Energy Efficiency, Solar PV and Biomass Based Systems for Energy Demand and Greenhouse Gas Emissions Reduction Potential of Food Processing Plant

By

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Reg. No. 204214

Session 2017

Supervised by

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THESIS ACCEPTANCE CERTIFICATE

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Abstract

This paper presents a comparative analysis of renewable energy (solar PV and biomass-based systems) and energy efficiency in an industrial site for the sake of reduction in energy demand and greenhouse gas emissions. The energy assessment of a poultry processing plant (evaluated under a defined selection criteria) has been carried out to identify the energy demand of the industry. Furthermore, a breakdown of significant energy uses is presented and loads that can be assessed under the renewable energy and energy efficiency scenarios are identified. Results of the energy assessment showed that the cooling and refrigeration is the most energy intensive unit in a poultry processing plant with approx. 75% of overall electricity consumption. A techno economic analysis is then carried out to assess different sustainable energy options for reduction in energy demand and GHG emissions. Three types of systems,1) solar PV, 2) biomass- wood pellets and 3) cofiring of biomass has been assessed and compared with the base case. Solar PV system is further assessed under technical (Tracking and fixed tilt) and financial (company owned and bank financed) scenarios. Tracking solar PV system has higher energy production and a shorter payback period as compared to fixed tilt system. It is found that both solar PV scenarios, company owned, and bank financed, have shown 6.2 % of total annual energy saving and 7.4 % GHG emission reduction potential with an equity payback period of 3.3 and 1 yrs. respectively as compared to the business-as-usual case. On the other hand, wood pellets-based biomass scenario has shown a significant GHG emissions reduction potential of 57 % as compared to business-as-usual scenario with payback period of 1.3 yrs. Cofiring of biomass in existing coal boiler has also proven itself a good low cost measure to mitigate emissions It is then concluded that, for a large-scale industrial setup, a biomass based system can be a better choice both in terms of cost effectiveness, energy demand reduction and greenhouse gas emissions reduction as compared to solar PV system.

Keywords— Renewable energy, Energy efficiency, Solar PV, Biomass, Poultry industry, GHG emissions

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List of Abbreviations

GHG	Greenhouse gas
SDG	Sustainable Development Goal
UNFCC	United Nations Framework Convention on Climate
EE	Energy Efficiency
RE	Renewable Energy
BES	Biomass Energy System
STC	Standard Test Conditions
PV	Photovoltaic
NPV	Net Present Value
IRR	Internal Rate of Return
B-C	Benefit to Cost Ratio
SPP	Simple Payback Period

Chapter 1: Introduction

1.1 Background

In 2015, the 21st Conference of Parties, an international congregation of representatives of the United Nations Framework Convention on Climate Change, took place in Paris (UNFCC). Significant decisions on sustainable development in the world have been made and, most significantly, a set of 17 priorities for achieving sustainable development has been identified. Out of those 17 goals, 7 and 9 are of special concern to us [1].The SDG 7 is to ensure access to reliable, affordable, modern and sustainable energy for all. According to United Nations sustainable development goals website, around 13% of the whole world population still don't have complete access to the modern forms of electricity and a 3 billion people in the world still consume conventional fuels and wood etc. for cooking and burning [2]. In context of Pakistan, there are 30% of households without proper access to modern electricity [3]. As combustion of conventional fossil fuels for energy causes emission of greenhouse gases, energy is the dominant contributor to global warming in the world. Sustainable development goal 9 addresses the development of resilient facilities and the promotion of industries' sustainability. The main objective of these SGDs is to achieve sustainable economic growth by improving and upgrading industries and infrastructure. It is important to consider renewable and clean sources of energy and invest in their implementation in the industry to achieve each of these objectives. The creation of renewable energy projects is an opportunity to expand access to inexpensive and sustainable energy, which can also provide a reliable source of employment, income and economic development, while at the same time allowing other industries to rise.

To stimulate economic growth, industry plays a dominant role. global history has demonstrated that by providing a developed and mature manufacturing market, nations have achieved high levels of socio-economic growth. The growth of the industrial sector is traditionally associated with excessive environmental pressures, such as the depletion of natural resources and territorial pollution.

In 2018, the manufacturing sector used about 45 percent of global energy, with an extra 5 percent or so of the fuels used for non- combustion purposes. In residential and commercial buildings (29 percent) and transportation sector (21 percent), the remainder was included [4].

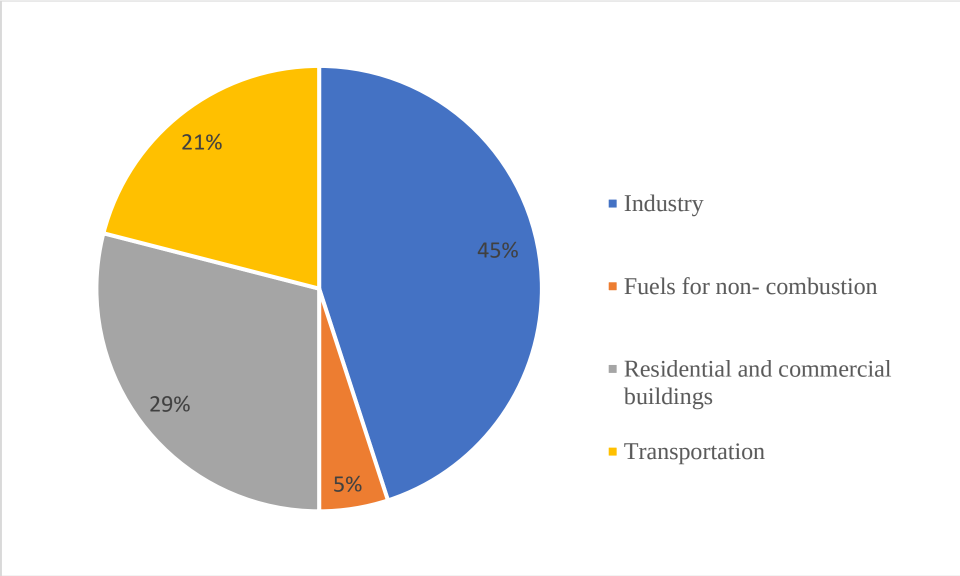

Figure 1.1 Sector wise share of energy use-World [4]

1.2 Energy Sector of Pakistan

The current electricity generation mix of Pakistan is highly skewed towards thermal powerplants, mostly operated on imported fuel oil. In addition to the carbon emissions, such dependence imposes a huge burden on country's economy and makes our electricity sector vulnerable to the fluctuations in international oil market prices. To overcome the supply-demand gap, the use of indigenous energy sources should be encouraged with a special focus on renewable energy deployment. This will lead to enhanced energy security of the country.

For Pakistan, industrial sector accounts for 37.5 of total final energy cosumption.Similarly, the share of residential and commecial buildings is 24.8%, for transporation sector it is 33.9% and 3.8% of other uses [5].

1.3 Renewable energy – Solar PV

Industries are large consumers of electricity and spend a lot of money on energy costs each year. On-site renewable energy deployment can generate clean electricity to meet the demands of the university and is increasingly becoming popular all over the world. Detailed techno-economic analysis is necessary before the installation of renewable energy systems to aid in decision making.

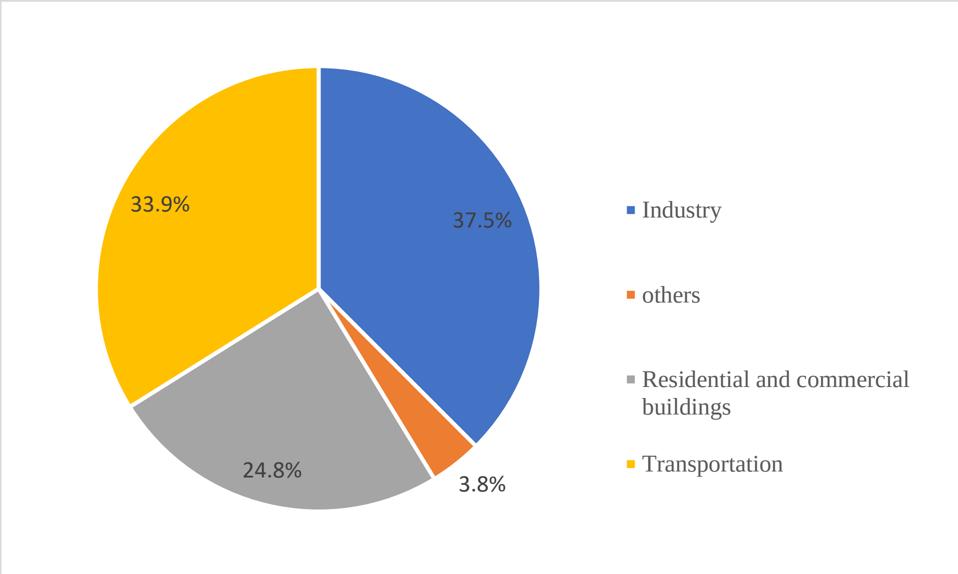

Figure 1.2 Sector wise breakdown of energy use for Pakistan [5]

The first step in this regard is the resource assessment of the site using long term weather data to get an idea of the generation potential of different renewable energy systems e.g., solar and wind. Electrical load data is also required to determine electricity requirements of the campus. A number of software tools are available to model system performance e.g., PVsyst, PV*SOL, SAM (System Advisor Model) and HOMER (Hybrid Optimization of Multiple Energy Resources) which can estimate energy output of the proposed system. Financial analysis is also performed to check if the project is economically viable.

Availability of space on rooftops, marginal lands and parking sheds in industrial facilities makes them good candidates for hosting renewable energy projects. Solar PV systems are very common in industries and are preferred over other renewable energy systems owing to their modularity, scalability, and ease of operation. Unlike wind turbines, a solar PV system can be installed at flexible locations, and it is increasingly becoming cost competitive. Eliminating the use of fossil fuel-based electricity can reduce greenhouse gas emissions produced as a result of industrial processes and also bring enormous economic benefit to the industry. Renewable energy systems can provide savings of over 5% for the first year and net present value (NPV) savings of 10-20% or more during the lifetime of the project.

1.4 Renewable Energy-Biomass

Bioenergy is the most abundant energy resource on Earth and has been used as an energy source for centuries by mankind. Biomass energy sources and new technologies have a great potential to solve the energy problems faced in particular by developing countries. Biomass technologies are an efficient way to dispose of public waste that is collected in large quantities daily from the urban and rural sectors. Future energy supply and environmental concerns are the key driving factors for the increased biomass.

Pakistan is an arable land and agriculture contributes to almost 24% of its GDP. Nearly half of population is employed here due to which Pakistan is ranked 8th in terms of farm output and is among biggest suppliers of food and crops. Punjab has a population of approximately 110 million and is bestowed with one of the best agriculture systems. Recently, World Bank also approved a budget of 300 million for its agricultural enhancement [6]. Economic values of renewable sources in Pakistan shows that biomass is the most favorable resource under current scenario as utilization of biomass will reduce dependency on fossil fuels [7].

1.5 Scope of this study

This work analyzes the renewable energy potential of a poultry processing plant. A techno-economic analysis is performed for a solar PV system and a biomass-based boiler for industrial processes which covers the following aspects:

i. Energy generation potential

ii. Economic feasibility

iii. Emission reduction analysis

1.6 Problem statement

The focus of this study is to assess the solar PV and biomass energy potential for a poultry processing plant. An energy audit and assessment technique is used to profile the current energy trends of the site. All electrical and thermal energy sources and their significant energy uses are identified based on the results of the audit. Furthermore, a comparative analysis of different solar PV scenarios for electrical loads and biomass-based system for steam generation and distribution has been performed using some software tools. At the end, best suitable scenario having greater potential in terms of energy demand reduction and GHG mitigation has been identified.

1.7 Research objectives

The following are the objectives of this research project:

- Selection of suitable site for assessment based on the described criteria.
- To carry out the energy audit and assessment activities for current energy profiling
- To identify the significant energy uses that can be operated on renewable energy (both electrical and thermal)
- To identify the solar PV and biomass energy potential for the selected site
- To carry out a cost benefit analysis of suggested solar PV system
- To perform a comparative analysis of solar PV and biomass scenarios find energy demand reduction and GHG emissions reduction potential.

1.8 Thesis outlines

1. Chapter 2 describes the literature review related to solar PV and biomass interventions.
2. Chapter 3 describes the methodology of research work in the form of a flow chart to obtain the required objectives.
3. Chapter 4 presents information on the case study.
4. Chapter 5 explains the results of both filed activities and computer simulations and discussed them in detail.
5. Chapter 6 summarizes the outcomes of the research project and recommended suggestions for future research.

Summary

This chapter gives a brief introduction of energy sector of Pakistan and the role of renewable energy technologies. The subsequent sections will explain the design of solar PV system for energy generation and biomass based industrial boiler.

References

[1] M. N. Hussain, S. B. Qamar, I. Janajreh, and S. Zamzam, “Solar PV Implementation in Industrial Buildings: Economic Study,” *Proc. 2017 Int. Renew. Sustain. Energy Conf. IRSEC 2017*, no. January 2020, pp. 1–5, 2018, doi: 10.1109/IRSEC.2017.8477355.

