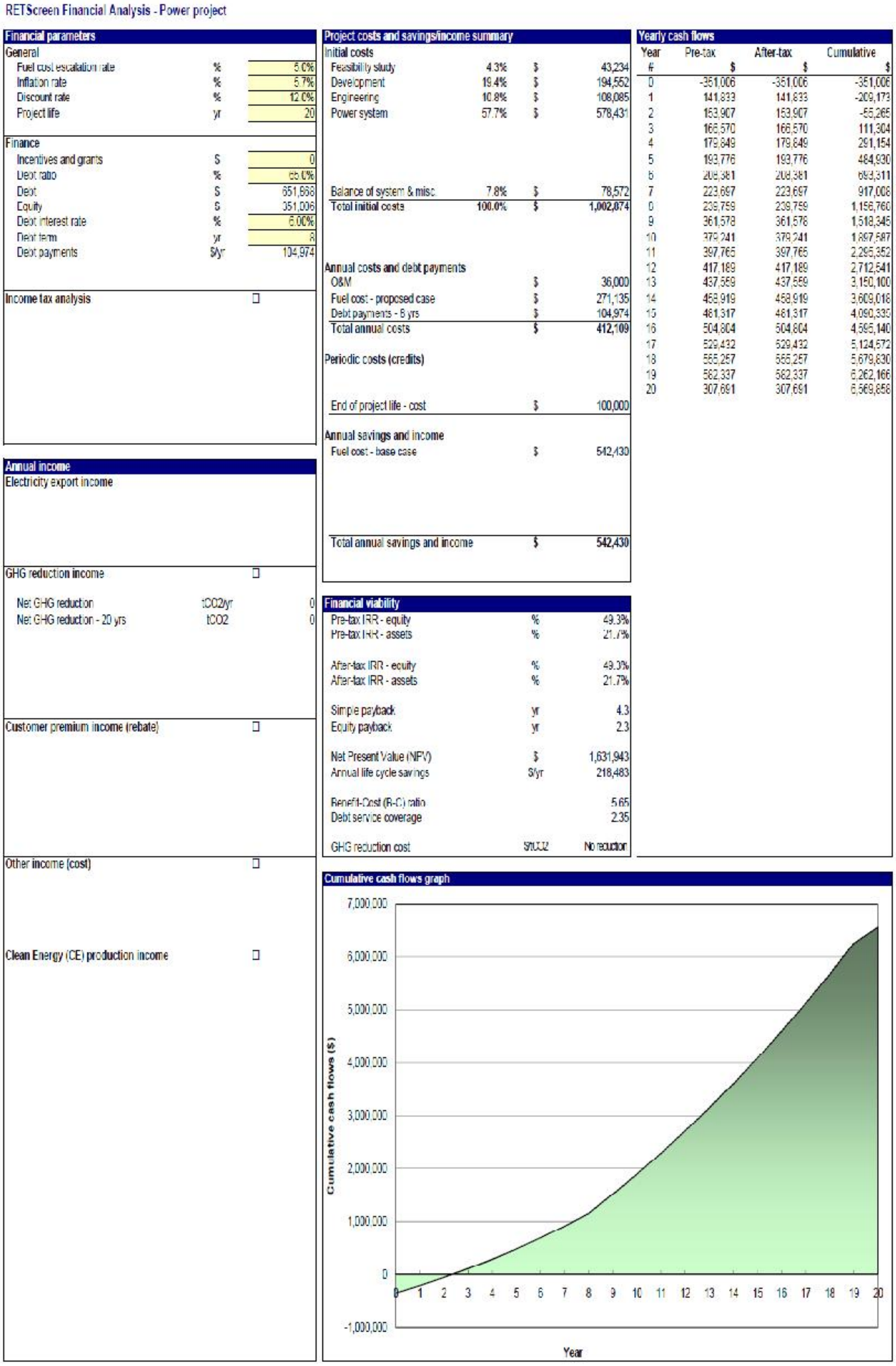
Proposed case energy efficiency measures

