# Environmental Life Cycle Assessment of Traditional and Solar Energy Integrated Brick Kilns in Pakistan

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## THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. **Affan Rauf,** (Registration No. **00000317484**), of U.S.-Pakistan Center for Advanced Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within similarities indices limit and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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# Certificate

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# DEDICATION

I dedicate this thesis to my inspirations in life, my father Abdul Rauf Qureshi a university professor who taught me what is life, how I can be a competent person, who embraced me when I was down, my mother Shazia Rauf a schoolteacher, who brought me up to this level. They made me what I am today.

# ABSTRACT

For years the brick kiln industry has been perceived as the main stationary source of environmental pollution. Life cycle assessments (LCA) are necessary to comprehend and improve process leakages and environmental risks associated with the expansion of this sector. The present study offers a comparative approach to analyze economic statistics and environmental impacts of three different brick-making technologies in Pakistan. Emission factors for various pollutants were calculated from the three brick kilns followed by determining the concentration of various pollutants. SimaPro software was used to perform LCA analysis on all stages of brick making at selected brick kilns sites. At the Hoffman kiln, the brick production-based emission factors for CO, $PM_{2.5}$, $CO_2$, and $SO_2$ resulted in 33%, 82%, 29%, and 58% reduction compared to the Fixed Chimney Bull's Trench Kiln (FCBTK) technology. The characterized impacts indicated that woods chips burdened 9 out of 10 impact categories at FCBTK while at Induced Draught Zigzag Kiln (IDZZK) and Hoffman kiln, the hard coal turned out to have a major negative influence on the environment. An on-grid photovoltaic (PV) system of 47 kW at Hoffman kiln was modeled on RETScreen expert software generating a total of 64544 kWh units of electricity, delivering 64284 kWh to the kiln load, and exporting 260 kWh back to the grid on annual basis. The system generated substantial financial and environmental benefits with the payback time of 3 years, benefits to cost ratio of 12.2, and reduction of 66.3 tons of $CO_2$ released per year thus reducing the problem of harmful emissions being released at power generation end. The outcome of this study highlights that Hoffman kilns in Pakistan can result in lesser emissions, better resource efficiency, increased sustainability, and better quality of bricks.



**Keywords:** Emission factors; life cycle assessment; impact categories; increased sustainability; brick kilns; photovoltaic

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# List of Abbreviations

| | |
|---|---|
| AQI | Air quality index |
| $EF_P$ | Brick production-based emission factor |
| EPD | Environmental protection department |
| FCBTK | Fixed chimney bull’s trench kiln |
| GCV | Gross calorific value |
| ICIMOD | International Centre for Integrated Mountain Development |
| IDZZK | Induced draught zigzag kiln |
| LCA | Life cycle assessment |
| PAH | Poly aromatic hydrocarbons |
| PM | Particulate matter |
| PV | Photovoltaic |
| SDG | Sustainable development goals |
| SLCP | Short lived chemical pollutants |
| VSBK | Vertical shaft brick kilns |

# List of Publications

| Title | List of Authors | Research Journal/ Category/Impact Factor | Status |
|---|---|---|---|
| Prospects Towards Sustainability: A Comparative Study to Evaluate the Environmental Performance of Brick Making Kilns in Pakistan | Affan Rauf<br>Sehar Shakir<br>Amos Ncube<br>H.M. Abd Ur Rehman<br>Abdul Kashif Janjua<br>Saeeda Khanum<br>Asif Hussain Khoja | Environmental Impact Assessment Review / $Q_1$-W / 4.59 | Accepted |

# Chapter 1
# Introduction

## 1.1 Background

Air pollution is one of the biggest problems the world is facing today. The negative health impact posed by air pollution in subcontinent Asia has mounted to over 9 billion US dollars in financial cost. Due to limited financial resources and lack of technological expertise, many developing countries are still struggling to come up with sustainable solutions to combat this problem [1], [2]. The problem is particularly horrifying in the countries with large number of densely populated areas such as Pakistan, India and Bangladesh [3].

Bricks are the primary building material in subcontinent Asia with its history going back to a century. Brick Kiln industry is one of the main contributors in polluting the local environment thus deteriorating the ambient air quality. Air pollution from brick kilns is the major concern for the developing nations such as Pakistan, India, Vietnam and Bangladesh [4]. The emissions from brick kilns do not only affect humans and animals but plants also undergo different physiological and biological changes as they come into contact with pollutants. These emissions contain several harmful gases such as $CO_2$, CO, $SO_X$, $NO_X$ and especially particulates in the range of $PM_{2.5}$ that cause negative health effects resulting in notable mortalities [5]. People exposed to harmful levels of $PM_{2.5}$ for a longer time are highly susceptible to skin diseases. Liao et al., [6] illustrated that prolonged exposure to $PM_{2.5}$ damages the anatomy of the skin epidermal layer by disturbing the cholesterol level in the epidermis. Moreover, pregnant women specifically in low-income countries with high levels of atmospheric $PM_{2.5}$ have been demonstrated to be at high risk of suffering from preeclampsia disease damaging the liver and kidney [7]

According to estimation the amount of $CO_2$ released into the environment by the brick kiln industry in South Asia is more than 130 million tons per year [8]. More than a quarter of the total bricks produced globally are based in South Asia where two types of brick kilns technologies namely Fixed Chimney Bulls Trench Kilns (FCBTK) and The Zig Zag

Kilns are the most dominant [9]. These conventional kilns have proved to be very inefficient as they consume large amounts of coal that is usually of low quality and also produce less number of bricks compared to other newly introduced and environmentally efficient kilns-The Zig Zag Kilns and Hoffman kilns [10].These old and inefficient brick kilns also produce dangerous short lived chemical pollutants (SLCP) such as Black Carbon that can create hindrance in achieving many sustainable development goals (SDG) by 2030 as framed by United Nations. Coal is the main source of fuel needed for combustion in all kilns. Sometimes the coal undergoes incomplete combustion and produces black soot which contains dangerous environmental pollutants such as polycyclic aromatic hydrocarbons (PAH's) severely endangering the lives of workers in the vicinity [11]. The incomplete combustion of coal does not only emit dangerous gases but also produces heavy toxic chemicals such as arsenic, benzene, mercury and dioxins that are then absorbed by the soil and underground water. Furthermore, these heavy metals get into the bloodstream through constant inhalation and raise the heavy metal index to harmful levels in the bloodstream particularly among the female brick kiln workers thus causing stress by bringing down the concentration of antioxidant enzymes [12]. The workers staying on brick kiln sites have high chances of suffering from pulmonary diseases because of prolonged exposure to ash and soot released from the chimneys. The ash contains radionuclide an atom with high nuclear energy and the potential to cause lung cancer [13]. In addition to other combustion sources, brick kilns release $PM_{2.5}$ particles particularly in the metropolitan cities like Delhi and Lahore causing episodes of smog every year[14].

## 1.2 Environmental issues of Pakistan

Pakistan is among the developing countries in South Asia that is facing several issues related to the environmental pollution [15]. According to the report generated form World Bank the main environmental problems of Pakistan include the pollution due to air, noise and water. These types of pollutions do not only cause health issues to the lives of people exposed to it but also cause damage to the economy of the country [16]. A huge population of the country lives in the rural areas that lack the availability of clean drinking water. Urban areas are not exempted from the harmful pollutants released from the industries and transportation sector. The pollutants from these industries especially manufacturing industries such as brick kilns create horrible episodes of smog every year [17]. Smog is primarily caused by the accumulation of particulate matter in the range of $PM_{2.5}$ in the lower atmosphere causing asthma and eye diseases in the people. Another issue is the lack of education and awareness among the people working in the industries in rural setting who are unable to comprehend the seriousness of this problem. Brick kiln industry in Pakistan is quite widely dispersed making it almost impossible for the government to ensure compliance related to the use to good quality fuel (coal) and restriction of child labor [18].

Traditionally, the basic raw material for producing bricks is clay but recently waste fly ash from different coal-powered industries has turned out to be an eco-friendly resource and a potential sustainable replacement for clay [19]. Moreover, using waste glass powder (WGP) together with natural clay as green brick production material tends to increase the compressive strength of the brick as well as reduce high temperature of the kiln [20]. Bricks with low compressive strength induce cracks over time and increase the fugitive emissions from various industrial processes [21].

The hidden cracks and pores in inefficient bricks also make buildings and structures vulnerable to earthquakes [22]. The fuel used here is mostly the cheap and poor-quality coal that contains high sulphur content and less calorific value. The workers also use waste tires as a fuel that produce visible black soot on burning containing harmful levels of short-lived chemical pollutants such as black carbon. The government has recently taken initiatives to combat this problem for example banning the operations of brick kilns that use poor quality fuel and giving an ultimatum to all the Fixed Chimney Bull's Trench Kiln (FCBTK) owners to convert their kilns into Induced Draught Zigzag Kilns (IDZZK) as IDZZK tend to be environmentally friendly compared to FCBTK [23].