[2] “Goal 7 | Department of Economic and Social Affairs.” https://sdgs.un.org/goals/goal7 (accessed Feb. 24, 2021).

[3] O. Bangoura, “The World Bank,” *Ann. Trop. Med. Parasitol.*, vol. 102, no. SUPPL. 1, 2008, doi: 10.1179/136485908X337463.

[4] bp, “Energy use by sector | Energy economics | Home,” 2018. https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector.html (accessed Feb. 24, 2021).

[5] E. Availability, T. Primary, E. Supplies, and F. E. Consumption, “Pakistan Energy Yearbook,” 2018.

[6] U. U. Rehman Zia, T. ur Rashid, W. N. Awan, A. Hussain, and M. Ali, “Quantification and technological assessment of bioenergy generation through agricultural residues in Punjab (Pakistan),” *Biomass and Bioenergy*, vol. 139, p. 105612, 2020, doi: https://doi.org/10.1016/j.biombioe.2020.105612.

[7] M. Amer and T. U. Daim, “Selection of renewable energy technologies for a developing county: A case of Pakistan,” *Energy Sustain. Dev.*, vol. 15, no. 4, pp. 420–435, 2011, doi: https://doi.org/10.1016/j.esd.2011.09.001.

Chapter 2: Literature Review

2.1 Deployment of solar photovoltaic system

To make industrial development sustainable and inclusive, an introduction of clean and renewable sources or energy is need of the day. One of these solutions is deployment of solar photo voltaic technology to industrial buildings.

In contrast to other types of buildings of comparable overall floor space, factory buildings, which are primarily single-floor structures, retained a comparatively high roof-to-floor ratio. In most cases, the proportionally wide rooftop area, which does not serve any specific function, can be used without much modification to mount energy-generating modules such as solar (PV) systems. Moreover, most of the industries are located in the open area where no surrounding high-rise buildings are present. This always results in high performance of solar PV systems due to less shading of surrounding buildings.

A team of researchers from Khalifa university of science and technology, UAE (2017) has carried out an economic study on the implementation of solar energy, mainly solar PV in industrial sector [1]. They have demonstrated a case study of an industrial building in which they have created five different scenarios for the purpose of detailed economic and technological assessment of solar PV deployment to industrial buildings. Three of these scenarios were based on the technological design variations of the system while the other two were based on different financing methods for the project.

- Tracking, in which a mechanical tracking device was mounted on each of the module.
- Non-tracking, fixed mounted modules
- Tracking with battery storage
- 100% debt, if complete project was financed by taking debt.
- 50% debt, half of the project expenses were covered by debt.

From the results, it was obvious that the scenario with tracking device mounted is the best case in terms of energy output while the 50% debt scenario is the best in terms of financing and payback.

The performance of a solar PV module is normally accessed by a parameter wat peak (wp) which is the maximum power output from a specific module under the standard test conditions (STC). The standard test conditions are 1000 W/m2 insolation, 258C cell temperature and an air mass of 1.5. But the actual performance of a solar PV module varies from location to location. Born et al. developed an hourly assessment tool that can match optimum demand and generation of a renewable energy system [2]. They have developed models that were based on manufacturers' specifications, location-related parameters, and hourly weather data to compare the design and actual energy performance of a system.

Another paper presented the assessment of the economic performance of a solar PV system with the help of a computational simulation tool [3]. The model considered both power generation capacity of solar modules and the power consumption of industrial buildings. Different scenarios based on different feed in tariffs net feed in tariff and gross fed in tariff) and locations were discussed and annual savings from deployment of solar PV system were compared.

2.2 Solar energy potential in Pakistan

Pakistan is endowed with a wealth of renewable energy resources but, to date, this potential has not been utilized except for large-scale hydropower projects.

In context of Pakistan, there is a huge potential of renewable energy generation through deployment of solar energy systems across the country. The solar insulation is 5.5 Wh m^{-2} d^{-1} with 8-10 hr. per day annual average sun duration in the country [4]. According to the national renewable energy laboratory (NREL) and USAID sun chart of Pakistan, the province of Baluchistan contributes more than 5-7 kWh/m2/day of mean annual global solar output, with an energy production volume of 18-25 MJ/m2/day and an average incident time of 6-8 hours a day [5].

Adnan et al. (2012) assessed the solar energy potential for different regions of Pakistan based on geographical locations [6]. They have collected climate data of different regions like minimum and maximum temperature and annual solar radiation to calculate the month wise solar energy potential with the help of Angstrom equation and Hargreaves formula.[1] Their work concluded that maximum solar radiation intensity was in the area Gilgit with figure of 339.25W/m^2 and the lowest solar radiation intensity 76.49W/m^2 observed at the area Cherat during the month of

December. The range of mean monthly solar radiation intensity across the country was from 136.05 to 287.36 W/m^{2}.

2.3 Biomass energy

Biomass is considered as carbon neutral or renewable source of energy. This is because of the fact that forests capture CO_2 from the surrounding atmosphere as they grow and store this carbon in the biomass.

A range of biomass resources, including forest, agriculture related residues, managed forests, woody biomass, the organic component of municipal solid waste, and other streams of organic matter, can be used to produce bioenergy. These feedstocks can be directly used to produce electrical energy through a range of methods [7].

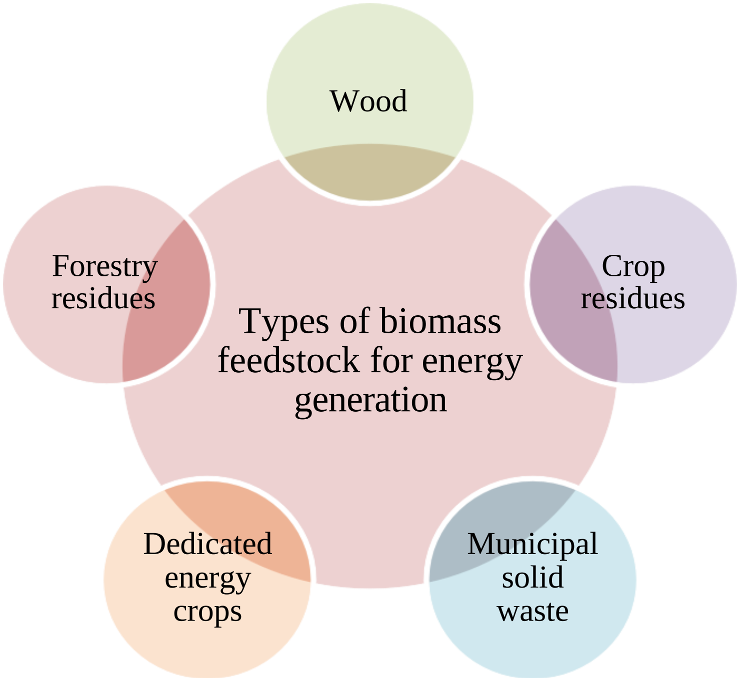

Figure 2.1 Different types of biomass-based feedstock used for energy generation

McKendry (2002) published a series of articles in which he discussed use of biomass feedstock for the purpose of energy production [8]. He further reviewed different energy conversion technologies using biomass as feedstock. His work helped establish a base of knowledge for use of various biomass-based feedstock for energy production with the help of different energy conversion technologies.

2.4 Biomass energy potential in Pakistan

Due to the country's vast and diverse biomass resources, bioenergy has the potential to make a key role in tackling the growing energy crisis in Pakistan. Pakistan's total projected biomass-based energy generation capacity is 50,000 GW h/year, adding up to 36 percent of the energy mix of the country [9][10]. Biomass comes in a number of types, including firewood, agricultural wastes, and urban waste products. Firewood supplies nearly 50% of household energy needs, while livestock and crop residues contribute 34% [11]. Most of Pakistan's biomass power is produced in steam power plants; biomass gasifier and the latest fermentation technologies are not commonly used [12]. A daily based availability chart of different biomass-based resources in Pakistan is shown in the Figure 2.2.

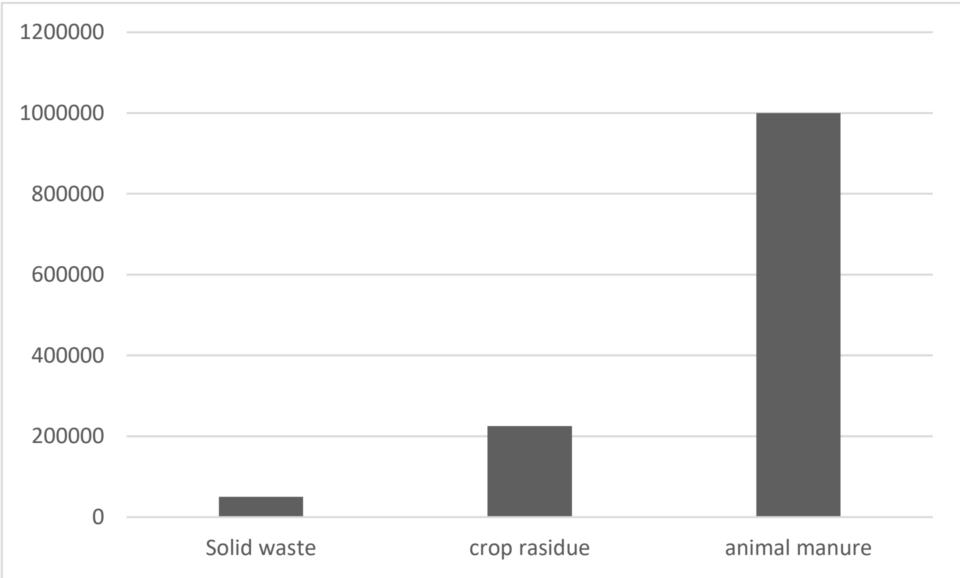

Figure 2.2 Availability of biomass and livestock resources in Pakistan [12]

Tareen et al. (2019) have recently conducted a study to explore the status and potential of biomass-based energy for Pakistan. They have assessed all the present and future resources to predict a complete picture of available biomass resources and their potential for energy generation in the country.

Another paper has described the case of efficient utilization of indigenous biomass resources for energy generation. Biomass energy production potential for Pakistan is reviewed based on the current energy scenarios. Various technologies for energy conversion and their status in Pakistan is also discussed [13].

2.5 Use of biomass in industrial applications

Industry uses biomass for a number of applications, including room heating, hot water heating and power generation. Many industrial plants, such as sugar mills, use biomass as primary source of energy [14]. In the energy market, there are some power plants that mainly burn wood to produce electricity, and there are many coal-fired power stations that burn wood chips with coal to mitigate Sulphur dioxide emissions [15].

Proskurina et al. has evaluated the potential of torrefied biomass for both power generation sector and non-power generation industries [16]. Results demonstrate that the demand for torrefied biomass relies strongly on the bioenergy market. Even after the uncertainties, the rise of torrefied biomass demand seems to have made significant progress soon.

R. Saidur. et al. have investigated the many aspects of biomass combustion in industrial boilers [17]. It has been discovered that using biomass-based feedstock in industrial boilers has numerous commercial, social, and environmental advantages, including financial savings, sustainable use of fossil fuel energy and mitigation of GHG emissions. However, there are many disadvantages associated with the used of biomass like land use, water sacristy, biodiversity and many more.

Summary

In this chapter, a background study is carried out to assess the potential of renewable energy (both solar PV and biomass). The deployment of solar PV system in industrial sector is presented and reviewed from the literature.

References

[1] F. J. Born, J. A. Clarke, and C. M. Johnstone, "Development of a simulation-based decision support tool for renewable energy integration and demand-supply matching." 2004, Accessed: Feb. 25, 2021. [Online]. Available: https://pureportal.strath.ac.uk/en/publications/development-of-a-simulation-based-decision-support-tool-for-renew.

[2] B. Lee, M. Trcka, and J. L. M. Hensen, "Rooftop photovoltaic (PV) systems: A cost-benefit analysis study of industrial halls," *Int. J. Low-Carbon Technol.*, vol. 9, no. 4, pp. 319–326, 2014, doi: 10.1093/ijlct/ctt008.

[3] A. Ghafoor, T. U. Rehman, A. Munir, M. Ahmad, and M. Iqbal, "Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability," *Renewable and Sustainable Energy Reviews*, vol. 60. Elsevier Ltd, pp. 1332–1342, Jul. 01, 2016, doi: 10.1016/j.rser.2016.03.020.

[4] M. A. Sheikh, "Renewable energy resource potential in Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9. pp. 2696–2702, Dec. 2009, doi: 10.1016/j.rser.2009.06.029.

[5] S. Adnan, A. Hayat Khan, S. Haider, and R. Mahmood, "Solar energy potential in Pakistan," *J. Renew. Sustain. Energy*, vol. 4, no. 3, 2012, doi: 10.1063/1.4712051.

[6] O. Edenhofer *et al.*, *IPCC, 2011: Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. 2011.

[7] P. McKendry, "Energy production from biomass (part 1): Overview of biomass," *Bioresour. Technol.*, vol. 83, no. 1, pp. 37–46, May 2002, doi: 10.1016/S0960-8524(01)00118-3.

[8] M. Asif, "Sustainable energy options for Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 4. pp. 903–909, May 2009, doi: 10.1016/j.rser.2008.04.001.

[9] S. Z. Farooqui, "Prospects of renewables penetration in the energy mix of

Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 29. Elsevier Ltd, pp. 693–700, Jan. 01, 2014, doi: 10.1016/j.rser.2013.08.083.