End-use energy efficiency measures	%	
Net peak electricity load	kW	539
Net electricity	MWh	3,616

Proposed case load and energy		Power
System peak load	kW	539
System energy	MWh	3,616

7

Appendix XIII: Wind Financial analysis



RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	5.0%
Inflation rate	%	5.7%
Discount rate	%	12.0%
Project life	yr	20
Finance		
Incentives and grants	$	0
Debt ratio	%	65.0%
Debt	$	651,868
Equity	$	351,006
Debt interest rate	%	6.00%
Debt term	yr	8
Debt payments	$/yr	104,974

Income tax analysis ☐

Annual income

Electricity export income

GHG reduction income ☐

Net GHG reduction	tCO2/yr	0
Net GHG reduction - 20 yrs	tCO2	0

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs			
Feasibility study	4.3%	$	43,234
Development	19.4%	$	194,552
Engineering	10.8%	$	108,085
Power system	57.7%	$	578,431
Balance of system & misc.	7.8%	$	78,572
Total initial costs	**100.0%**	**$**	**1,002,874**
Annual costs and debt payments			
O&M		$	36,000
Fuel cost - proposed case		$	271,135
Debt payments - 8 yrs		$	104,974
Total annual costs		$	412,109
Periodic costs (credits)			
End of project life - cost		$	100,000
Annual savings and income			
Fuel cost - base case		$	542,430
Total annual savings and income		$	542,430