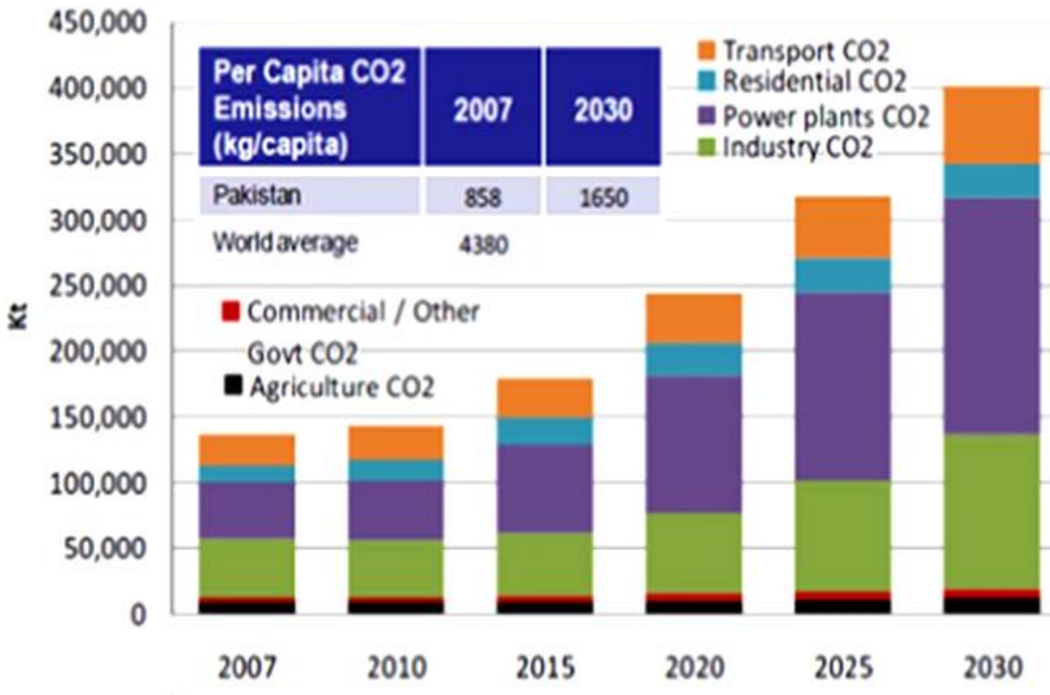


**Figure 1-1 Sector wise annual $CO_2$ emissions in Pakistan[24]**

## 1.3 Motivation of research and problem identification

Pakistan is one of the developing nations that are facing problems regarding the sustainability of the brick kiln sector. It is the third largest brick producer in the world after China and India with an annual production of over 100 billion bricks[15]. In Pakistan currently there are 16000 operating units employing over half a million people generating yearly revenue of more than 6 billion US dollars [25]. More than 99% of the brick kilns in Pakistan are-almost a century old-Fixed Chimney Bulls Trench Kilns (FCBTK). There is a growing demand for houses in the country due to a 2.4% annual population growth rate as per census 2017[26]. However, the demand for good quality bricks has also increased the same way prompting the industrialists to put millions into newer technology efficient kilns such as Induced Draught Zigzag Kilns (IDZZK)[9]. In 2016, the government of Punjab gave an ultimatum to convert all Fixed Chimney Bulls Trench kilns (FCBTK) into Induced Draught Zigzag Kilns (IDZZK) from because of low quality bricks, fuel conversion efficiency and reduced $CO_2$ emissions. However, the progress and uptake of the proposed conversion is slow and hampered by financial constraints[27]. The problem with brick kiln sector in Pakistan is that it consumes nearly half of the coal produced in the country yet lacks proper emission inventory and these emissions are increasing on yearly basis[28]. Thus, due to the scattered and dispersed nature of this sector in the country there is a need to take rigorous steps to bring sustainable solutions to the environmental and health problems that this sector is causing today.

## 1.4 Objective of the study

This study aims to discover that newly established Hoffman kiln in Pakistan is relatively efficient and cleaner technology compared to FCBTK and IDZZK through following findings

- Calculation of brick production-based emission factors by collecting the stack emission samples of all the three kilns taken under study
- Performing life cycle assessment (LCA) by first preparing an inventory with inputs and outputs of all processes based on the functional unit of 1 kg brick
- Software based modeling of an on-grid photovoltaic (PV) system at Hoffman kiln and then analyzing financial and economic benefits

## 1.5 Limitations of research

The research work has been conducted on three brick kilns that differ in terms of their operating procedures. These three brick kilns are fixed chimney bull’s trench kiln (FCBTK), induced draught zigzag kiln (IDZZK) and Hoffman kiln. The results should be analyzed with discretion as the findings of the present study come with some limitations. Less than 1% of the total brick kilns operating in the country have been undertaken for analysis due to the limited scope in coverage. The amount, quality, and type of fuel used in all the brick kilns are different subject to the traditional and financial aspects of kiln owners at different locations. Therefore, more brick kilns across different provinces should be analyzed for possible emissions variation. Also, if the emission monitoring time is increased to the 24-hour regime then the results could become more inclusive. Consequently, the aging of brick kiln stacks and furnaces results in invisible structural damages that ultimately open paths for fugitive emissions. Developing a methodology to measure stack and fugitive emissions together will make the results more promising.

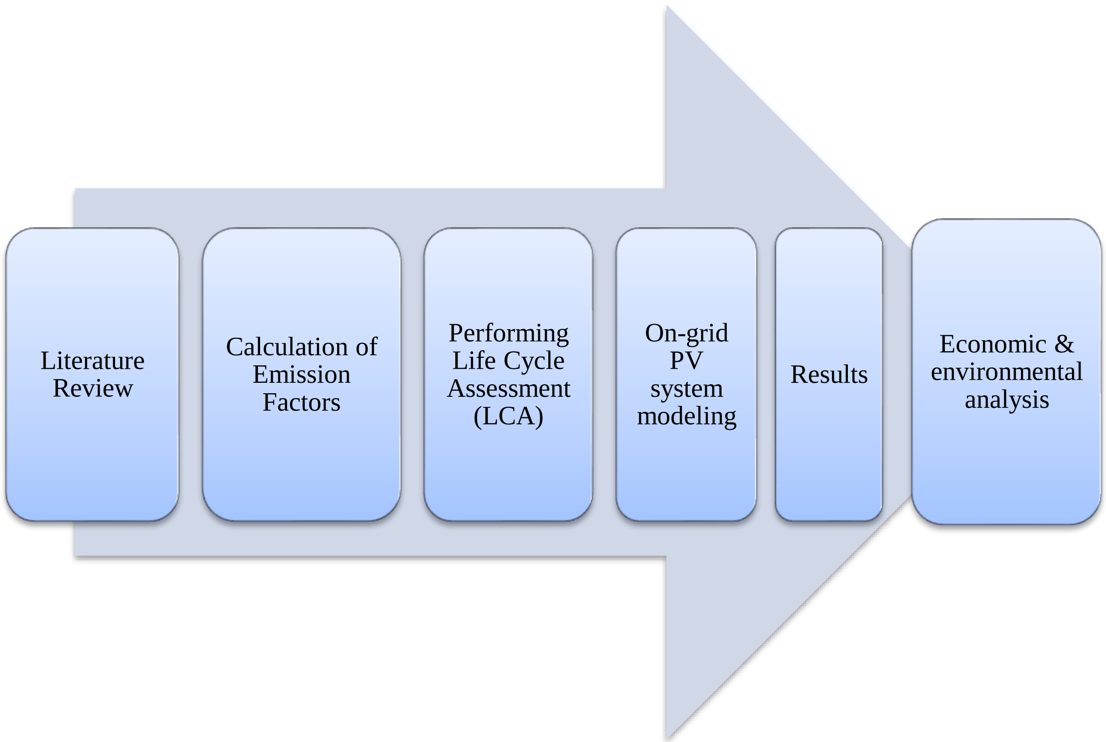


**Figure 1-2 Flow chart for research methodology**

## Summary

The environmental pollution in Pakistan is causing serious damage to the economy of the country. The brick kiln sector has particularly been discussed in this regard as the research conducted in this area is very limited. The number of brick kilns in country is increasing rapidly to meet the demand of bricks due to the special initiatives taken by the government of Pakistan to uplift the construction industry. The environmental regulations on the brick kiln sector are not as stronger as it is on the other manufacturing industries. This sector has considerable contribution to the harmful levels of air quality index (AQI) that Lahore and other metropolitan cities record every year.

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# Chapter 2
# Literature review

## 2.1 Steps involved in brick production

A typical brick production involves several processes which are briefly described below.

The first step involved in the making of the green bricks is the extraction of clay. In usual practice the brick kilns are constructed at the places which are nearby clay extraction pit to reduce the cost related to bringing the clay to the brick marking area. The quality of clay varies from region to region. The tensile strength of the bricks is highly dependent on the quality of clay [1]. In certain regions clay is mixed with other materials such as fly ash for the production of green bricks. This does not only reduce the level of emissions to a considerable level but also increases clay resource efficiency as clay is limited at certain regions and cannot serve this brick making process for a longer term [2].