[10] T. Iqbal *et al.*, "Sketching Pakistan's energy dynamics: Prospects of biomass energy," *J. Renew. Sustain. Energy*, vol. 10, no. 2, p. 023101, Mar. 2018, doi: 10.1063/1.5010393.

[11] FAO, *Wood Fuels Handbook*, vol. 53, no. 9. 2013.

[12] "Biomass Potential – Pakistan Biomass Cluster." https://biomasscluster.nust.edu.pk/biomass-cluster/biomass-potential/ (accessed Mar. 15, 2021).

[13] S. R. Naqvi *et al.*, "Potential of biomass for bioenergy in Pakistan based on present case and future perspectives," *Renewable and Sustainable Energy Reviews*, vol. 81. Elsevier Ltd, pp. 1247–1258, 2018, doi: 10.1016/j.rser.2017.08.012.

[14] "Renewable Energy: Biomass Energy - Applications of Biomass | Young People's Trust For the Environment." https://ypte.org.uk/factsheets/renewable-energy-biomass-energy/applications- of-biomass (accessed Mar. 15, 2021).

[15] "Wood and wood waste - U.S. Energy Information Administration (EIA)." https://www.eia.gov/energyexplained/biomass/wood-and-wood-waste.php (accessed Mar. 15, 2021).

[16] S. Proskurina, J. Heinimö, F. Schipfer, and E. Vakkilainen, "Biomass for industrial applications: The role of torrefaction," *Renew. Energy*, vol. 111, pp. 265–274, Oct. 2017, doi: 10.1016/j.renene.2017.04.015.

[17] R. Saidur, E. A. Abdelaziz, A. Demirbas, M. S. Hossain, and S. Mekhilef, "A review on biomass as a fuel for boilers," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5. Pergamon, pp. 2262–2289, Jun. 01, 2011, doi: 10.1016/j.rser.2011.02.015.

Chapter 3: Methodology

The methodology used to carry out this research work is combination of field work for data collection and software-based simulations. The scheme of work is presented below in Figure 3.1.

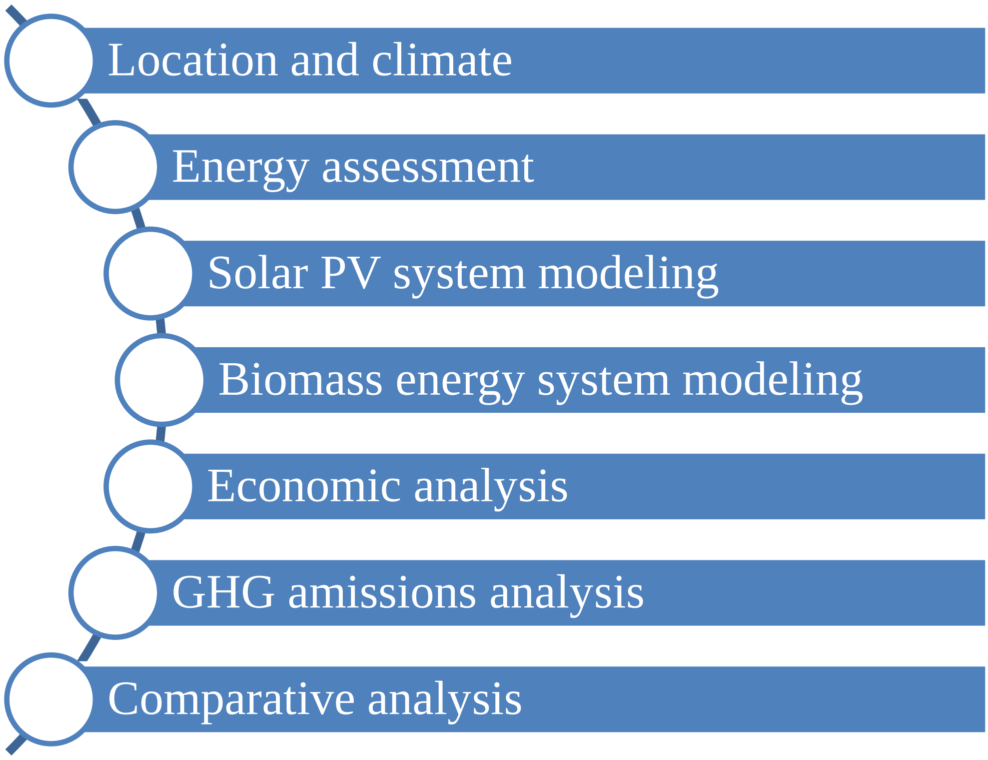

Figure 3.1 Methodology flow chart for research work

3.1 Location and climate

Because of the increased capital investment in the solar photovoltaic market, locating great sites for solar power plant construction has become a core topic in planning phase[1].Keeping this in mind, following selection criteria is used to select the site.

- Geographical location
- Higher roof to floor ratio of industrial building
- Availability of data required for the assessment
- Annual solar irradiation
- Availability of biomass-based energy resources

Geographical location and overall roof to floor area are two major factors in selection of preferred site to mount solar PV modules for energy generation. While availability of biomass-based energy resource as boiler fuel is deciding factor in case of thermal scenario. In this study, a large-scale poultry processing plant is selected for assessment. The facility is located near Lahore district of Punjab, Pakistan at latitude (°N) and longitude (°E) of 31.4 and 74.3 respectively in dry hot climate zone. The plant is equipped with state-of-the-art poultry processing technology and houses one of the largest refrigeration plants in Pakistan

3.2 Energy assessment

Annual energy and production data is collected for the purpose of baselining and benchmarking energy use of the facility. This gave us a clear overview of industrial energy use vs production trends. The data includes annual Utility bills of all the energy sources, production details and process flow, building dimensions and roof area, plant's operating schedules and no. of shifts. An assessment is conducted for the facility for the purpose of energy profiling. The main objectives of energy assessment are to analyze energy use and consumption, to identify areas of significant energy usage, to identify which significant energy use can be switched to the RE & EE options. Specific energy consumption of different sources is then calculated by given formula:

$$Specific\ Energy\ Consumption\ (SEC) = \frac{Energy\ consumed}{Production\ volume} \quad (1)$$

Several significant energy uses of thermal and electrical energy sources are then identified and assessed for their potential of energy savings and greenhouse gases emissions reductions. Different scenarios were developed and compared to carry out a fair assessment of the system.

Separate model for solar photovoltaic and biomass integration to the current system were developed and assessed in terms of technical and economical improvements. For the comparative analysis, RETScreen Expert software is used. It is a sustainable energy management system that ensures energy efficiency, renewables, co-generation analysis, and ongoing energy performance monitoring. It is an excellent tool for examining and evaluating the feasibility of a renewable energy system.

3.3 Solar PV system modeling

Grid-connected photovoltaic systems are made up of PV arrays that are connected to the grid via a power conditioning unit and are designed to run in parallel with the electricity grid. The proposed PV system for the site is mainly based on two technologies i-e fixed tilt and tracking solar modules. Compared to fixed-tilt systems, tracking systems improve the plane of panel irradiance and, as a result, the energy output (kWh/kWp/yr.) of photovoltaic system by needing fewer modules and related balance-of-systems (BOS) elements per kWh generated. As per the authors in [26], the most important factors to consider while developing a Photovoltaic system are:

- Energy demand of facility (ED)

$$(ED) = Energy\ consumption\ of\ all\ loads\ connected\ to\ the\ system \qquad (2)$$

- Power generation factor (PGF)

$$PGF = \frac{Solar\ irradiance \times Sun\ hrs}{STC\ irradiance} \qquad (3)$$

- Total energy (TE) needed from PV modules

$$TE = Peak\ energy\ requirement\ \times Energy\ lost\ in\ the\ system \qquad (4)$$

- Optimum efficiency of PV modules

$$\eta p = \eta r\ [1 - \beta\ (Tc - Tr)] \qquad (5)$$

Where ηp is the optimum efficiency of the system, ηr is nominal efficiency, β is temperature coefficient, Tc is ambient module temperature, and Tr is reference temperature of the site.

The monocrystalline solar modules of Trina solar are selected for the proposed 1300 KW solar PV system. The electrical and other characteristics of selected panels are tabulated below. The optimal tilt and azimuth of the PV modules is set by consultation with the solar services providers and from the literature after the assessment of location and climate data of the facility.

Table 3.1 Electrical data of PV modules

Peak Power Watts-PMAX (Wp)*	350
Watts (PTC)	217
Maximum Power Voltage-VMPP (V)	38.7
Maximum Power Current-IMPP (A)	9.04
Open Circuit Voltage-VOC (V)	47
Module Efficiency ηm (%)	18

3.4 Biomass energy system modeling

Based on the results of energy assessment, a 5 ton/hr. capacity coal fired steam boiler is identified as significant energy use of thermal resources at the site. Two biomass energy-based options are proposed to minimize the energy demand of the boiler and to reduce the GHG emissions caused by burning coal. The first option is replacing the coal fired boiler with biomass fired boiler system and other is cofiring of biomass in the existing coal fired boiler.

The annual fuel consumption of boiler is calculated by the formula:

$$Annual\ fuel\ consumption = \frac{Fuel\ consumption\ in\ measurement\ period}{Number\ of\ days\ in\ measurement\ period} \times 365 \quad (6)$$

3.5 Economic analysis

An economic feasibility analysis is performed using RETScreen Expert software package. The debt financing and company owned financing modes are selected for the purpose of analysis. The net present value (NPV), internal rate of return (IRR), levelized cost of electricity (LCOE), payback period (PB), annual life cycle savings (ALCS), and benefit-cost ratio (B-C) are all key economic indicators computed in this analysis.

- Net present value (NPV):

$$\text{NPV} = \sum_{n=0}^{N} \frac{Cn}{(1+r)n} \quad (7)$$

- The internal rate of return (IRR)

$$0 = \sum_{n=0}^{N} \frac{Cn}{(1+IRR)n} \quad (8)$$

- Levelized cost of energy (LCOE):

$$LCOE = \frac{Sum\ of\ all\ the\ costs\ over\ the\ lifetime}{Units\ of\ energy\ generated\ over\ lifetime} \quad (9)$$

- Simple payback period (SPP):

$$SPP = \frac{C-IG}{(Ce+Cc+Cre+CGHG)-(Cf+Co)} \quad (10)$$

- Equity payback (EP):

$$EPP = \sum_{n=0}^{N} \text{Cn} \quad (11)$$

Where N is the lifespan of the project in years, C_n is nth year's cash flow after tax deduction , r denotes the discount rate, C stands total initial cost of the project, IG stands for incentives and grants from funding bodies, C_e is the income generated by annual energy savings, C_c is the income annual capacity savings , C_{re} stands for annual renewable energy (RE) production credit income, C_{GHG} is the GHG reduction credit, C_o is the annual operation and maintenance costs and C_f is the yearly cost of fuel.

3.6 Greenhouse gas emissions analysis

The net estimate of annual power supplied by the photovoltaic system (given the 10% miscellaneous loss) should be considered when calculating the amount of CO_2 emission reduction. The contributions of the power source mix by type of fuel and baseline transmissions and distribution (T&D) loss are used to calculate the base case emissions. For simplicity, default emission factors are used. The formula for GHG emissions calculation is:

$$GHG\ emission = 0.001 \times Fuel\ Usage \times Higher\ heat\ value \times Emission\ factor \quad (12)$$

The change in GHG emissions volume for electricity can be calculated:

$$\Delta GHG = (ebase - eprop)Eprop(1 - \lambda prop)(1 - ecr) \quad (13)$$

where e_{base} is the base case GHG emission factor, e_{prop} is the proposed case GHG emission factor, E_{prop} is the proposed case annual electricity produced, λ_{prop} is the fraction of electricity lost in transmission and distribution (T&D) for the proposed case, and e_{cr} the GHG emission reduction credit transaction fee. The emissions reduction for heating systems can be calculated as:

$$\Delta GHG, heat = (ebase, heat - eprop, heat)Eprop, heat \quad (14)$$

Where *ebase, heat*, *eprop, heat*, are the base case and proposed case GHG emission factors for heating. *Eprop heat,* is the proposed case end-use annual heating energy delivered.The default emission factors used are tabulated below.

Table 3.2 Default emission factors

Fuel type	**Emission factor (kgCO_2/kWh)**
Electricity	0.44
Coal	0.338
LPG	0.220

3.7 Comparative analysis of scenarios

Finally, a comparative analysis of solar PV, biomass and cofiring scenarios is performed to assess them against the criteria and to identify the best suitable scenario for the selected site in terms of energy demand, cost and greenhouse gas emissions reduction potential.

Summary

In this chapter, the above-described methodology was followed to achieve the research objectives discussed in chapter 1. The research methodology consists of seven major steps. One of the major steps is the selection of potential site and technical energy audit of the selected site followed by development of different scenarios to obtain suitable solar PV and biomass solution for the industry. A Helioscope model is developed in order to harness the solar energy potential of the case study building. Further, RETSCREEN EXPERT software is utilized to carry out a techno economic analysis of the solar PV and biomass integration to the industrial site and results are discussed.