Yearly cash flows

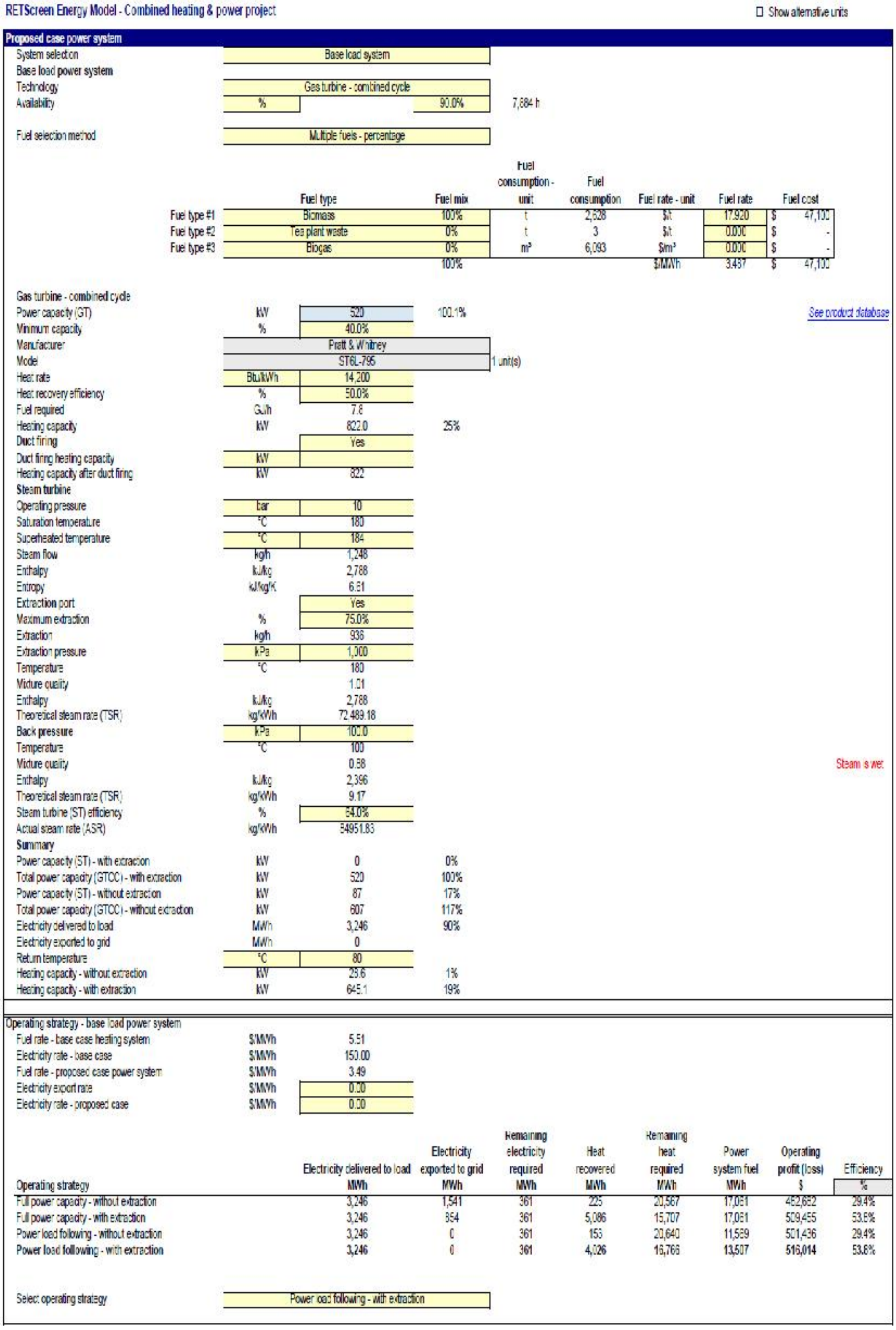
Year \#	Pre-tax $	After-tax $	Cumulative $
0	-351,006	-351,006	-351,006
1	141,833	141,833	-209,173
2	153,907	153,907	-55,265
3	166,570	166,570	111,304
4	179,849	179,849	291,154
5	193,776	193,776	484,930
6	208,381	208,381	693,311
7	223,697	223,697	917,008
8	239,759	239,759	1,156,760
9	361,578	361,578	1,518,345
10	379,241	379,241	1,897,587
11	397,765	397,765	2,295,352
12	417,189	417,189	2,712,541
13	437,559	437,559	3,150,100
14	458,919	458,919	3,609,018
15	481,317	481,317	4,090,335
16	504,804	504,804	4,595,140
17	529,432	529,432	5,124,572
18	555,257	555,257	5,679,830
19	582,337	582,337	6,262,166
20	307,691	307,691	6,569,858

Financial viability

Pre-tax IRR - equity	%	49.3%
Pre-tax IRR - assets	%	21.7%
After-tax IRR - equity	%	49.3%
After-tax IRR - assets	%	21.7%
Simple payback	yr	4.3
Equity payback	yr	2.3
Net Present Value (NPV)	$	1,631,943
Annual life cycle savings	$/yr	218,483
Benefit-Cost (B-C) ratio		5.65
Debt service coverage		2.35
GHG reduction cost	$/tCO2	No reduction

Cumulative cash flows graph

Appendix XIV: Combined Heat and Power energy model



RETScreen Energy Model - Combined heating & power project

☐ Show alternative units

Proposed case power system

System selection	Base load system		
Base load power system			
Technology	Gas turbine - combined cycle		
Availability	%	90.0%	7,684 h
Fuel selection method	Multiple fuels - percentage		

	Fuel type	Fuel mix	Fuel consumption - unit	Fuel consumption	Fuel rate - unit	Fuel rate	Fuel cost
Fuel type #1	Biomass	100%	t	2,628	$/t	17.920	$ 47,100
Fuel type #2	Tea plant waste	0%	t	3	$/t	0.000	$ -
Fuel type #3	Biogas	0%	m³	6,093	$/m³	0.000	$ -
		100%			$/MWh	3.437	$ 47,100