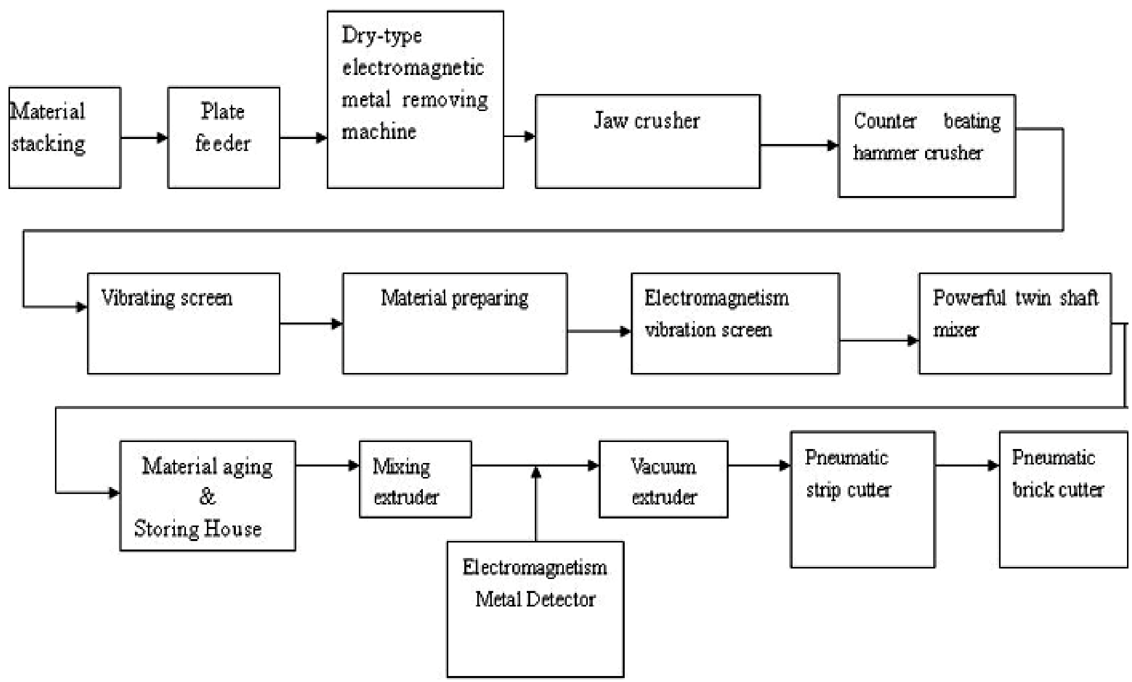


**Figure 2-1: Basic steps involved in brick making process [3]**

The next step after preparation of clay is green brick molding. This process can be done either with the help of electrical machines or by hand labor. In this process clay is mixed with water to produce a mixture that is put into brick molds. Since a mixture includes water more than 50% by weight so it requires ample time for drying. Green brick molds are prepared and then left for drying in open space. Now-a-days this process has completely been automated to reduce the clay losses and to increase the production efficiency. The quality of a brick highly depends on the material used to produce green brick at this stage. Several researches have been conducted regarding the use of fly ash replacing clay or using fly ash in combination with clay [2]. That does not only enhance the tensile strength of a brick but also significantly reduces the number of emissions released through the kiln chimneys. The complete atomization and mechanization of process is yet to be in practice in developing and under developing countries. In these countries this process is still done by hand labor by pathers (molders) but this result in clay losses [4].

Third step of brick production is brick drying. In this process the moisture content from the mixture is removed. The moisture content is removed in natural way by sunlight or with the help of some dryer. In most of the developing countries where this process is carried out naturally the total time required for green brick drying is highly dependent on the intensity of sunlight. The countries where the climate remains hot and humid this process is highly efficient, but some regions where the weather remains damp and cloudy the most efficient way is to use a blower or a dryer that can speed up the whole process. This is considered as one of the critical stages of brick production because it determines the quality and therefore, the tensile strength of the final roasted brick. Bricks with excess moisture tend to develop cracks and can even become responsible for making infrastructure vulnerable [5]. It is also a time taking process as the countries located near the equator have higher annual temperatures making this process relatively quicker as opposed to the countries that have humid and moist climate.

The final step is drying of the bricks. This process is carried out in brick kilns at a high temperature. The number of roasted bricks produced in a day depends on the type of the kiln in which the roasting is done. There are some brick kilns in which once fire is extinguished it never stops throughout the year. This is the most energy intensive process emitting heat as well as releasing greenhouse gases such as carbon dioxide. The roasting is carried out in a specially designed kiln and exhaust gases are released through the chimney. The height of chimneys varies depending upon the type of the kiln and location. Higher will be the height of the chimney lesser will be the impact of the toxic chemicals on the plants as well as on the people living in the vicinity. These are called continuous brick kilns. Fixed chimney bulls trench kilns (FCBTK) and Hoffman kiln are the examples of continuous brick kilns [6]. The other category includes brick kilns called the intermittent kilns where the bricks are fired in stacks and clusters. Each of those categories are briefly described below [7]

## 2.2 Types of the brick kilns based on production method

### 2.2.1 Intermittent kilns

In this category of brick kilns, clusters of bricks are made and then firing process is done. The fire does not run throughout the year. When the bricks are roasted, the fire is allowed to stop, and the hot roasted bricks are allowed to cool down. The fire has to be started again when new load/cluster of bricks has to be roasted. Every time the process of starting the fire requires different materials that most of the time are cheap wasted tires, municipal and industrial waste that puts a very negative impact on the local environment. These technologies have become a history even in most of the developing nations.

However, under developing nations that lack the resources to construct latest technology kilns are still using intermittent kilns and uptake or adoption to the continuous kiln seems to take ample time. There is no as such defined kiln structure in intermittent kilns. Intermittent kilns are further divided into two categories: intermediate kilns with chimney and intermediate kilns without chimney. Clamp and scotch kilns are the examples of intermittent kilns with chimney while climbing kiln and down draught kilns are the examples of intermittent kilns with chimney [8]. All these kilns are shown with images in Figure 2-2 [7]

**Figure 2-2 (a) brick clamp** **Figure 2-2 (b) scotch kiln**

**Fig. 2-2 (c) Brick climbing kiln** **Fig. 2-2 (d) down draught kiln**

### 2.2.2 Continuous kilns

In this category of brick kilns the fire never stops throughout the year. Bricks are roasted and cooled in different sections of the kiln. These are the most common types of kilns and are widely in operation in South Asia in countries such as Pakistan, India, Bangladesh, and Vietnam. the rate at which the roasted bricks are produced is almost constant in these kilns as compared to intermittent kilns where not only the output is highly variable but overall production efficiency is also very less. These kilns are further divided into two types: moving fire kilns and moving ware kilns [9]. The examples of moving fire kilns include fixed chimney bulls trench kilns (FCBTK) and Hoffman kiln while vertical shaft brick kilns (VSBK) are categorized as moving ware kilns.