References

[1] G. Rediske, J. C. M. Siluk, N. G. Gastaldo, P. D. Rigo, and C. B. Rosa, “Determinant factors in site selection for photovoltaic projects: A systematic review,” *Int. J. Energy Res.*, vol. 43, no. 5, pp. 1689–1701, Apr. 2019, doi: 10.1002/er.4321.

Chapter 4: The Case Study

4.1 The poultry and meat processing industry

The value-added poultry and meat processing industry is growing worldwide due to a rise in demand of processed food items. For the forecast timeframe of 2020-2025, the worldwide demand of the market is expected to rise at an annual CAGR of 7.35%.Owing to the growing population and shifting lifestyle, Asia is the leading market of poultry and processed meat products with a CAGR of 9.32% [1].

4.2 Status of poultry industry in Pakistan

The poultry industry is one of Pakistan's most competitive and growing sectors and has made an important contribution to the country GDP (1.4 %)[2]. It is the second largest sector in Pakistan after textile manufacturing to provide 1.25 billion broilers chickens a year. Currently, the business is valued 700 billion PKR (5.9 billion USD) and the Punjab area accounts for 73 per cent of its potential [3].

Highlights: [4]

- For around 1.5 million individuals, the poultry industry produces jobs and revenue.
- Poultry industry is one of Pakistan's most developed agro-based industries and growing yearly at the rate of 10-12%.
- Currently, over 190 billion rupees of farm products and agricultural items are being used in chicken feeds.
- There are more than 20000 poultry farming units distributed wide into rural regions of the country.
- Around 40%-45% of overall meat consumption is derived from poultry meat.
- Sadly, the added value of poultry processing industry in the organized sector is only 5-6 per cent and should be increased to meet the demands.
- The annual production of chicken meat is approximately 2,250 million kgs in Pakistan.

- The per capita poultry meat consumption is only 9 kg which is very low as compared to the other countries. The developed world consumes approximately 40 kilograms of chicken per individual per year. A bar graph is presented below for the comparison (Figure 4.1).

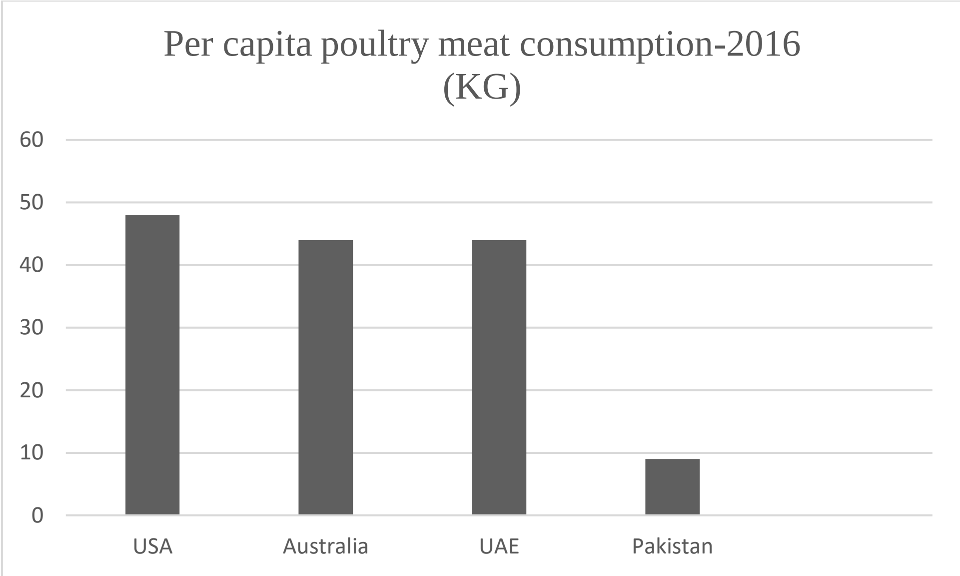

Figure 4.1 Comparison of per capita poultry meat consumption [4]

4.3 The site selection

Based on the above-mentioned points and the decided selection criteria, a large-scale poultry processing plant located in Punjab region of Pakistanis selected for the assessment. The plant is in the area where weather is very favorable for the deployment of solar PV system and biomass-based system. The key points for the section of the site are:

- The average roof to floor area of the selected building is relatively high means more solar PV modules can be mounted on the roofs.

- The average daily solar irradiation for the whole year is around 4.68 kWh/m2/day that will result in higher solar energy generation.

- There are no high-rise buildings and big trees around the site so very minimal or no shading losses.

- The plant is in the area where biomass-based crop residue and wood is abundant. The availability of rice husk and wood to fuel steam boiler will not be a big issue.

- Biomass based system can easily be integrated into the current boiler running on coal as fuel with minimal changes.

4.4 Process description

There are three major manufacturing processes of the poultry processing:

- Primary processing (live bird to processed meat production)
- Further processing (production of ready to cook and ready to eat products)
- Rendering Plant (Production of chicken feed from production waste)

The summary of each production process can be seen in this section.

4.4.1 Primary poultry processing

The processes of receiving of live birds to prepare and store raw meat are called primary poultry processing. Broilers from the holding shed are brought to the primary processing plants in crates with the help of conveyer belts. The empty crates are washed with high pressure water at 40 bar in the reception section.

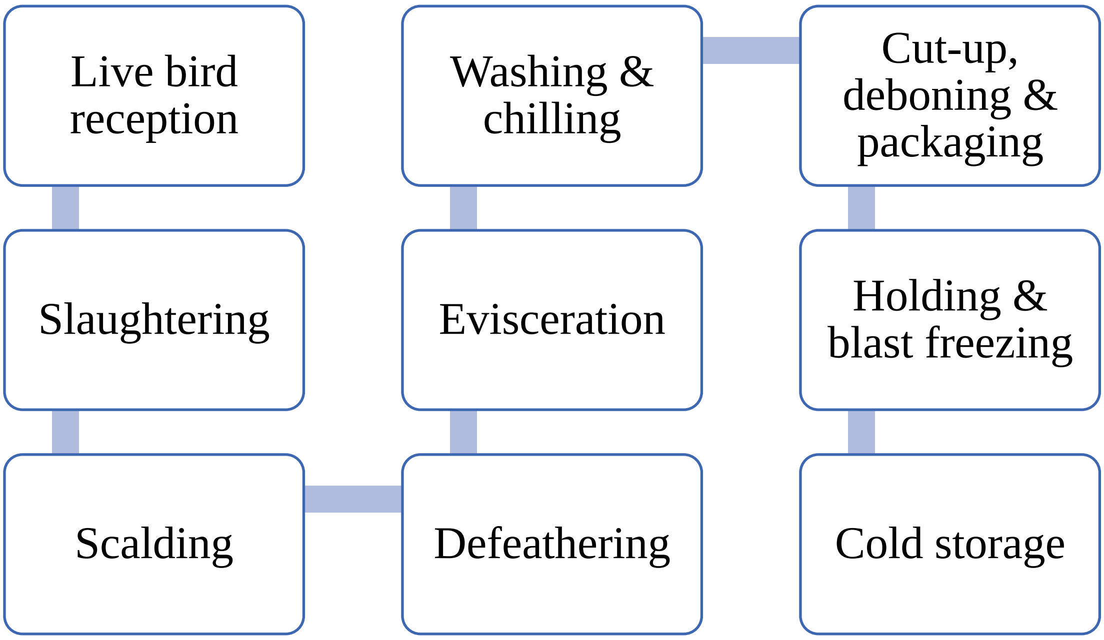

Figure 4.2 Primary poultry processing flow chart

Live birds are hanged with their feet in the shackles or hangers. There is not stunning of birds and slaughtering is performed manually as per Islamic rules. The hanger line is completely automated and lift the bird from conveyers to different parts of the slaughtering section.

Next, scalding is done to loosen the feathers to facilitate their removal. Carcasses are submerged into the scalder that contains water heated to 56-58 °C. This high-water temperature serves to loosen the connection of feathers to the skin. There are two phases in the scalding process.

Defeathering or picking is done to remove feathers from a carcass. The Tunnel Picker removes the feathers on the carcass using rotating finger disks.

Then, a device named eviscerator is used for automatic removal of internal organs from chickens. Chickens are fitted with a spoon to remove their internal organs from the inside of a chicken. The spoon is guided along the chicken's sternum up to the throat. Then it is turned towards the back part of the chicken and taken out with the viscera.

The carcasses are cleaned for microbial and visible concerns. The carcass temperature must be reduced to prevent microbial growth. The carcass is submerged in an ice (chilled water) to reduce their temperature. The chilled water temperature is around 4 °C. The central refrigeration plant is utilized for chilling the water for this purpose.

The carcasses are weighed and then sent to the cut-up line. Cut up includes removal of the breast, thigh, drumsticks, and wings. Deboning refers to the removal of bone from the cut-up meat. The process is manual while the only energy is used by the hanger line to move the carcass in this stage.

Holding refers to temporary storage of raw meat at 0-4 °C. This raw meat will be transferred to further processing area for ready to cook or ready to eat product preparation.

The processed and packaged product is frozen in forced air blast tunnels where the circulating air flows at 3 to 8 m/s, at temperatures ranging from -35 to -40 °C for 8 hours. This provides food conservation for long time, maintaining most of its original characteristics. A central refrigeration plant which utilizes two stage ammonia cycle caters the freezing requirements. After 8 hours of blast freezing, the final product is stored in the cold storage area at -18 °C. The storage time depends on the market demand.

4.4.2 Further Processing

Further processing of the poultry products includes preparation of ready to cook and ready to eat products. These include chicken nuggets, kebabs, pakoras, meat balls etc. There are three main stages of this process:

Raw material preparation includes grounding of chicken meat (minced meat preparation), preparation of ingredients and mixing of the meat with the ingredients. For this purpose, heavy duty grinders and mixers are available in the Further Processing Section. The major energy source is electricity for this section.

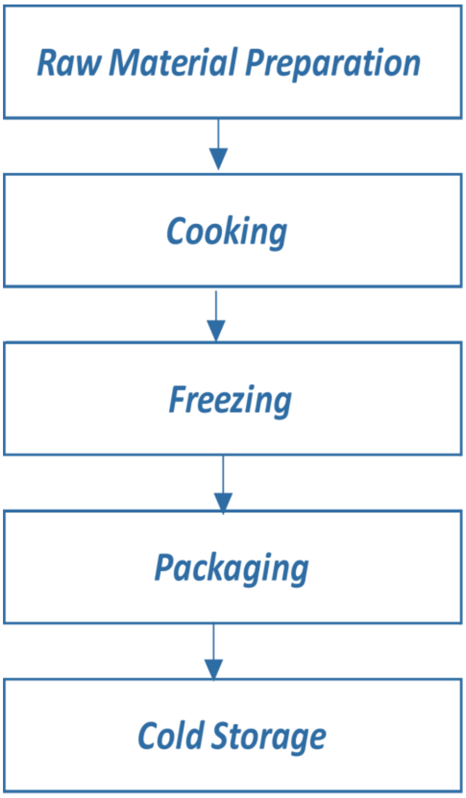

Figure 4.3 Further processing flow chart

The cooking of the product is done via three different processes:

- Thermal oil-based cooking:

For the products requiring deep frying, the cooking oil is heated by pre heated thermal oil. A thermal oil boiler is used to heat the thermal oil by LPG. This heated thermal oil is then transferred to the cooking section to heat the cooking oil to suitable frying temperatures.

- LPG cooking kettle:

LPG Cooking Kettle is used for the preparation of BBQ, kebabs etc. In this kettle, LPG is directly used for cooking purposes. Flow Cooking is a specialized type of cooking for the preparation of low-calorie products. In this type of cooking, air is heated by thermal oil to cook the food. Steam is also provided for maintaining water level/humidity of the product. The final product after freezing and packaging is stored in the cold storage for market dispatch.

4.4.3 Rendering process

Rendering is the process to convert dead chicken / chicken waste / feathers / tissues / market waste into valuable material like feather meal / chicken meal. In rendering process autoclaving at high temperature and pressure is done which turn down the whole poultry waste including soft wastes, bones, feathers, and other portions of the carcass separately or in a mixture. Many conventional rendering processes turn organic animal waste materials into marketable goods, including meal, oil, and rendered fats. Each of rendering product is an excellent source of specific use and generally provides a cost-effective source of animal protein.