Gas turbine - combined cycle			
Power capacity (GT)	kW	520	100.1%
Minimum capacity	%	40.0%	
Manufacturer		Pratt & Whitney	
Model		ST6L-795	1 unit(s)
Heat rate	Btu/kWh	14,200	
Heat recovery efficiency	%	50.0%	
Fuel required	GJ/h	7.8	
Heating capacity	kW	822.0	25%
Duct firing		Yes	
Duct firing heating capacity	kW		
Heating capacity after duct firing	kW	822	
Steam turbine			
Operating pressure	bar	10	
Saturation temperature	°C	180	
Superheated temperature	°C	184	
Steam flow	kg/h	1,248	
Enthalpy	kJ/kg	2,788	
Entropy	kJ/kg/K	6.61	
Extraction port		Yes	
Maximum extraction	%	75.0%	
Extraction	kg/h	936	
Extraction pressure	kPa	1,000	
Temperature	°C	180	
Mixture quality		1.01	
Enthalpy	kJ/kg	2,788	
Theoretical steam rate (TSR)	kg/kWh	72,489.18	
Back pressure	kPa	100.0	
Temperature	°C	100	
Mixture quality		0.88	Steam is wet
Enthalpy	kJ/kg	2,396	
Theoretical steam rate (TSR)	kg/kWh	9.17	
Steam turbine (ST) efficiency	%	64.0%	
Actual steam rate (ASR)	kg/kWh	84951.83	
Summary			
Power capacity (ST) - with extraction	kW	0	0%
Total power capacity (GTCC) - with extraction	kW	520	100%
Power capacity (ST) - without extraction	kW	87	17%
Total power capacity (GTCC) - without extraction	kW	607	117%
Electricity delivered to load	MWh	3,246	90%
Electricity exported to grid	MWh	0	
Return temperature	°C	80	
Heating capacity - without extraction	kW	23.6	1%
Heating capacity - with extraction	kW	645.1	19%

See product database

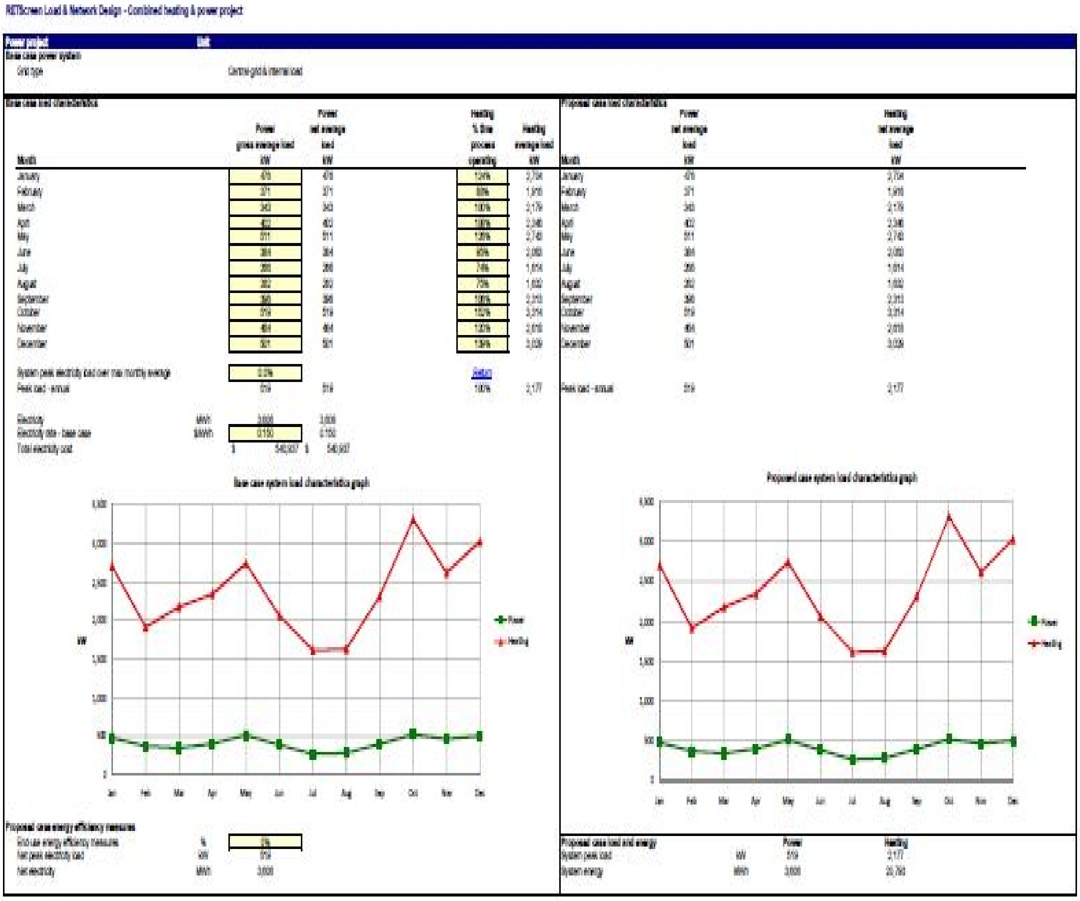
Operating strategy - base load power system