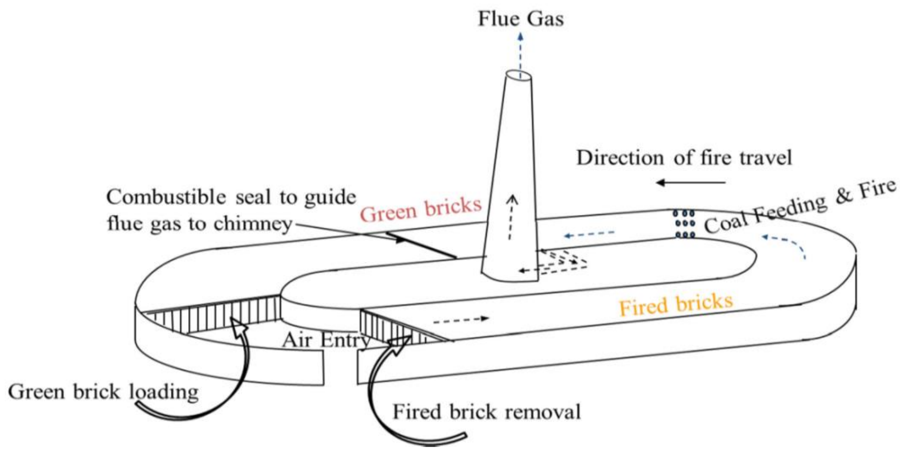


**Figure 2-3 (a): A typical fixed chimney bull's trench kiln (FCBTK) [7]**

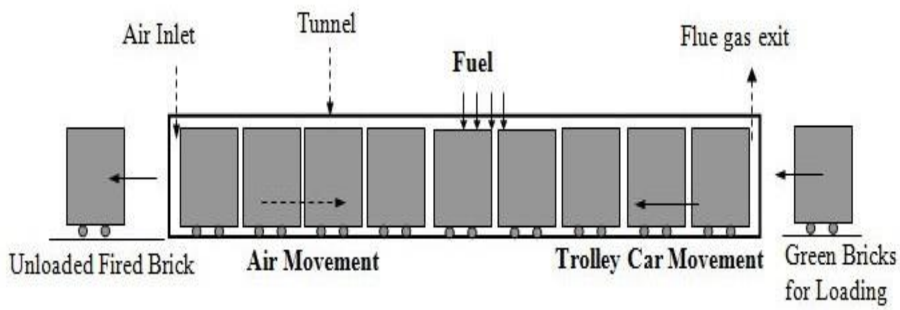


**Figure 2-3 (b): A Schematic diagram of vertical shaft brick kiln [7]**

## 2.3 Brick kiln types based on the air passage

In this category the classification parameter of brick kilns is the direction of the flow of the air because it highly affects the efficiency and time consumed in the whole process of roasting. Natural speed of the air passing through the brick kiln chamber is usually slow so these days such types of kilns are constructed in which they don't have to rely on natural flow of air. The draught is induced forcefully or artificially that does not only reduces considerable amount of time but also increases production efficiency and helps in attaining even roasting of bricks [10]. Such brick kilns are called zigzag kilns and are widely capturing the attention of the investors. Following are the types of brick kilns based on air passage.

- Up draught kilns
- Down draught kilns
- Cross draught kilns

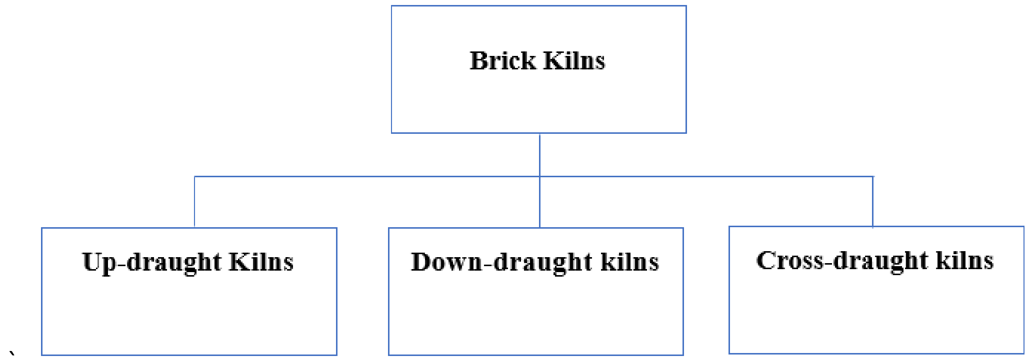


**Figure 2-4: Brick kilns classification on the basis of air flow direction [7]**

### 2.3.1 Up draught kilns

These types of brick kilns are designed in a way that makes the passage of the air such that it moves into the kiln from the bottom space. When the air enters the kiln, it comes in contact with the fire that is already set. The fire thus increases the temperature of the air which then starts to more upwards following the natural phenomenon of convection. These types of brick kilns do not need the installation of any stack or the induction of forced/artificial draft because the natural current of heated air is sufficient for the roasting of the bricks. The examples of this category are vertical shaft brick kilns and clamps [11].

The vertical shaft brick kiln (VSBK) comes under the category of up draught kilns. The firing zone is located at the center of the kilns. The passage of hot air is upwards. This air becomes hot after entering the kiln from bottom to top and after coming in contact with the fire at the center. The heat from the air is transferred to the bricks that move downward through the kiln at the roasting stage. Bricks are stacked in batches and after that firing are done. These stacks of green bricks are arranged in a particular zigzag pattern. Each firing arrangement includes four layers of bricks. There are three zones in VSBK [12].

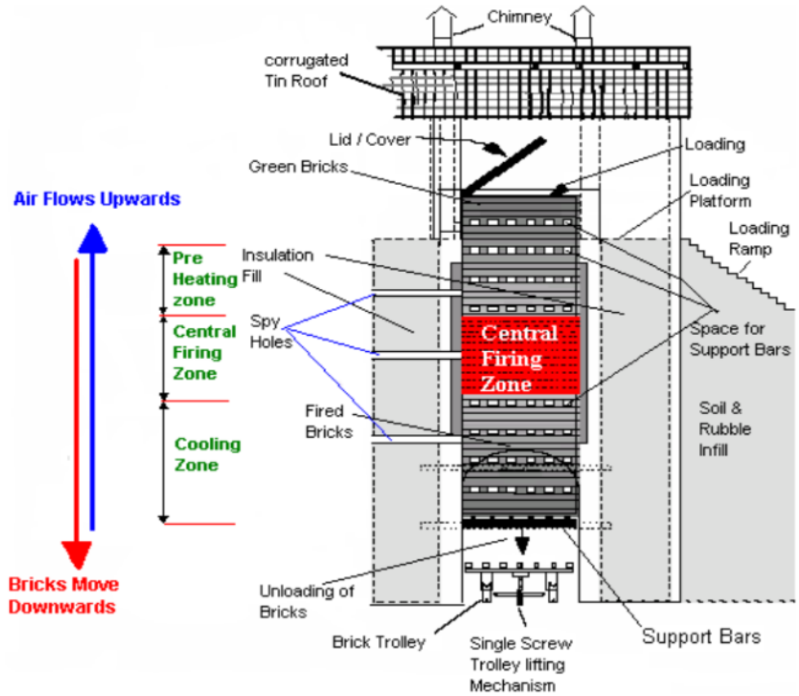


**Figure 2-5: Different zones of a vertical shaft brick kiln (VSBK) [12]**

- The first zone is the area where the green bricks encounter the hot air released from the firing area.
- The second zone is the area where green brick firing takes place. This is the step where soft green bricks are turned into red hard roasted bricks.
- The third zone is the area where the cooling of the hot roasted bricks takes place

The feeding of fuel in VSBK is done in two stages and two forms. Two forms of fuel are internal fuel and external fuel. The internal fuel is fed into the kiln before the brick molding process. Fly ash, coal powder and different types of biomasses are the types of fuels that come under this category. The external fuel is fed from the space at the top of the kiln where stacks of green bricks are already set to undergo firing. Hard coal is the example of the external fuel used in this process. In FCBTK there is no as such fan or any other blower that can artificially induce draught so the natural currents of air pass through the combustion chambers. The process does not incorporate latest automation technologies such as brick cutting systems, conveyer belts, box feeders, vacuum extruder and auto brick cutting system which can be seen in the case of Hoffman kiln.

Clamps are the type of brick making structure that do not have proper purposely built kiln for roasting of the green bricks. Bricks are stacked above each other to form layers. Generally, the times the fuel that is used for combustion is coal. This fuel is interspersed with the arrangement of green bricks that are stacked in a particular way to form layers to undergo combustion. These brick making structures are designed in a way to allow the convenient placement of the fuel through the tunnel constructed at the base of the stack. This technology is not being opted these days due to the loss of large amounts of heat but is still prevalent in many parts of India and some other developing countries [13].

In some clamps improvisations have made with time such as development of outer walls made of mud to prevent the heat loss and increase process efficiency. Such kilns are called scove kilns. The improvements that were made in scove kiln technology were the construction of permanent walls in outer sides to contain the heat within the structure. The scove kiln technology was exclusively being used till the end of $18^{th}$ century. However with the development of FCBTK and Hoffman kilns these kilns are gradually phasing out [14] .

### 2.3.2 Down draught kilns

In this type of kilns, the air temperature is increased with the help of fire that is already in place. In up draught kilns the air moves into the kiln from the lower part of the kiln but in the case of down draught kilns the heated air moves into the kiln from upside. The hot air comes into contact with the bricks and transfers the heat to them. The roasting here is carried out without keeping the bricks directly placed in the fire. So, the name indicates that the passage of air is from top to bottom. In this type of kiln bricks are stacked into each other in the form of clusters and then put for baking. It is among the oldest brick making technologies. One of the benefits of using down draught kiln from the early days was that the final roasted bricks produced from the method were free from the different toxic pollutants deposited in their surface [15]. This way the down draught kilns prevented a lot of health-related issues in the workers having physical contact with the bricks. This technology was particularly prevalent in the developing countries such as India, Pakistan, and Vietnam. The value of the specific energy consumption in the case of down draught kilns is smaller as compared to other older technology kilns such as clamps but its trade off was that the quality of the roasted bricks produced were reasonably better compared to the bricks produced by clamp. The initial investment required for the construction of such kilns was quite minimal [9].