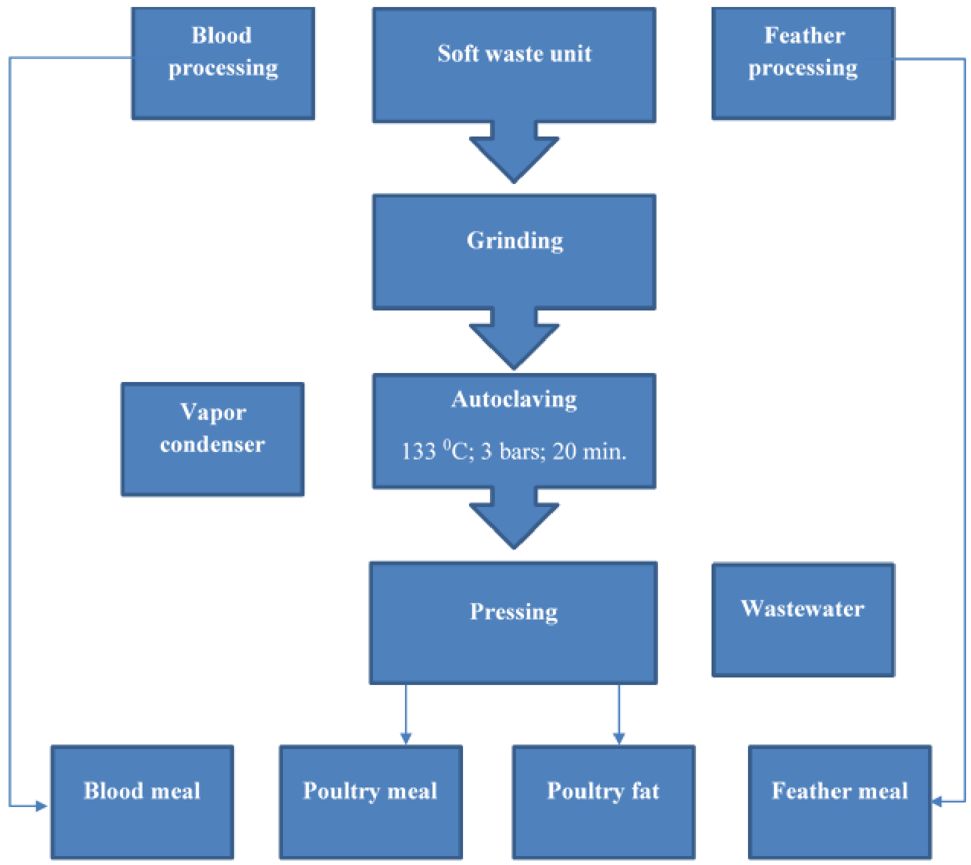

Figure 4.4 Rendering process flow

Summary

In this chapter, a global outlook of poultry and meat processing industry is discussed along with the status of poultry industry in Pakistan. The value-added poultry and meat processing industry is growing worldwide due to a rise in demand of processed food items. Asia is the leading market of poultry and processed meat products. The poultry industry is one of Pakistan's most competitive and growing sectors. It is the second largest sector in Pakistan after textile manufacturing and has a significant impact on national GDP.

As a case study, a large-scale poultry processing plant located in Punjab region of Pakistan is selected for the assessment based on the mentioned selection criteria. A detailed process description of the plant along with process flow charts for each section is presented and discussed for better understanding.

References

[1] "Processed Poultry & Meat Market Analysis 2020-2025 - Global Market Forecast to Grow at a CAGR of 7.35% During 2020 and 2025." https://www.globenewswire.com/news-release/2020/06/08/2044720/0/en/Processed-Poultry-Meat-Market-Analysis-2020-2025-Global-Market-Forecast-to-Grow-at-a-CAGR-of-7-35-During-2020-and-2025.html (accessed Feb. 28, 2021).

[2] "(PDF) Poultry industry and its thriving future in Pakistan." https://www.researchgate.net/publication/334030390_Poultry_industry_and_its_thriving_future_in_Pakistan (accessed Mar. 20, 2021).

[3] "A Glance Inside Pakistan's Poultry Processing Industry | Meyn." https://www.meyn.com/news/a-glance-inside-pakistan-s-poultry-processing-industry (accessed Mar. 22, 2021).

[4] "Poultry Status – Pakistan Poultry Association." https://pakistanpoultrycentral.pk/poultry-status/ (accessed Mar. 23, 2021).

Chapter 5: Results and Discussions

5.1 Historical energy consumption

A technical energy assessment is conducted for the purpose of energy monitoring and benchmarking. The historical energy consumption of the facility is plotted for each energy resource used. The results showed that the main energy sources are electricity, coal and liquified petroleum gas (LPG).

Electricity is the main energy source of the industry. We have received electricity consumption data of one years. Grid electricity is the central power source; however, four diesel generation sets of 1250 KVA are also present in case of load shedding. During the analysis period, electricity consumption reached a maximum of 964 MWh for the month of July 2019. The average annual electricity consumption of the facility is 9938 MWh.

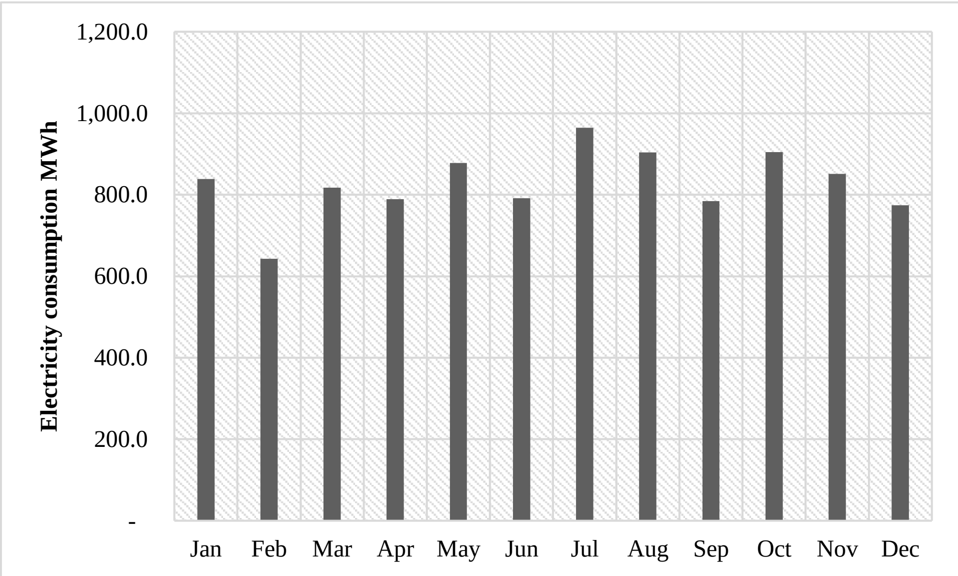

Figure 5.1 Monthly electricity consumption trend

Submetering of electricity consumption has been done at the plant and different departments are grouped, and energy meters are installed in the low tension (LT) room to record their consumption. An analysis of the submetering data has been carried out and it is found that refrigeration is the biggest electricity consumer and accounts for 75.5% of electricity consumption.

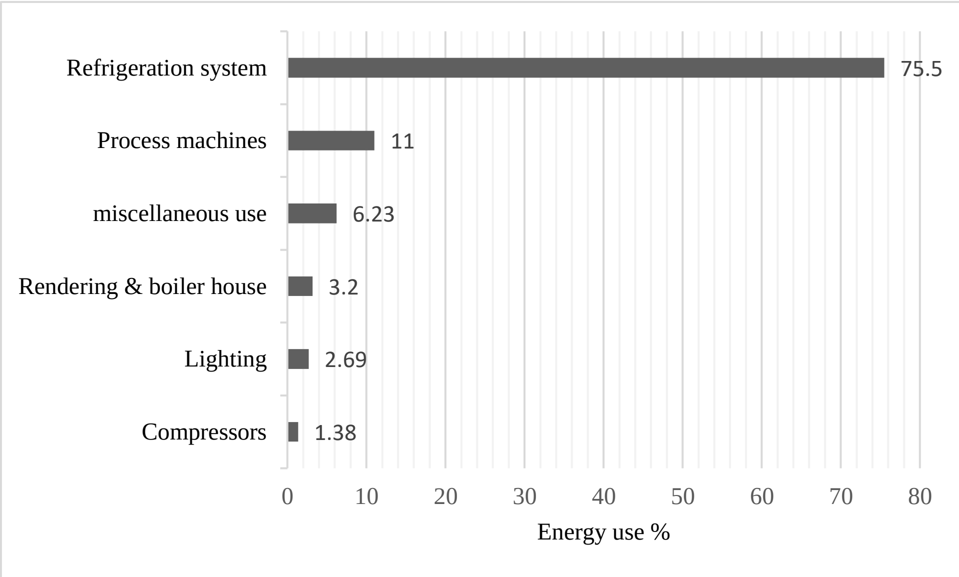

Figure 5.2 Breakdown of departmental electricity use

The primary usage of Liquified Petroleum Gas (LPG) is in the thermal oil boiler. LPG is used to heat the thermal oil, which is then pumped to the cooking area, where it transfers its heat to the cooking oil. LPG is also used directly in cooking products. This like BBQ and kebabs which do not require deep frying. LPG consumption data of one years was provided for the purpose of energy review. A maximum consumption of 381 MMBtu was recorded for April 2019.

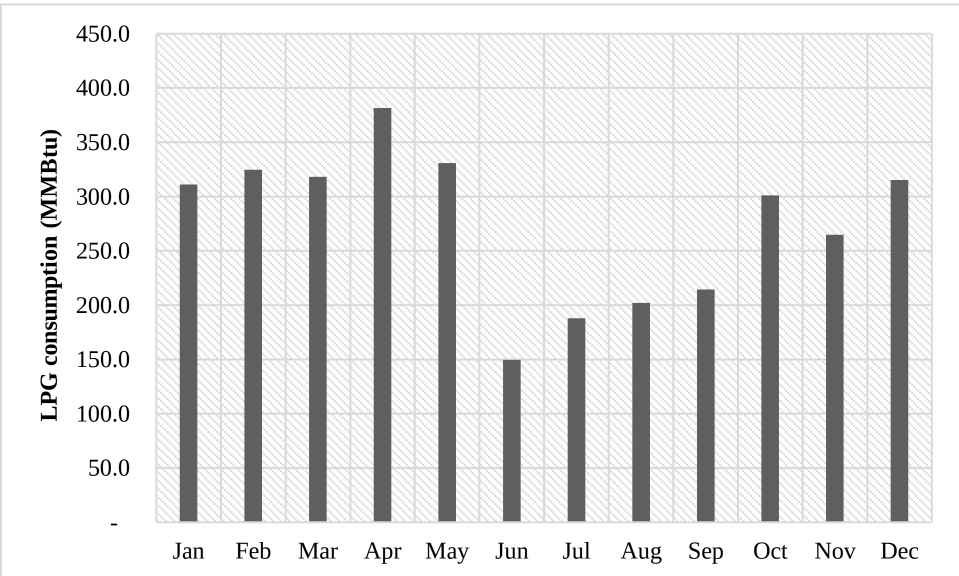

Figure 5.3 Monthly LPG consumption trend

There is a 5-ton size coal fired boiler for the steam needs. It was found that the five ton per hour boiler is presently only able to produce three tons of steam. The steam is generated at 170 °C and 8.5 bars. The steam is used for the following process. Coal consumption of one year was obtained. The coal consumption reaches 3791 MMBtu for December 2019.

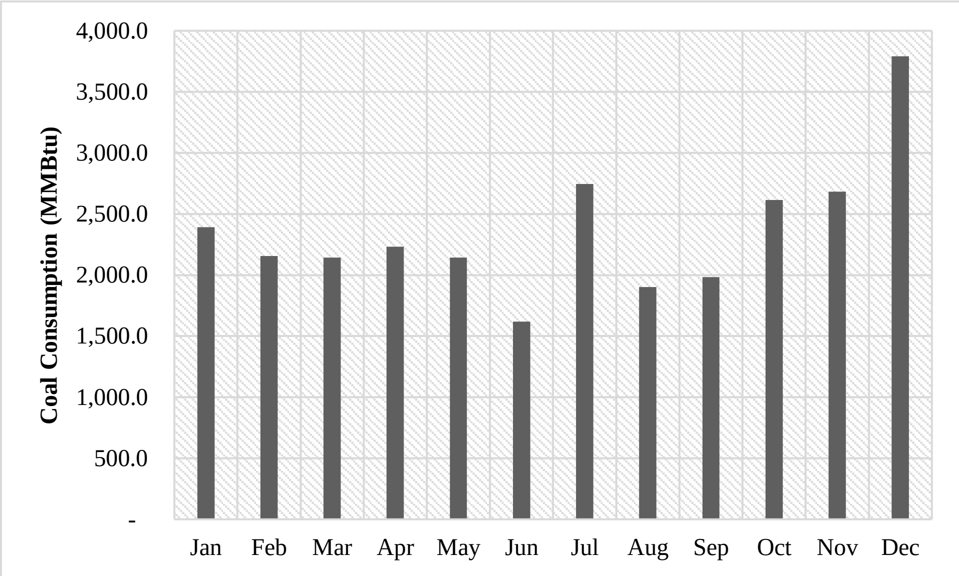

Figure 5.4 Monthly coal consumption trend

The monthly energy demand profile of the facility for the year 2019 is shown below. All the units are converted to MMBtu for uniform representation.