Fuel rate - base case heating system	$/MWh	5.51
Electricity rate - base case	$/MWh	150.00
Fuel rate - proposed case power system	$/MWh	3.49
Electricity export rate	$/MWh	0.00
Electricity rate - proposed case	$/MWh	0.00

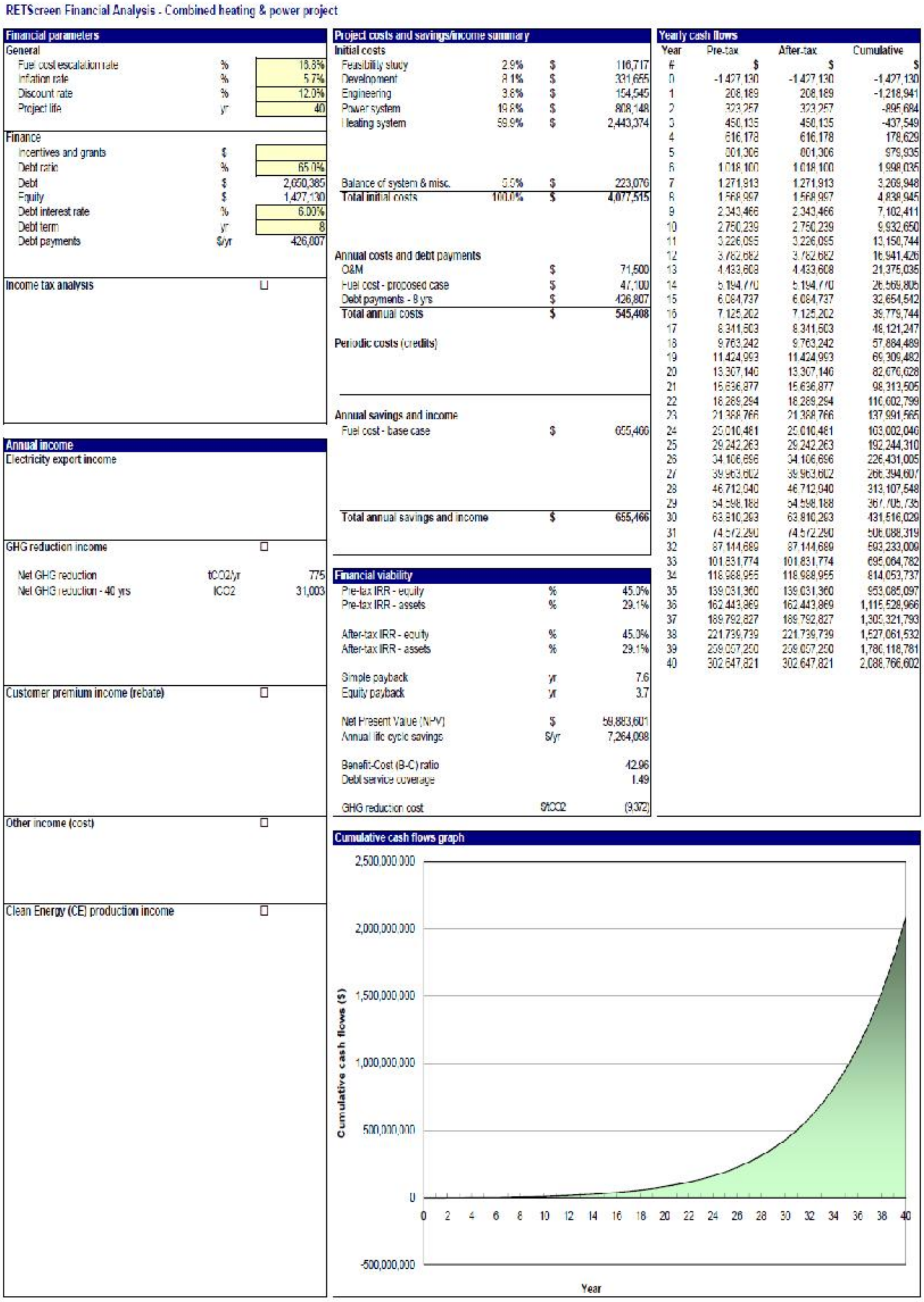
Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Heat recovered MWh	Remaining heat required MWh	Power system fuel MWh	Operating profit (loss) $	Efficiency %
Full power capacity - without extraction	3,246	1,541	361	225	20,567	17,081	462,682	29.4%
Full power capacity - with extraction	3,246	854	361	5,086	15,707	17,081	509,455	53.8%
Power load following - without extraction	3,246	0	361	153	20,640	11,589	501,436	29.4%
Power load following - with extraction	**3,246**	**0**	**361**	**4,026**	**16,766**	**13,507**	**516,014**	53.8%