**Figure 2-6: A typical view of down draught kiln [16]**

### 2.3.3 Cross draught kiln

In this category the passage of air is horizontal, and air moves in horizontal way through the brick kiln stack and transfers the heat to the bricks for roasting and is one of the most widely used technology in terms of producing bricks. Different designs have been proposed to make its several types such as Hoffman kiln more efficient [17]. In this case the draught is forcefully or artificially induced with the help of a fan that is installed inside the chimney. This fan is called zigzag fan. In some types of these cross draught kilns the passage of air is can also be natural and air moves through the chimney designed to facilitate its movement [18]. Cross draught kilns have primarily been used in many of the developed as well as developing nations because of the cost as well as environmental benefits that it offers. The overall efficiency of brick production and the quality of the bricks thus produced is man times better than the final bricks produced by the old and inefficient technologies such as clamps and down draught kilns. Higher number of bricks can be produced by this technology which solves the problem of meeting the high demand because of rapidly growing global construction industry. The amount of toxic chemical pollutants that are released by producing bricks from this technology are small compared to old technologies particularly the Hoffman kiln which serves as the least greenhouse gas emitting brick kiln among its three types. The examples of this category of kilns are widely in use fixed chimney bulls trench kilns (FCBTK) and Hoffman kilns [19].

**Figure 2-7: A typical view of cross draught kiln [16]**

- **Fixed Chimney Bulls Trench Kilns (FCBTK)**

This is the most commonly used brick production technology in South Asia. The design concept of these kilns was introduced for the first time in 1876 by an engineer named W. bull. It was then called as bull's trench kiln because initially it had a moveable chimney which later went through some design improvisations and turned into fixed chimney bull's trench kiln. In 1990's most of the countries like Bangladesh and India put a complete ban on the operation of kilns that had moveable kilns. Despite of the fact that most of developing countries in this subcontinent have started to move on to the technologies that have comparatively less negative effect on the environment such as zigzag kilns but this old and conventional technology is still prevalent in many regions [20]. Fire never stops all the year and hence to save the cost of the coal that is used as fuel other cheap materials such as waste tires are put into fire to keep it on. Out of all the registered brick kilns in Pakistan more than 97% are these old styles FCBTK [21]. These kilns do not involve process automation at any step of the production therefore overall production efficiency is less compared to zigzag and Hoffman kilns. There are three different compartments in FCBTK where the brick kiln operation is carried out. In first compartment fuel is placed periodically to ensure continuity in the combustion process. In second compartment the green bricks are heated by the hot air currents before the final roasting process take place. In third compartment the roasted bricks are placed to cooled and ready to be transported to end consumers [4]. There is no mechanism as such for the removal of the harmful pollutants from the flue gases coming out of the chimney thus the workers and local residents in the vicinity are at serious risk of getting health issues such as asthma and lung cancer [22].

- **Hoffman kiln**

Hoffman kiln is also the type of continuous kiln where fire is set all year along. The design patent of this kiln was developed for the first time by a German engineer Fiedrich Hoffman in 1858. It is basically a cross draught kiln where the passage of the hot air is not straight. In fact the air moves in zigzag manner through the bricks inside the roasting chamber that are stacked with each other in rectangular and circular manner enclosed within the roof [23]. Here the rainy season does not affect the green brick molding process because these kilns have shelter which protects the green bricks being damaged by the rain and hence the extensive moisture after that in the early of the introduction of this design concept these kilns gained considerable attention in European countries. Later the Hoffman kilns also became common in India in early 19$^{th}$ century [24]. As of today, different improvisations have been made in Hoffman kiln design. The overall production efficiency of Hoffman kiln is greater compared to Fixed Chimney Bull's Trench Kilns because the former incorporates fully/semi-automated production steps depending on the different regions. This also reduces the labor cost in terms of monthly salaries being dispersed to the labor resources. In Pakistan there is only one Hoffman Kiln operational as of today. The design of Hoffman kiln is such that it helps in attaining the even roasting of bricks while reducing the clay losses during brick molding phase. Since the fuel is properly combusted in Hoffman kilns so the quantity of the harmful pollutants released from the chimney are less compared to FCBTK. Workers and local residents living in the vicinity are comparatively safe [25].

## 2.4 Previous research related to brick kiln emissions

Former studies that have been conducted on the production of the bricks report the release of several harmful gases such as the oxides of carbon, sulphur and nitrogen. Total suspended particles with aerographic diameters in the range of 1µm, 2.5 µm and 10µm as well as metals such as copper, chromium, lead and zinc are also emitted as a result of poor and inefficient methods of combustion taking place in the kilns. Other toxic chemicals being released include hydrochloric acid (HCl) and hydrogen cyanide (HCN) ultimately get dissolved with the rain water and become the precursors for acid rains destroying valuable infrastructure [26] [27].

### 2.4.1 Contribution of brick kilns to the Global emissions

Akinshipe and Kernelius [28] conducted a comprehensive study on the emissions of the brick kilns and indicated that the share of particulate matter in the range of $PM_1$ emitted from the brick kilns to the global emissions is 1.6%. The share of sulphur dioxide ($SO_2$), back carbon and carbon monoxide (CO) to the word wide emissions was calculated to be 1.6%, 5.5% and 1.6% respectively. The contribution of the brick kiln industry to the global pollution is very large in Central Asia [29]. To get the perspective, the share of black carbon emitted from the brick industry to the local emissions in the region is as high as 10.4%. Bangladesh is a densely populated country having similar environmental problems as Pakistan. Here brick kiln industry is taking its toll on the local residents' causing different respiratory diseases. The industry releases more than 23000 tons of $PM_{2.5}$, around 300000 tons of carbon monoxide and 2 million tons of carbon dioxide ($CO_2$). Therefore new and efficient technologies are needed to solve this problem to save our future generations [30].

### 2.4.2 Technical causes of brick kiln related pollution

The following are the main technical reasons of the emissions due to brick kiln industry according to work done by Febres [31]

- Quality and chemical composition of the fuel used
- Poor and irregular passage of air inside a brick kiln

There are many brick kilns in South America and Central Asia that use bad fuel such as wasted tires for combustion because of financial constraints related to the high cost of coal [29], [32]. Even though this practice comparatively shortens the roasting time but comes with the release of so many harmful pollutants. Luby et al. [33] conducted research related to the economic parameters to indicate that the bricks produced in Artisan brick kilns (ABK) are not only cost effective but also commonly used in most of the construction related projects. The bricks produced from the modern techniques are high in cost. A lot of it has to do the personal financial interests of the brick kiln owners. They want their investments to be viable without putting large amount of money on stakes on new technologies. Akinshipe and Kornelius [28] ranked the brick kilns in terms of releasing emissions from least to the most: (1) Vertical shaft brick kiln, (2) Zigzag kiln, (3) US coal-fired kiln, (4) Clamp kiln, (5) Fixed chimney Bull's trench kiln, (6) Down-draught kiln and (8) Bull's trench kiln.

## 2.5 Fuel used in the Brick kilns

The chemical composition of the fuel that is used in artisan brick kilns makes it not a viable option to be used in the brick kilns. The primary reasons that make the fuel poor in quality are as follows

- Non uniformity in the size of fuel particles grains
- Non uniformity in the moisture content
- Presence of harmful amounts of toxic organic chemicals
- containment of local municipal and industrial waste

The composition, consumption and nature of the fuel vary a lot when it comes to brick kilns operation. Some of the brick kilns also used combination of different types of fuels including the biofuels such as bagasse, rice-husk and typical organic material such as coal [26], [34]. Many studies have indicated coal as a conventional fuel used in brick kiln industry [24]. In some studies, it is added in the chamber separately while in other cases it is added being mixed with other fuels [35]. Several practices include the addition of fuels in the clay preparation stage [36]. Such types of fuels are usually very low in energy content. Some investments are being made around the world to produce fuel that has high energy content and low in cost. In some countries in South America chestnut shells are used as a fuel that allows a total reduction of more than 30% in the consumption of the fuel [37] .

## 2.6 Specific Energy Consumption (SEC) of brick kilns

Energy efficiency of brick kilns depends primarily on Specific Energy Consumption. It varies from one type of kiln to another depending on heating value of the fuel and bricks sizes [38]. The secondary factors that alter the energy efficiency of the brick kilns include the weight of the bricks and quality of the final roasted bricks. The specific energy consumption of several brick kilns in India that has been calculated ranged from 1.17 MJ/Kg to 1.90 MJ/Kg depending on the type of the brick kilns based on the operations [39], [40].

### 2.6.1 Recent improvements in energy efficiency measures

There are certain measures that have been taken related to improving the energy efficiency of the bricks. Some of them which have been found to be practically effective are as follows

- Covering brick clamps with roofs
- Constructing the walls providing heat insulation. The walls can be made up of mud and relevant biomass such as rice-husk
- Increasing stack heights
- Enclosing and insulating the fire chamber

All these measures can insure high energy efficiency. It has been indicated in several studies related to brick kilns that tunnel kilns and hybrid Hoffman kilns are efficient in terms of conserving energy. The specific energy consumption of these brick kiln energy is comparatively lower than conventional brick kiln technologies such as FCBTK and IDZZK. The hybrid Hoffman kiln particularly has been turned out to burn lesser quantity of fuel and also gives high rates of return on the initial investment [41]. An important thing is that the measures related to energy efficiency give the brick kiln operators more power to control the fuel combustion stage which can result in the overall decrease in the number of emissions released from the brick kilns. The global research in the brick kilns is revolving around making the overall brick production process as efficient as possible. The research that has been carried out in different types of kilns indicates that the small brick kilns with the brick production capacity of just over 30 million bricks per year best suit the construction of VSBK that requires the specific energy consumption of over 2 MJ/Kg but requiring ample energy to remove the moisture from the green bricks [42].