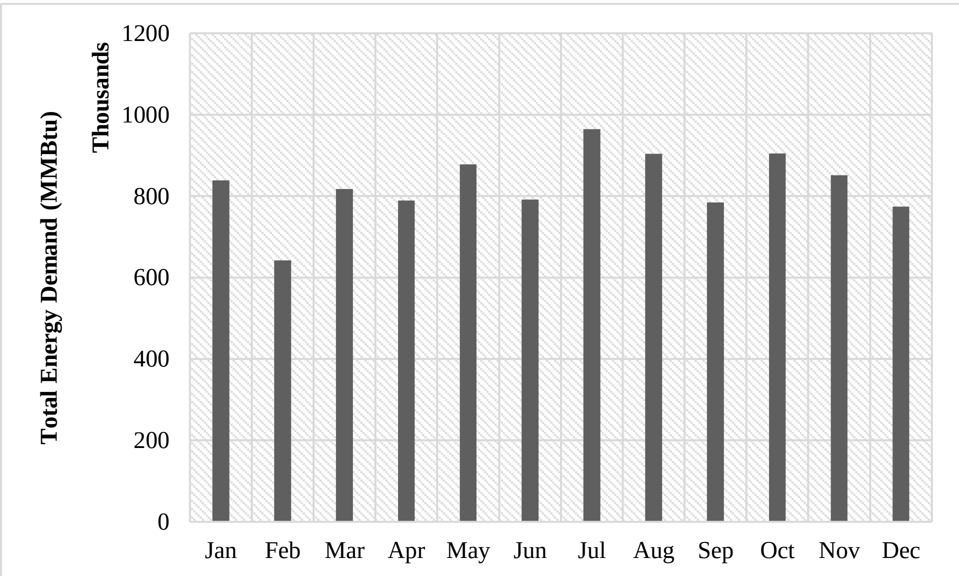

Figure 5.5 Total energy demand of the facility

Based on the analysis, compressed air and ammonia refrigeration systems are selected to assess the potential of energy and GHG emissions savings. Energy saving measures are categorized into no cost, low cost and capital-intensive energy saving measures. It is found that compressed air system energy demand can be reduced by eliminating the system leaks and for ammonia refrigeration system, installation of dehydrator to remove the moisture content from refrigerant can save the energy.

5.2 Scenario development for comparative analysis

Different scenarios are developed and assessed for comparative analysis of both solar PV and biomass-based systems. The scenarios are further divided into three categories.

- Technical analysis
- Financial analysis
- Emissions analysis

In technical scenarios, different fuel shifts and technical changes to system are made while in the financial category, different financing options are considered for renewable energy system financing.

5.2.1 Business as Usual Scenario (BAU)

Current system is considered as base case and data of the present settings is entered for the assessment. The year 2019 is taken as base year and energy and consumption data is analyzed. The total electricity consumption for the year 2019 was 9938 MWh and the production was 17559 tons. Results from the analyses showed a specific electricity consumption of 0.57 kwh/kg for the business-as-usual scenario. There is a coal fired steam boiler present to cater the steam and heating demands of the industry. The annual coal consumption is 1997 tons for the base year 2019. LPG is also used for thermal oil heating and for cooking purposes. The cumulative energy use intensity of both fuels is 1.1 KWh/kg. The greenhouse gas emissions for each energy source are calculated using the equation (11) and added up to find the total GHG emissions for the facility. The total annual GHG emissions of the facility are thus 10986 tCO_2.

5.2.2 Solar PV system Scenarios

In these scenarios, a prefeasibility analysis of 1300 KW grid- tied solar PV system integration into the current system is discussed. As discussed earlier, the baseline electricity consumption for the year 2019 is 9938 MWh and we need to cut down this figure to some extent by installing solar renewable energy system on- site. For this purpose, it is planned to meet a portion of the overall energy demand for process electricity. The solar PV modules selected for the proposed system are monocrystalline type with fixed and tracking technology. The invertors selected for the system are of

1035 KW capacity with 1.25 optimum DC/AC ratio. This is because PV modules works at the less efficiency as compared to the nameplate efficiency in the real environment The input parameters to the 1300 KW solar PV system are listed in the table below.

Table 5.1 Input parameters for solar PV system

Parameter	**Technology**		
Solar tracking mode	Fixed	Single Axis	Two Axis
Slope α	30	30	Variable
Azimuth β	0	0	Variable
Module type	Mono-crystalline	Mono-crystalline	Mono-crystalline
Power capacity KW	1300	1300	1300
Number of modules pcs	3714	3714	3714
Cell efficiency%	18	18	18
Nominal cell operating temperature C	45	45	45
Inverter efficiency %	98.5	98.5	98.5
Inverter capacity KW	1035	1035	1035
System capacity factor %	16.2	20.3	20.9
Initial cost $/KW	550	600	650
O&M cost$/KW/yr.	12	15	18

Technical analysi**s**

There are two types of solar PV system considered in the analysis, fixed tilt or non-tracking solar panels and tracking solar panels. Tracking solar PV system is further categorized to single axis rotation and two axis rotation systems. The annual energy generation of three technologies for 1.3 MWp proposed system is tabulated below.

Table 5.2 Annual energy production from all technologies

Technology	Annual energy production MWh
Two axes	2381
Single axis	2316
Fixed tilt	1843

It is clear from the figure 5.6 below that solar tracking system has higher annual energy saving than non-tracking system. The specific electricity consumption is 0.46 and 0.43 for non-tracking and tracking systems respectively as compared to the base case value (0.57).

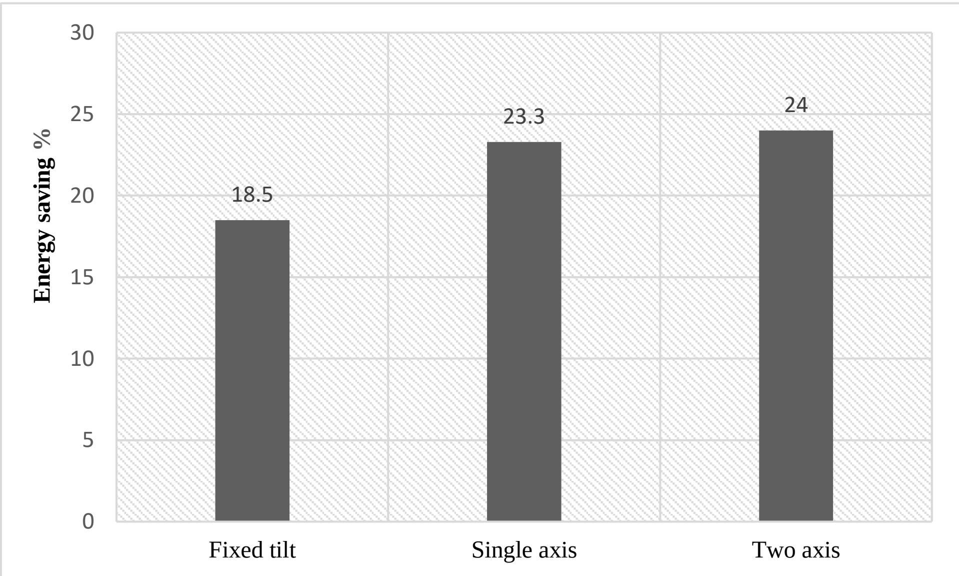

Figure 5.6 Energy savings from all technologies

Emissions analysis

The fossil fuel units that were neutralized by renewable generation were calculated in this study. The three types of solar PV systems discussed above are assessed for their potential for emission reduction. Figure 5.7 shows the annual GHG emissions reduction achieved by each type. The two-axis solar tracking system has the highest greenhouse gases emission reduction value of 1047 tCO_2 followed by the single axis and fixed tilt systems as compared with the base case value.

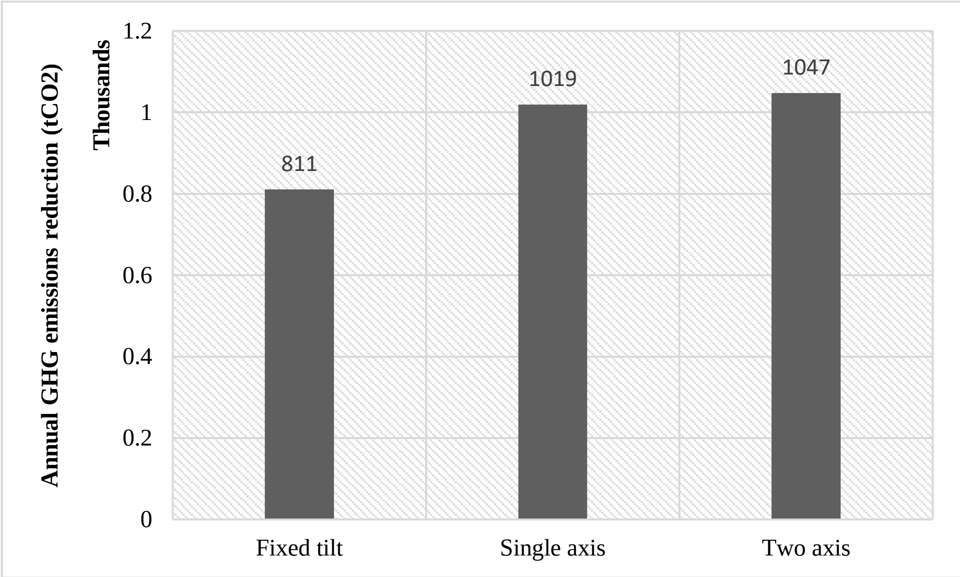

Figure 5.7 Annual GHG reductions from all technologies

The proposed model is validated by comparing with the energy production values from Global Solar Atlas [27]. For 1300 KWp capacity solar PV system with the similar climate condition and settings, our proposed model resulted in annual electricity production of 1843 MWh while the solar atlas annual energy production is 1851 MWh.

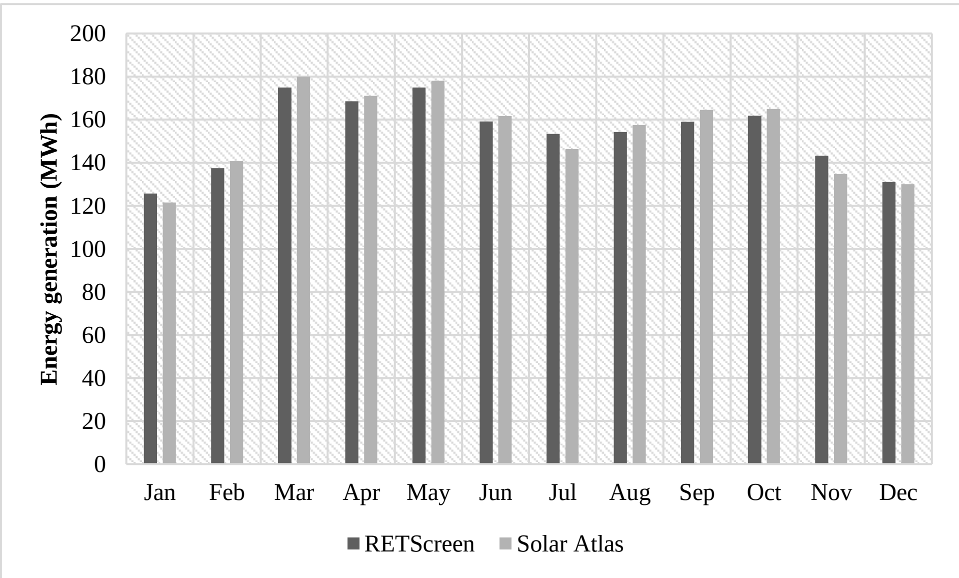

Figure 5.8 Comparison of two models for validation

Financial analysis

For the successful competition of a project, financial analysis is very important. To check the viability of the project, there are two financing modes considered to finance the proposed system, debt financing from bank and company owned systems. The initial incremental cost for 1300 kW proposed system is 0.719 million US$ with annual

O&M cost of 15600 US$/yr. The 80% debt with 20% equity on company is considered for bank financed scenario. The important parameters discussed under these scenarios are Net Present Value (NPV), Payback Period (PB), Internal rate of return (IRR), Benefit-Cost (B-C) ratio and Annual life cycle savings. Table 5.3 indicates the input parameters for both the scenarios taking into consideration the fixed tilt scenario only.

Table 1.3 Input financial parameters

Parameter	Company owned	Bank financed
Inflation rate %	2	2
Fuel cost escalation rate %	2	2
Discount rate%	7	7
Reinvestment rate%	0	3
Project life yr.	30	30
Debt ratio %		80%
Debt interest rate%	0	6
Debt term yr.	**0**	12

It is obvious from results that the single axis solar system has lowest simple and equity paybacks followed by two axis and fixed tilt technologies. It is strange that two axis system harnesses more energy than single axis but has greater payback period. Figure 5.9 (a) validates the statement. Figure 5.9 (b) compares the two financing methods for their payback periods taking into consideration the fixed tilt technology

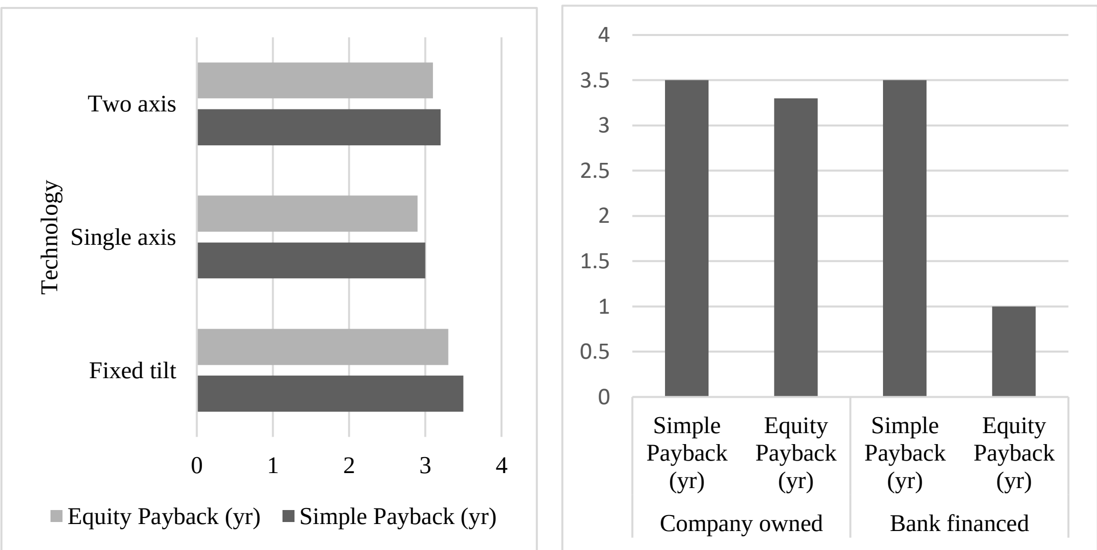

Figure 5.9 (a) & (b) Comparison of payback periods by technology and by financing method

For company owned scenario, the net present value (NPV) of the proposed fixed tilt model is 2.48 million USD with the annual life cycle savings of 199,952 USD a year. The benefit to cost ratio (B-C) of the system is 4.5 and pre-tax internal rate of return (IRR) is 31.3 %. While in case of debt financing from bank, the net present value (NPV) is 2.5 million USD with annual life cycle cost savings of 202,378 USD a year. The benefit to cost ratio (B-C) in this case is 18.6 and the pre-tax internal rate of return (IRR) is 102 %. Figure 5.10 (a) and (b) compares the cumulative cash flows of both scenarios.