Select operating strategy: Power load following - with extraction

Appendix XV: Combined Heat and Power Load and Network



Appendix XVI: Combined Heat and Power Financial analysis



RETScreen Financial Analysis - Combined heating & power project

Financial parameters

General		
Fuel cost escalation rate	%	16.8%
Inflation rate	%	5.7%
Discount rate	%	12.0%
Project life	yr	40
Finance		
Incentives and grants	$	
Debt ratio	%	65.0%
Debt	$	2,650,385
Equity	$	1,427,130
Debt interest rate	%	6.00%
Debt term	yr	8
Debt payments	$/yr	426,007

Income tax analysis ☐

Annual income

Electricity export income

GHG reduction income ☐

Net GHG reduction	tCO2/yr	775
Net GHG reduction - 40 yrs	tCO2	31,003

Customer premium income (rebate) ☐

Other income (cost) ☐

Clean Energy (CE) production income ☐

Project costs and savings/income summary

Initial costs			
Feasibility study	2.9%	$	116,717
Development	8.1%	$	331,655
Engineering	3.8%	$	154,545
Power system	19.8%	$	808,148
Heating system	59.9%	$	2,443,374
Balance of system & misc.	5.5%	$	223,076
Total initial costs	100.0%	$	4,077,515
Annual costs and debt payments			
O&M		$	71,500
Fuel cost - proposed case		$	47,100
Debt payments - 8 yrs		$	426,807
Total annual costs		$	545,408
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	655,466
Total annual savings and income		$	655,466