## 2.7 The process of green brick firing

The process of green brick firing has been divided into following stages as described below

- The first stage is evaporation which takes in the temperature range of 20°C to 150 °C. It primarily involves the removal of the moisture content from the clay. It is very important to maintain a uniform increase in the temperature to minimize the cracking of the bricks.
- The second stage is dehydration that takes place from 149 °C to 650 °C. It involves the chemical splitting of the carbonate matter. It is critical to make sure that the heat is increased gradually otherwise black soot will appear to possibly accumulate around the brick kilns and change its color [26].
- One of the primary things to maintain in brick kilns is the complete oxidation of the components of iron and carbonate matter. This could be achieved by circulating the excess air within the chamber through natural or induced mechanisms. The variables that is process depend on include heating rate, carbon quantity in the clay and the density if the bricks [30].
- This process involves strengthening the fired roasted bricks. The strength and hardness of the bricks depends upon the highest temperature that is reached during the combustion stage.
- This is the last stage of the brick firing process. In this process the temperature of the brick kiln chimney gets down to almost outside atmospheric temperature taking few days [28].

## 2.8 Solar energy integration in brick kilns

One of the ways to make the brick kilns sustainable is to efficiently integrate the renewable energy sources to power all the electrical systems that are the integral part of the brick making process. Hoffman kilns have recently come up to gain attention owing to their improved overall efficiency and automation in every step of brick production [2]. This electrical equipment is burden on the main electricity grid in terms of the release of toxic greenhouse gases at the generation end. Converting all the electrical loads at the brick kilns from fossil fuel-based grid electricity to the solar would be one step closer to sustainability. It can result in economic as well as environmental benefits. The most viable system that can be modeled is on-grid PV system [43]. The basics of PV modules and their types are being discussed in the sections below.

## 2.9 Solar Photovoltaic modules

These are the silicon-based chips that collect the solar radiation falling on them and directly convert it into electrical energy. PV modules are capturing attention these days to be incorporated as a source of electrical energy in residential as well as commercial sector. This does not only provide a sustainable solution to the problem of harmful emissions being released from the burning of fossil fuels that are used as primary fuel in electricity generating power plants [44]. Fossil fuels are also limited with crude oil being available for few more decades.

PV modules are primarily divided into two categories.

- Monocrystalline
- Polycrystalline

**Monocrystalline Photovoltaic modules**

The production of monocrystalline silicon involves the cutting of silicon inglots that are cylindrical in shape. The cutting results in the making of silicon wafers that have increased efficiency compared to polycrystalline silicon. Since there efficiency is greater so that lesser area is required to convert same amount of solar energy into electricity compared to polycrystalline photovoltaic modules that require larger space [45]. The cost of these modules is generally higher but benefits that they offer in terms of efficiency makes them the most viable option to be used these days [46].

**Polycrystalline photovoltaic modules**

The production of these multi crystalline PV modules involves pouring the melted silicon into specially shaped molds. The melted silicon is then allowed to cool down before it is turned into wafers. These wafers are square in shape. The conversion efficiency of these modules is lower compared to monocrystalline modules hence the production cost is also small. The performance of polycrystalline modules increases at higher temperature even then they are not preferred to be used as the clean energy source because they occupy large area and produce less amount of electrical energy [46].

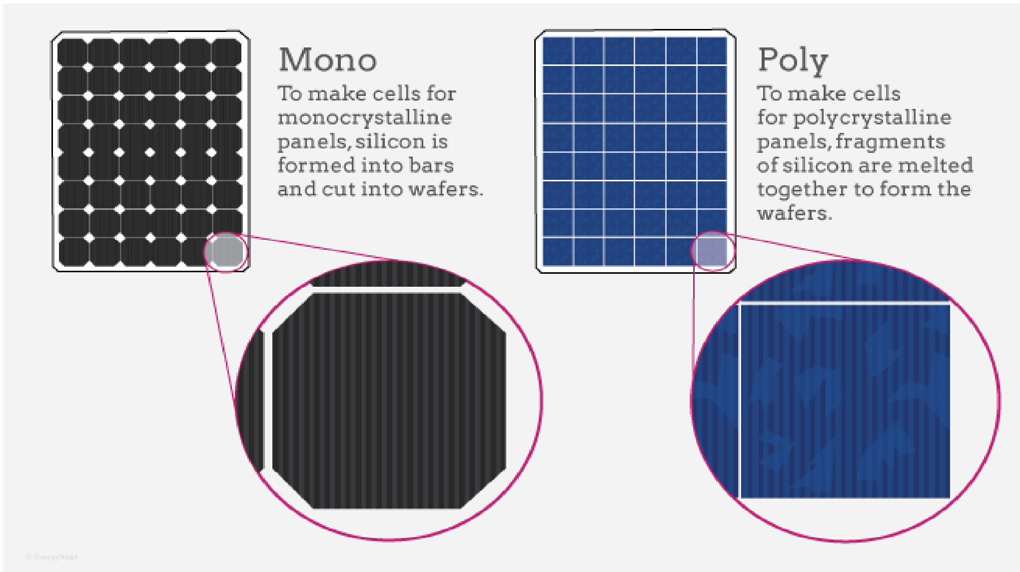


**Figure 2-8: Monocrystalline and polycrystalline solar panels [47]**

## 2.10 Types of Photovoltaic systems

The PV module systems are primarily divided into three categories

- On-Grid systems
- Off-Grid systems
- Hybrid systems

### 2.10.1 On-Grid systems

In this type of the PV module system is directly connected to the grid. On-Grid systems are the most used PV module systems supplying clean energy to the businesses as well as local residential consumers. This system does not require storing the electrical energy therefore batteries are not the part of this system. PV modules are connected to the grid through the inverters. The concept of net-metering has also originated from the development of these systems. Through net metering the end consumers can get paid by injecting the electricity to the grid that is generated by PV modules. During the times when the grid is not energized for example during blackouts, this system also becomes dysfunctional or does not produce electricity due to the safety reasons. Because if this system was still injecting electricity back the grid that would make the life of the workers at the grid completely at risk. Simple benefit of this system is that the electricity generated by PV module does not get wasted and excess electricity is transferred back to the grid at a tariff that is decided by the relevant electricity distribution companies [44].

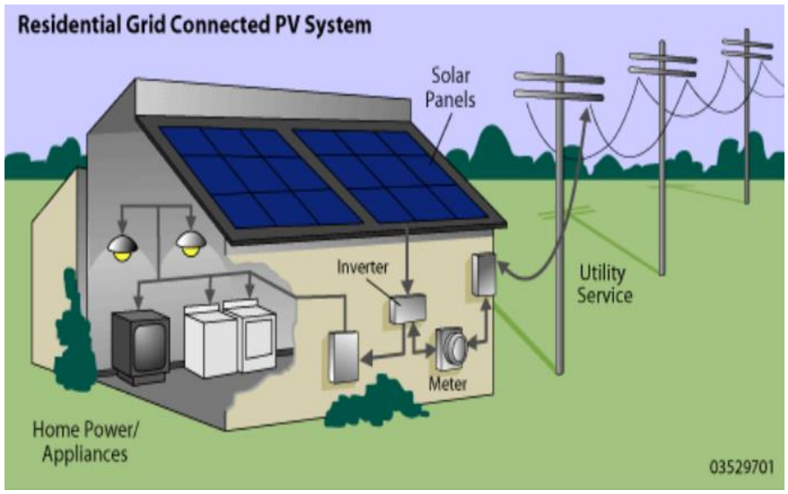


**Figure 2-9: A typical view of residential on-grid PV system [48]**

### 2.10.2 Off-Grid systems

The off-Grid PV module systems are not connected to the grid therefore the electricity cannot be injected back to the grid. This system requires storing the electrical energy produced by the PV module therefore storage batteries are the integral part of this system. The installation of the batteries increases the overall cost of the system. Off-Grid systems require concise calculation on the basis of which the number of PV modules and batteries are installed so that the generated electricity from the module does only meet all the loads at the demand side but also gets stored in the batteries for feeding the loads during the night as well as during the days of autonomy such as rainy seasons. The electricity produced by the PV modules is directed towards the batteries through the charge controllers. The batteries are further connected to the inverters for feeding the AC current to the loads. The direct connection of charge controllers with the batteries ensures smooth charging and discharging of batteries without damaging it. This system is mostly used at the places where low voltage generation is required or to provide direct DC to smaller loads such as lights, fans etc [49].