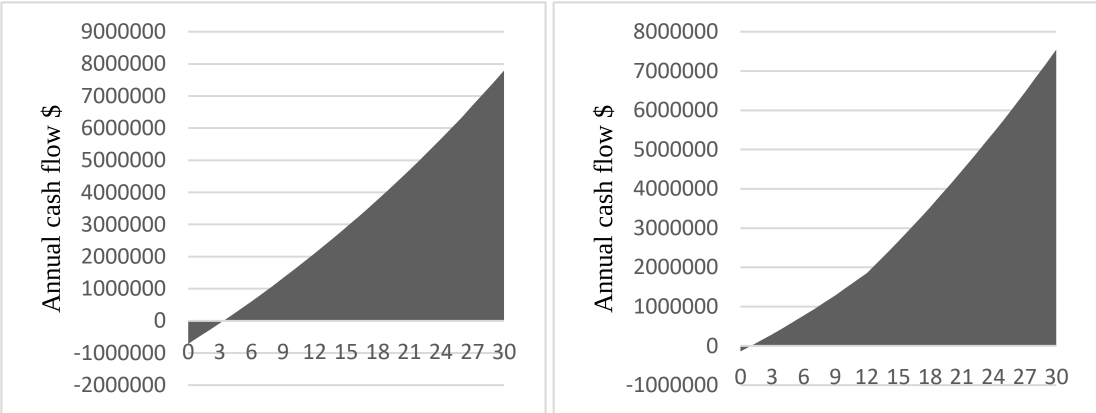

Figure 5.10 (a) (b) Cumulative cash flow diagrams for company owned and bank financed scenarios

5.2.3 Biomass scenario

Coal fired steam boiler present in the facility is the major source of greenhouse gases emissions. Also, the current steam generation system is highly inefficient and consumes more fuel to generate a ton of steam. Replacing fossil fuels with bioenergy is probably the fastest and most convenient option to replace significant volumes of fossil fuel-based power with sustainable energy. Considering the facts stated, a biomass energy scenario is developed and assessed for the energy, cost, and greenhouse gases emissions reduction potential. In this scenario, coal is completely replaced by equivalent amount of biomass-based feedstock, wood pellets in this case, to fuel the steam boiler. fuel. A cost and GHG emission reduction summary is presented below.

Technical analysis

The overall energy input demand of a boiler is not reduced by wood fuel-based system. The only way to reduce the energy consumption in the proposed scenario is the installation of a high efficiency biomass wood fired boiler with 84% efficiency to replace the old inefficient coal boiler with efficiency 80%. Figure 5.12 shows the energy savings resulted from the scenario. A total of 4.5 % fuel consumption is reduced in proposed case scenario as compared to base case by new installation.

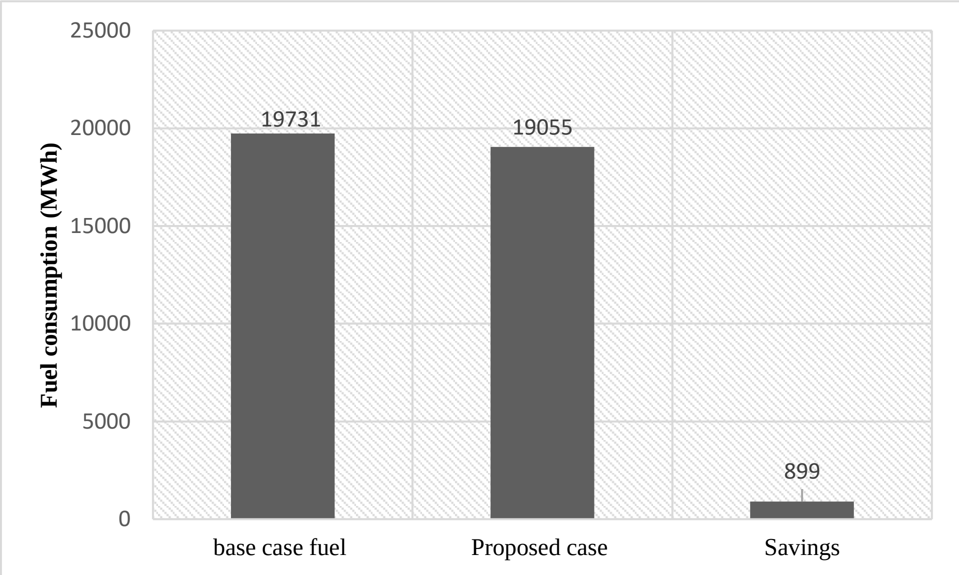

Figure 5.11 Fuel savings from biomass scenario

Greenhouse gas emissions analysis

In this scenario, reduction in greenhouse gas (GHG) emissions by installing new biomass-based boiler is evaluated. The base case GHG emissions volume resulting from both coal and LPG combustion is 6614 tCO_2. Figure 5.12 is presented as a proof of this assertion and shows the volume of GHG emissions neutralized in this scenario which is 95 % as compared to base case.

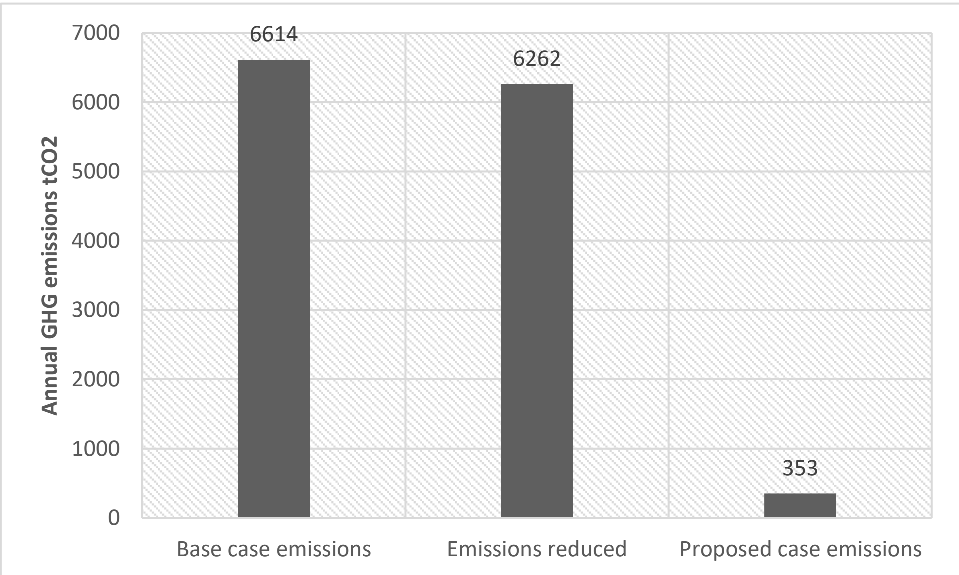

Figure 5.12 Emissions reduction summary

It is important to note that CO_2 is emitted during biomass burning. However, because the CO_2 emitted during biomass burning was previously absorbed from the atmosphere during plant development, it is considered that the carbon dioxide emission balance during biomass combustion is neutral.

Financial analysis

Overall boiler fuel consumption costs have been reduced by replacing coal with relatively inexpensive biomass-based fuel source. The sufficient supply of low-cost biomass resources is important for these reductions. The base case unit cost is 115 $/ton for coal and 0.87 $/kg for LPG used. The cost of locally available wood pellets used in proposed case is 53 $/ton. The total incremental cost of installing a 5-ton wood fired boiler is set to be 800,00 $ for the analysis. This value came after proper consultation with many local and international venders. Figure 5.13 shows the cost reduction pattern of the scenario. It is found that 19% fuel cost savings can be achieved by switching to wood as boiler fuel in proposed model as compared to base case.

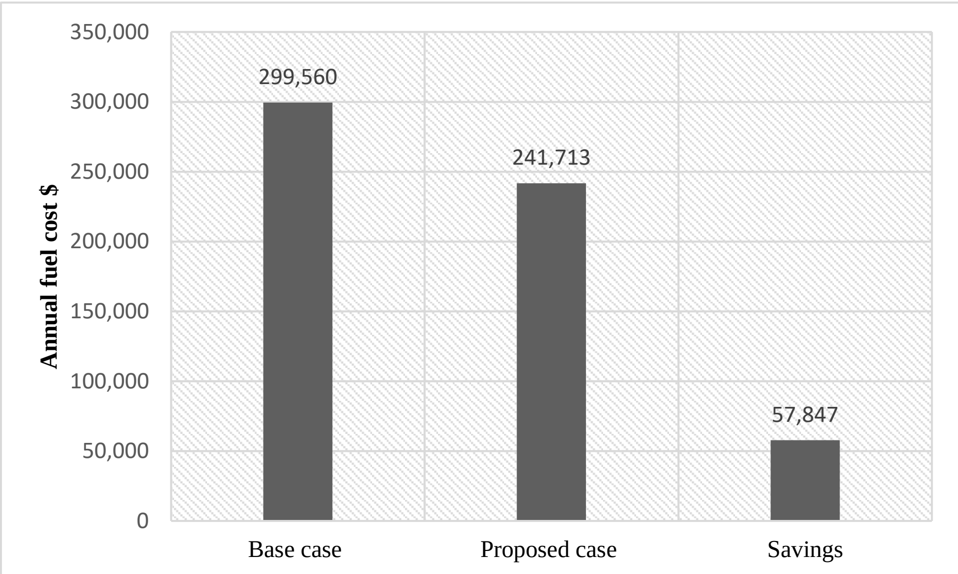

Figure 5.13 Cost reduction from biomass scenario

The simple payback period for this scenario is 1.5 years and the net present value (NPV) stands at the figure of 819,282 $. The annual life cycle cost savings are 66023 $ with pre-tax internal rate of return (IRR) 75.8 %.

5.2.4 Biomass cofiring

Cofiring of biomass-based feedstock with coal in existing coal-fired boilers is amongst the most appealing and simply deployed bioenergy solutions. In this technique, a part of coal is substituted with biomass fuel in the existing coal fired boiler. Both biomass and coal are burned at the same time.

In this scenario, a part of coal, 15 %, is replaced with biomass-based feedstock (wood). The energy saving and GHG emissions reduction potential is then estimated by the analysis. It is assumed that cofiring will not impact on the efficiency of boiler and it will remain same for base case and proposed case. Cofiring of biomass in existing coal boiler do not reduce the energy demand of the boiler. Hence no energy savings are achieved through this scenario.

Greenhouse gases emissions analysis

The use of coal-biomass co-firing technology is an efficient approach to minimise CO_2 emissions and other contaminants. A partial substitution of biomass to coal fired boiler has resulted in 14.2% of boiler GHG emissions reduction with no or minimal costs without any loss of efficiency. Figure 5.14 highlights the emissions summary of both scenarios.