Financial viability

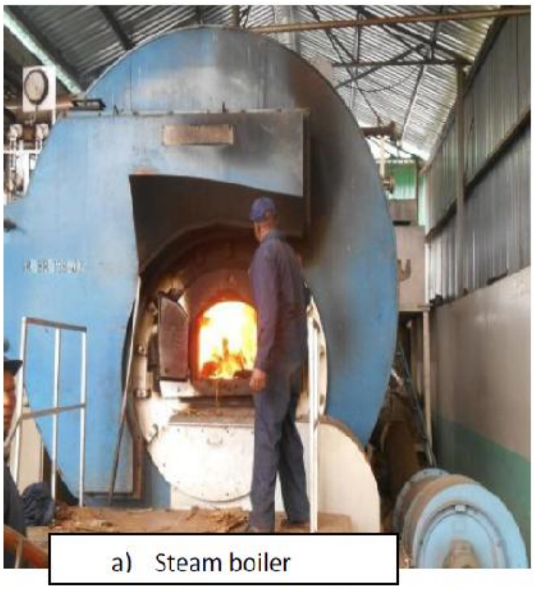
Pre-tax IRR - equity	%	45.0%
Pre-tax IRR - assets	%	29.1%
After-tax IRR - equity	%	45.0%
After-tax IRR - assets	%	29.1%
Simple payback	yr	7.6
Equity payback	yr	3.7
Net Present Value (NPV)	$	59,883,601
Annual life cycle savings	$/yr	7,264,098
Benefit-Cost (B-C) ratio		42.96
Debt service coverage		1.49
GHG reduction cost	$/tCO2	(9,372)

Yearly cash flows

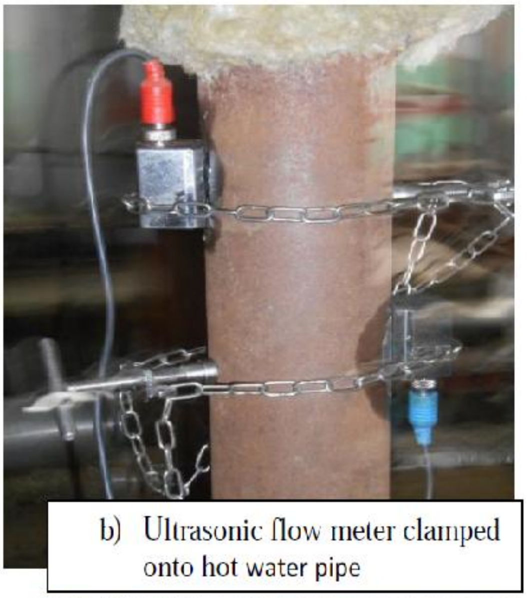
Year #	Pre-tax $	After-tax $	Cumulative $
0	-1,427,130	-1,427,130	-1,427,130
1	208,189	208,189	-1,218,941
2	323,257	323,257	-895,684
3	458,135	458,135	-437,549
4	616,178	616,178	178,629
5	801,306	801,306	979,935
6	1,018,100	1,018,100	1,998,035
7	1,271,913	1,271,913	3,269,948
8	1,568,997	1,568,997	4,838,945
9	2,343,466	2,343,466	7,182,411
10	2,750,239	2,750,239	9,932,650
11	3,226,095	3,226,095	13,158,744
12	3,782,682	3,782,682	16,941,426
13	4,433,608	4,433,608	21,375,035
14	5,194,770	5,194,770	26,569,805
15	6,084,737	6,084,737	32,654,542
16	7,125,202	7,125,202	39,779,744
17	8,341,503	8,341,503	48,121,247
18	9,763,242	9,763,242	57,884,489
19	11,424,993	11,424,993	69,309,482
20	13,367,146	13,367,146	82,676,628
21	15,636,877	15,636,877	98,313,505
22	18,289,294	18,289,294	116,602,799
23	21,388,766	21,388,766	137,991,565
24	25,010,481	25,010,481	163,002,046
25	29,242,263	29,242,263	192,244,310
26	34,186,696	34,186,696	226,431,005
27	39,963,602	39,963,602	266,394,607
28	46,712,940	46,712,940	313,107,548
29	54,598,188	54,598,188	367,705,736
30	63,810,293	63,810,293	431,516,029
31	74,572,290	74,572,290	506,088,319
32	87,144,689	87,144,689	593,233,009
33	101,831,774	101,831,774	695,064,782
34	118,988,955	118,988,955	814,053,737
35	139,031,360	139,031,360	953,085,097
36	162,443,869	162,443,869	1,115,528,966
37	189,792,827	189,792,827	1,305,321,793
38	221,739,739	221,739,739	1,527,061,532
39	259,057,250	259,057,250	1,786,118,781
40	302,647,821	302,647,821	2,088,766,602