**Figure 2-10: A typical view of commercial pole mounted off-grid PV system [50]**

### 2.10.3 Hybrid systems

This is the combination of off-grid as well as on-grid systems. The electricity is injected back to the grid at the same time can be stored in the batteries. This system is becoming a viable choice for most of the consumers due to the decreasing cost of the batteries. The end consumers can benefit in both ways, from the grid and from the stored energy in the batteries. During the day, the solar energy generated by the PV modules gets stored in the batteries to be able to use it at night. When the stored energy in batteries falls below a certain level the consumer can smoothly shift the loads to the grid to ensure the continuity of both the systems. The primary objective of the hybrid system is to reduce excessive grid electricity consumption during the day time [51].


**Figure 2-11: Basic layout of a hybrid PV system [52]**

## Summary

In this chapter a general overview of different brick making technologies has been given. The brick making kilns are categorized into different types based on the parameters like the fuel used direction of air flow and brick production method. In the earlier times the scotch kilns and clamp kilns were mostly designed for brick production because of low initial investment and low demand of bricks for construction purposes. With urbanization these inefficient brick kilns have not been able to meet the demand of good quality bricks. Latest brick making technologies include different types of down draught kilns such as FCBTK, IDZZK and Hoffman kiln. Among these three types of down draught kilns Hoffman kiln has turned out to be the most efficient as signposted by several researchers.

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# Chapter 3

# Research Methodology

## 3.1 Site selection

Three brick kilns one from each technology-FCBTK, IDZZK and Hoffman kiln-were selected to analyze their impacts on the environment by using life cycle assessment (LCA) approach. The study was carried out on three brick kilns in the province of Punjab, Pakistan with different operating technologies. Two of them were located in the district of Layyah (a small district in Southern Punjab) and one of them in the district of Sargodha. All investigated kilns varied in terms of their operating procedures. Among the two brick kilns in Layyah one was conventional Fixed Chimney Bulls Trench Kiln (FCBTK) and other one was Induced Draught Zigzag kiln (IDZZK). The brick kiln in Sargodha was the Hoffman Kiln that was established recently and incorporated completely different technology compared to the rest of the two kilns. The technology was different as it incorporated completely mechanized brick production unlike FCBTK and IZZK where everything was done by hand labor. The location coordinates and name of kiln sites are given in Table 3-1.

## 3.2 Selection parameters

**Table 3-1: Location coordinates and name of kiln sites**

| | **FCBTK** | **IDZZK** | **Hoffman Kiln** |
|---|---|---|---|
| Name of the kiln site | Rehman Bricks Company, Shah Alam | Anwar bhatta Kasht Company | Saif Ur Rehman bricks Company |
| Location coordinates | 31.98° N, 71.17° E | 31.60° N, 71.08° E | 32.07° N, 72.68° E |

The parameter for selecting the brick kilns was their location and operating technology. We chose Southern Punjab because according to the database of government of Punjab out of almost 20000 brick kilns in Pakistan more than 9000 are located in Layyah and its adjoining cities[1]. Since most of them were located in close proximity of each other, studying the impacts of one could be generalized for the rest of the kilns and further make emissions estimations for other brick kilns in vicinity. No previous research has been conducted on the environmental foot print of any type of brick kiln in Southern Punjab region which contains more than quarter of all the brick kilns in Pakistan. Moreover the type of clay and the quality of coal was also quite similar among many kilns located there. The third kiln refers to the Hoffman Kiln located in Sargodha and it is the only of its kind operating in Pakistan [2].

## 3.3 Data acquisition for brick kiln inventories

The environmental protection department EPD helped connecting us to the respective brick kiln owners. All the data required to make the inventories of the three brick kiln was collected through site surveys and by conducting in person interviews with brick kiln owners and the accountants staying on site.

### 3.3.1 Data acquisition for FCBTK and IDZZK

The brick production at FCBTK incorporated no latest technology. Green bricks were prepared by hand by Pathers (molders) following traditional practice. The number of green bricks made in a day was more than the number of green bricks put for baking the same day. That is because in all brick kilns in Punjab the Friday is not a working day, but even during Friday the brick roasting continues but green brick production stops because there is no labor for green brick production. The excess stock of green bricks is used for roasting in this case. Also higher quantity of green bricks stored in stocks helps continue roasting during rainy season when there is excessive moisture which makes green brick production almost impossible because green bricks are made in open air and require ample time for drying. Coal is the main source of combustion for the two brick kilns except that at FCBTK other cheap materials such as waste wood logs and saw dust were also used owing to the high cost of coal. The proximate analysis was performed to find the gross calorific value (GCV) of coal and it showed that the GCV of coal used at FCBTK was 23.50 KJ/kg and at IDZZK and Hoffman kiln it was 22.75 KJ/Kg and 25.00 KJ/kg respectively. No mechanical equipment was used in FCBTK. Although IDZZK contained an electric fan in the chimney to forcefully and artificially induce the draught to improve the combustion and even roasting of the bricks. The number of labor resources at IDZZK was slightly higher because the number of green and roasted bricks produced, and the land allocated for their production was also greater.

Raw data was collected relating to the production materials and electrical equipment used to produce the bricks and all the values were converted to give the values based on the functional unit of 1kg bricks as shown in the Table 3-2 and Table 3-3. At FCBTK a total of 40500 green bricks were produced in day, 23000 of them were put for baking and 20500 was the number of final bricks produced. At IDZZK a total of 58550 green bricks were produced in day, 44500 of them were put for baking and 42000 was the number of final bricks produced. The overall brick production efficiency of FCBTK and IDZZK was 83% and 85% respectively.

### 3.3.2 Data acquisition for Hoffman kiln

The brick production at the Hoffman kiln incorporated all the latest technologies such as auto brick cutting system and double stage vacuum extruder for processing bricks. The number of labor resources was small and every step of brick production from clay grinding to final brick involved heavy machinery run by electricity. The green bricks were produced by mixing fly ash with clay. Machine operators work in a single shift of 8 hours a day.

Green bricks are not produced in excess as the whole production setup has a shelter above to save green bricks from rain unlike open air production in case of FCBTK and IDZZK. A total of 24000 green bricks are produced in a day and out of them 21500 are put for baking the same day and 21000 final roasted bricks are produced. All three brick kilns fall under the category of continuous brick kilns as fire in their roasting areas never stops the whole year. The overall production efficiency at Hoffman kiln was 96%. The quality of bricks produced here was better and hence profit margins were also greater compared to FCBTK and IDZZK [3].

**Table 3-2: Inventory of of all three kilns based on functional unit of 1 kg bricks**

| Brick molding phase | FCBTK | IDZZK | Hoffman Kiln |
|---|---|---|---|
| **outputs** | **Amounts** | **Amounts** | **Amounts** |
| Green bricks produced per day | 40500 | 58550 | 24000 |
| **Inputs (all values are based on the functional unit of 1 kg green brick)** | **Amounts** | **Amounts** | **Amounts** |
| Water consumed (ml) | 350 | 370 | 290 |
| Total land to make green bricks ($m^2$) | 0.19388 | 0.14662 | 0.15329 |
| Clay used (kg) | 0.65 | 0.63 | 0.577 |
| Fly ash used (kg) | Not used | Not used | 0.133 |
| Quantity of gasoline/electricity consumed per day by water pump | 0.000041 liters | 0.0001015 liters | 0.000253 kWh |
| Water bore hole ($m^3$) | $4.27e^{-6}$ | $5.61e^{-7}$ | $4.67e^{-7}$ |
| **Brick roasting phase** | **FCBTK** | **IDZZK** | **Hoffman Kiln** |
| **outputs** | **Amounts** | **Amounts** | **Amounts** |
| Bricks roasted per day | 20500 | 42000 | 21000 |
| **Inputs (all values are based on the functional unit of 1 kg green brick)** | **Amounts** | **Amounts** | **Amounts** |
| Total area of land allocated for a brick kiln chimney ($m^2$) | 0.16729 | 0.0964 | 0.0649 |
| Green bricks put for baking per day | 23000 | 44500 | 21500 |
| Coal (kg) | 0.022 | 0.0703 | 0.056 kg |
| Sawdust (kg) | 0.0426 | 0.035 | Not used |
| Wood (kg) | 0.177 | Not used | Not used |

**Table 3-3: Inventory of electrical equipments based on the functional unit of 1 kg brick**

## Details of Electrical equipment used in FCBTK

**Molding phase**

No Equipment used

**Roasting phase**

No Equipment used

## Details of Electrical equipment used in IDZZK

**Molding phase**

No Equipment used

**Roasting phase**

| Sr. No | Name of the equipment | Electricity units (kWh) consumed per 1kg brick per day | Total mass of equipment (tons) | Life cycle (years) | Material composition | Mass of equipment (kg) per 1 kg brick per day |
|---|---|---|---|---|---|---|
| **01** | Zigzag fan to induce draught (to improve combustion) | 0.000992 | 2.2 | 20 | mild steel | $3.67\ e^{-6}$ |