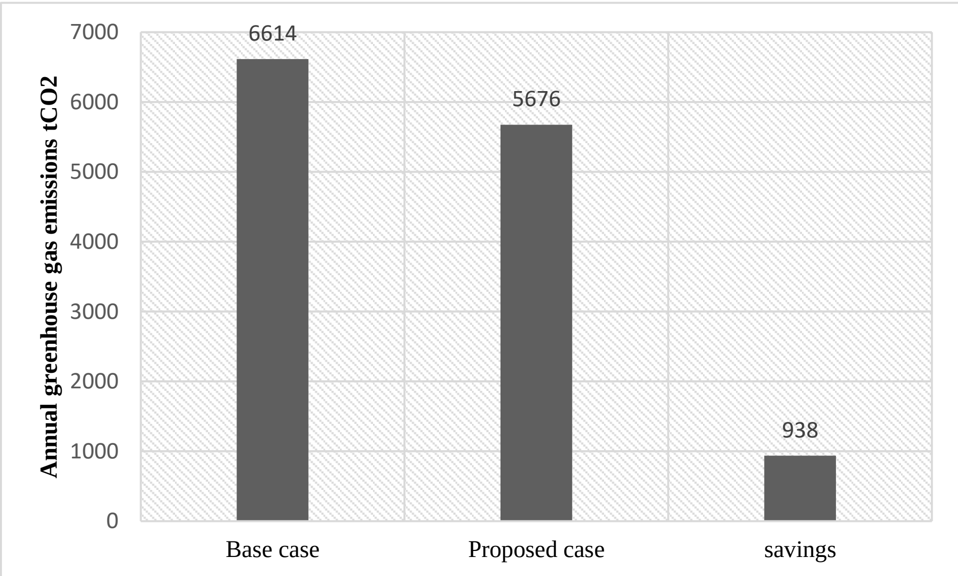

Figure 5.14 GHG emissions summary

Financial analysis

Integrating biomass to coal fired boiler for cofiring requires minimal initial investment as there is no major changes to boiler has been don. The initial incremental cost of the proposed system is 4300 $. The payback period is less than one year with pre-tax internal rate of return (IRR) 177 %. The net present value of the project is 110271 $ and cost0 benefit ratio (C-B) stands 26.6. The life cycle cost savings achieved by this project are 8886 $/yr. Figure 5.15 depicts the cost savings from cofiring scenario. The scenario has resulted in 2.5 % of fuel cost savings only.

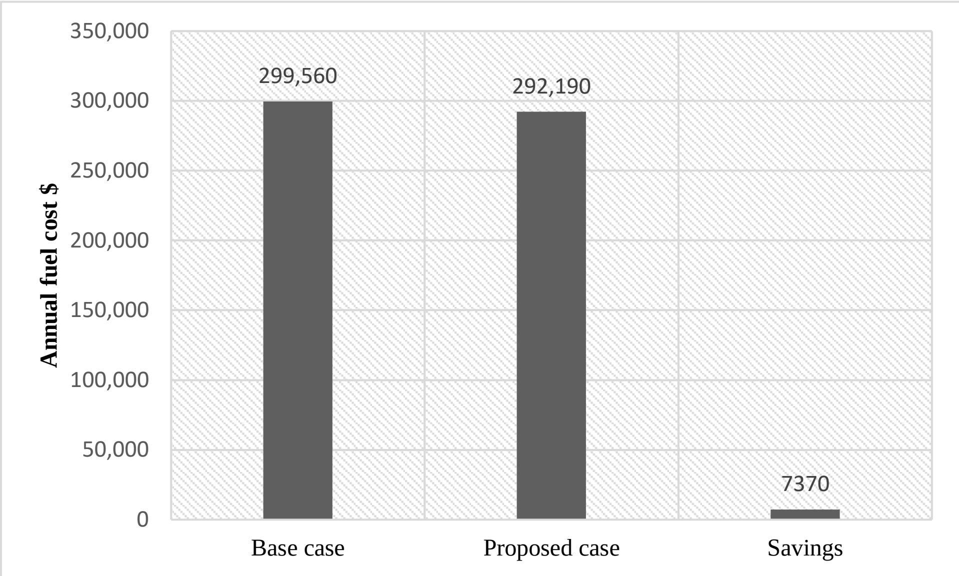

Figure 5.15 Fuel cost savings from cofiring

5.3 Comparative analysis of scenarios

It is evident form the results that the energy efficiency and renewable energy intervention in the industry can help in energy demand and greenhouse gas emissions reduction. In the quest of finding the best fit for the industry in context of cost and energy savings, a comparative analysis has been performed.

Table 5.4 compares the summary of savings from solar PV, biomass and cofiring systems. Fixed tilt technology has been selected from solar PV systems for comparison.

Figure 5.16 shows the energy savings resulted from all three scenarios. The annual onsite energy demand of the facility is 29669 MWh for the base year. The deployment of a 1300 KW solar PV system in the industry has resulted in 6.21 % overall energy saving. On the other hand, biomass scenario has resulted in 3 % of total annual energy demand reduction of the facility by replacing the old inefficient coal fired boiler with high efficiency wood fired boiler. It is assumed that cofiring of 15 % wood in coal fired boiler will not change the efficiency of the system so there will be no energy savings from the scenario.

Table 5.4 Comparison of savings from all scenarios

	Parameters	Solar PV scenarios		Biomass Scenario	Cofiring scenario
		Company Owned	Bank financed		
Energy savings	Energy demand reduction (MWh)	1843	1843	899	-
	Fuel cost saving $	221,196	221,196	57,847	7370
Economic benefits	Payback period (Years)	3.3	1	1.3	0.6
	Net present value (Million $)	2.48	2.5	0.82	0.1
	Internal rate of return (%)	31.3	102	75.8	177
	Annual life cycle savings ($/yr.)	199,952	202,377	66023	8886
Emissions	GHG reduction (tCO_2)	811	811	6262	938

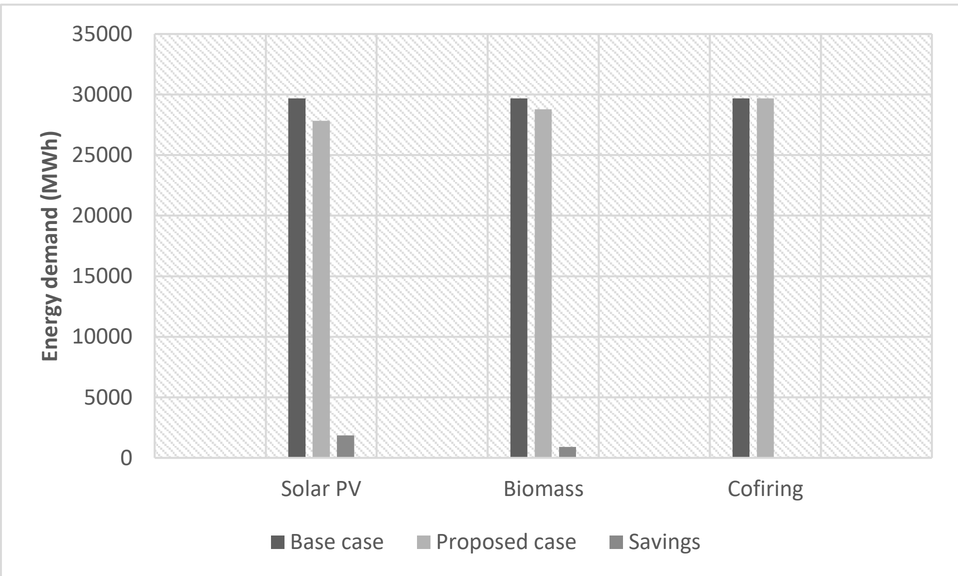

Figure 5.16 Comparison of energy savings from all scenarios

But in context of greenhouse gas emissions reduction, it is evident from the side-by-side comparison of both solar PV and biomass scenarios that wood fueled biomass boiler has reduced 57 % of plant's annual greenhouse gas emissions. While on the other hand, 1300 KW solar PV system has resulted in only 7.4 % of annual greenhouse gas emissions reduction. Cofiring scenario has shown 8.5 % emissions reduction potential. Figure 5.17 illustrates the savings from three scenarios.

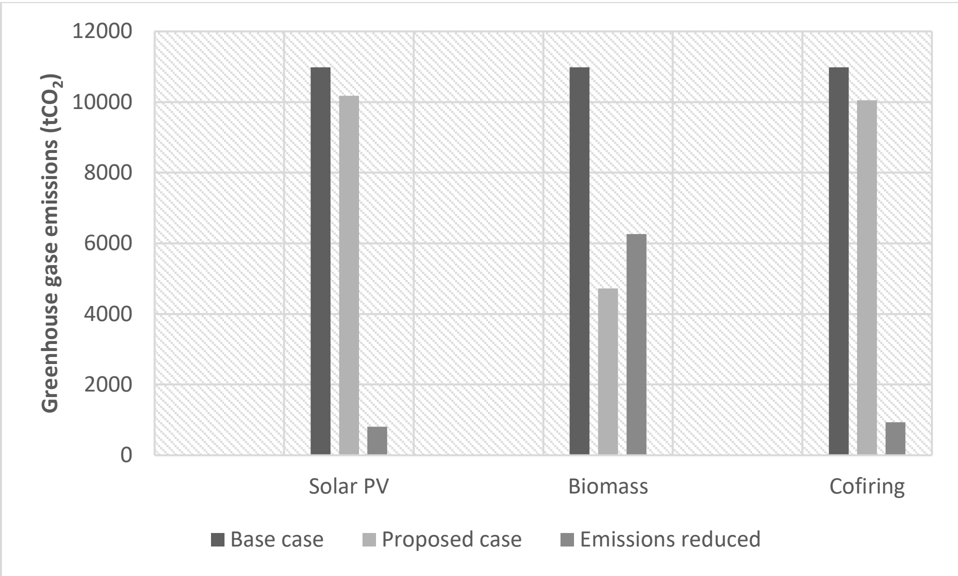

Figure 5.17 Summary of emissions savings from all scenarios

Payback period is most important parameter to check the financial viability of a renewable energy project along with many other measures. Figure 5.18 compares the payback periods of all three options The payback period of solar PV system is greater than biomass-based and cofiring systems.

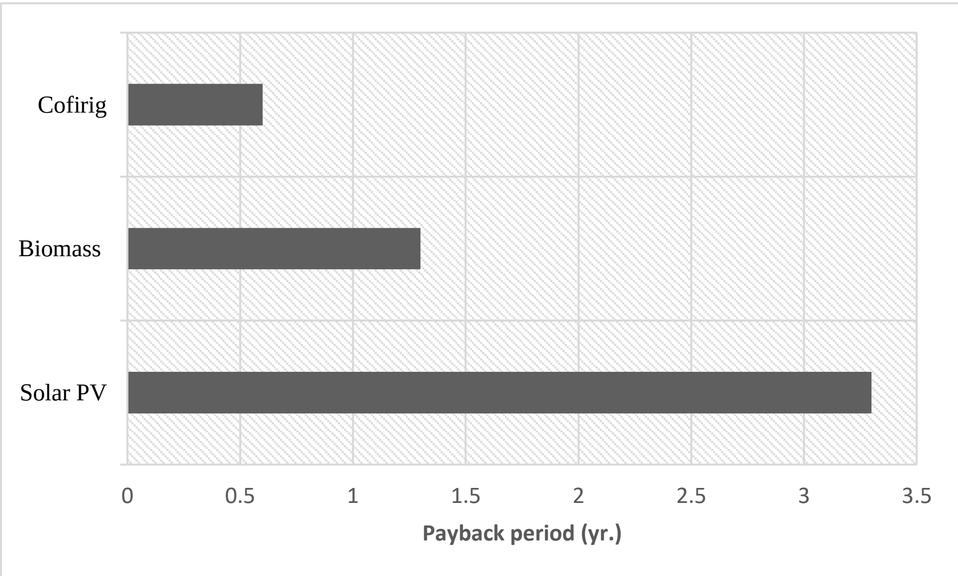

Figure 5.18 Comparison of payback period

Summary

In this chapter, findings of energy audit are presented, and it is concluded that refrigeration system is the biggest consumer of electricity to be operated by solar System. Moreover, boiler and steam system are assessed, and different aspects are discussed. Based on the results, different scenarios are developed, and results are discussed for greater energy, cost ang GHG emission savings.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

Industrial sector having major share of overall energy consumption and greenhouse gas emissions is assessed for the saving potential. It is concluded that the energy efficiency and assessment should be practiced for greater efficiency and less emissions. Moreover, integration of renewable energy systems to the industry can also be promoted. For this purpose, three different systems are proposed 1) solar PV, 2) biomass fired boiler,3) cofiring of biomass with coal. Solar PV from all showed the highest impact in terms of energy demand reduction, but for the greenhouse gas emissions reduction potential, biomass-based system has topped the list with up to 57 % of total annual greenhouse gas emissions savings. Cofiring has also proved itself a good option to integrate into an industrial setup with minimum incremental costs. In terms of energy savings, both biomass and solar PV systems are tough competitors.

Based on all above discussion, in can be concluded that solar PV alone should not be the first option for power generation in large industrial setups as it offers longer payback periods and less GHG mitigation potential. Biomass based systems are more cost effective than solar PV systems and offers greater emissions reduction potential. Solar PV coupled with cofiring of biomass can also be a good option with less cost investment and process changes required. Other options like biomass-based gasification system for captive power generation should be explored. While on the other hand, biomass is more viable option to integrate in industrial boiler and steam systems due to the huge GHG mitigating potential.

6.2 Recommendations

There is always room of improvement and furthers scenarios like those of discussed earlier can be developed and assessed for better system performance and to prevent climate change actions. Some of the recommendations are:

- Periodic energy audits should be performed for both electrical and thermal systems to enhance the efficiency of overall process.
- 10-ton steam boiler should be resized for optimum steam demand for the purpose of fuel cost savings.
- Other option such as biomass-based gasification for combined heat and power generation and Organic Rankine Cycle (ORC) for power purposed can be discussed.
- Co-firing of different biomass-based feedstock in the same boiler can be a good option if wood is scarce in the area.
- A hybrid solar thermal (PVT) model can be developed and discussed for the same setup.