Cumulative cash flows graph

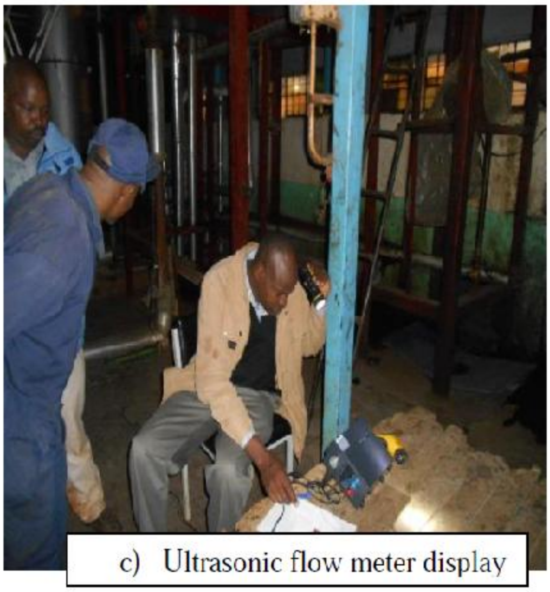
Appendix XVII: Field photos



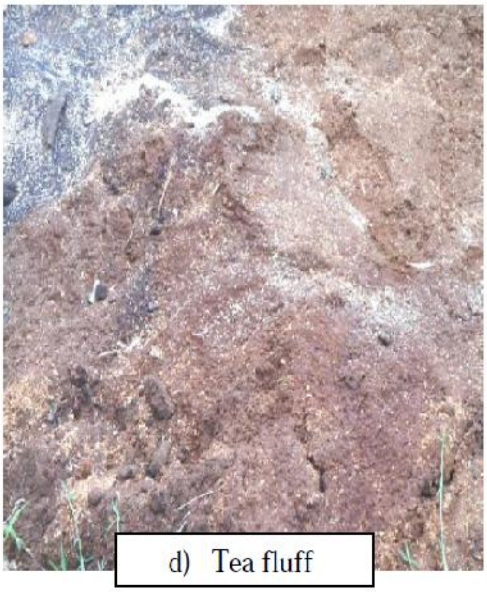
a) Steam boiler



b) Ultrasonic flow meter clamped onto hot water pipe

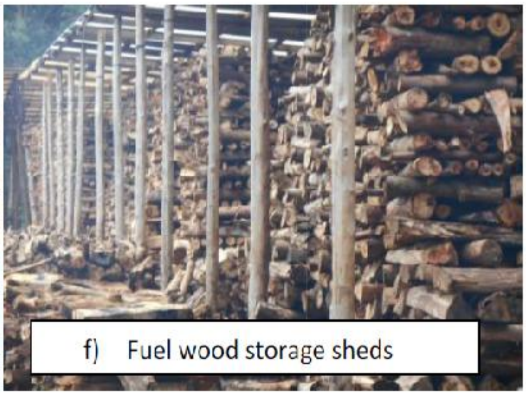


c) Ultrasonic flow meter display



d) Tea fluff

e) Wood sawdust



f) Fuel wood storage sheds

Appendix XVIII: Field photos

g) Firewood weighment before

h) Billeting fuel wood

Withering trough

j) Fluid bed drier temperature indicator