## Details of Electrical equipment used in Hoffman Kiln

| Sr. No | Name of the equipment | Electricity units (kWh) consumed per 1kg brick per day | Total mass of equipment (tons) | Life cycle (years) | Material composition | Mass of equipment (kg) per 1 kg brick per day |
|---|---|---|---|---|---|---|
| **Molding phase** | | | | | | |
| **01** | Box Feeder | 0.0003 | 2 | 25 | mild steel | $2.4e^{-6}$ |
| **02** | Roller Crusher | 0.00189 | 6 | 25 | mild steel | $7.32\ e^{-6}$ |
| **03** | Clay Mixer | 0.00183 | 3 | 20 | Iron | $5\ e^{-6}$ |
| **04** | Extruder | 0.00252 | 5 | 25 | Iron | $6\ e^{-6}$ |
| **05** | Vacuum | 0.00101 | 0.4 | 20 | Iron | $6.62\ e^{-6}$ |
| **06** | Brick cutter | 0.0000252 | 0.5 | 20 | Iron | $8.3\ e^{-6}$ |
| **Roasting phase** | | | | | | |
| **07** | Fan to induce draught | 0.0020 | 2.2 | 20 | mild steel | $3.67\ e^{-6}$ |
| **08** | Hammer crusher | 0.000136 | 2.75 | 20 | mild steel | $5.63\ e^{-6}$ |
| **09** | Conveyer belt | 0.000160 | 0.7 | 15 | mild steel | $1.88\ e^{-6}$ |

### 3.4 Emission sampling

The sampling of particulate matters was conducted by following the procedure as given by US EPA methods [2]. US EPA method 17 was followed for taking PM samples. In all of the three kilns the particulate matter sampling was conducted using Apex-572. Stack emissions at all the kilns were measured using Horiba PG-350E that was calibrated from laboratory at a public sector university located near the brick kiln site at district Layyah. The methodology for stack emission sampling was adapted from method 2 of US EPA methods. At IDZZK the emission sampling was conducted for 2 hours each day, at a stack height of 11.7m. The process was repeated on alternate days for two weeks and then average value was taken. At FCBTK the emissions were monitored for 1 h both for feeding and non-feeding cycle at a stack height of 9.8m for measuring the relevant concentrations of harmful gasses. The values were taken on alternate days for two weeks and average value was calculated. At Hoffman kiln the management had already monitored the emissions two months prior to ensure compliance with the relevant government organization. They used similar PG-350 E emission sampler and updated their emissions record after every four months [2]. Both the devices used for the calculation of the concentration of pollutants from stack emission samples are shown in Figure 3-1 below.


**Figure 3-1(a): Horiba PF-350-E [4]**

**Figure 3-1(b): Apex-572 console [5]**

The brick production based emission factors (g/kg of the fired brick) for $CO_2$, CO, black carbon and particulate matter (PM) for FCBTK and IDZZK were calculated by adapting the methodology used by Rajarathnam in his study[6]. This value was obtained by first calculating the emission rate *(ER)* by using Eq. (1)

$$ER = S \times Q_s \quad (1)$$

Where S is the stack concentration in $mg/m^3$ and $Q_s$ is the flue gas flow rate in $m^3/h$.

Fuel mass-based emission factor $EF_m$ was calculated by Eq. (2) as follows

$$EF_m = ER/F \quad (2)$$

Where F is the rate of consumption of fuel in kg/h

Energy input-based emission factor is calculated by Eq. (3) as given below

$$EF_e = EF_m \times EC \quad (3)$$

Where EC s energy content in MJ/kg

Finally, $EF_b$; the brick production-based emission factor in g/kg of the roasted brick calculated by using Eq. (4)

$$EF_p = EF_e \times SEC \quad (4)$$

Where SEC is specific energy consumption in MJ/kg of roasted brick

## 3.5 Life cycle assessment

LCA has proved to be a very efficient method used for evaluating the burden of the brick manufacturing process on the environment and has widely been used by several other researchers on various industrial [7]–[10] major steps are provided in accordance with the standard LCA format, namely; goal and scope, method and indicators, life cycle inventory, sensitivity and uncertainty analysis (ISO 14040:2006)

### 3.5.1. Goal and scope definition of the LCA study

A cradle-to-gate approach was applied since the system boundary in this study was restricted and limited to the production of bricks, while neglecting the transportation, consumer usage and final brick disposal stages. This approach helps to get a deep and detailed analysis from cradle to the gate. The system boundary consists of all processes from brick molding to roasting phase as shown in Figure. 3-2 [12]

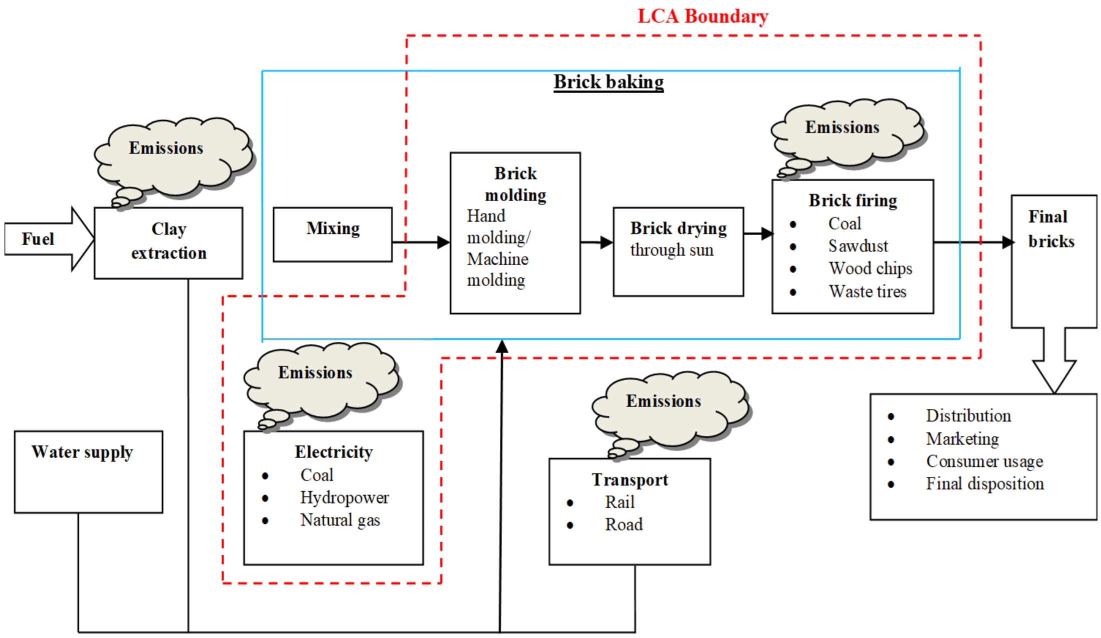


**Figure. 3-2. LCA boundary of brick kilns production stages**

### 3.5.2. Method and Indicators

In this study, the professional LCA SimaPro software v.9.1.1 integrated with the updated Ecoinvent v3.6 database was used to analyze environmental impacts [13]. The ReCiPe 2016 midpoint (H) method was employed in the study to perform impact assessment providing 18 different environmental impact categories. 10 impact categories were selected for analysis based on their relevance to major environmental issues in Pakistan. The selected impact categories, their units, and abbreviations are shown in Table 3-4.

**Table 3-4**

**Impact categories considered within the ReCiPe 2016 Midpoint (H) v.1.03 impact method**

| Impact category | Unit | Abbreviation |
|---|---|---|
| Global warming | kg $CO_2$eq | GWP |
| Stratospheric ozone depletion | kg CFC11 eq | SOD |
| Ionizing radiation | kBq Co-60 eq | IR |
| Ozone formation, human health | kg $NO_x$eq | OFH |
| Fine particulate matter formation | kg $PM_{2.5}$eq | FPMF |
| Ozone formation terrestrial ecosystems | kg $NO_x$eq | OTE |
| Land use | m2a crop eq | LU |
| Mineral resource scarcity | kg Cu eq | MRS |
| Fossil resource scarcity | kg oil eq | FRS |
| Water consumption | $m^3$ | WC |

### 3.5.3. LCA Inventory acquisition and impact analysis

The LCA inventory (Table 3-2 and 3-3) was developed from the qualitative data collected directly by conducting in-person interviews with brick kiln accountants and their managers staying on the site. Input data of all the three brick kilns that included the materials used for the production of green bricks, type of fuel, electricity consumed, and the electrical equipment used was based on a functional unit of 1 kg brick (ISO 14040:2006; ISO 14044:2006).

### 3.5.4 About the SimaPro software

The life cycle assessment (LCA) on the three brick kilns has been performed on SimaPro software as mentioned earlier. SimaPro is professional LCA software that is widely used for analyzing the detailed environmental impacts of different industrial and agricultural systems. The input data that is fed into SimaPro is usually in the form of an inventory based on the functional unit of a material or a product manufactured by a particular industry under analysis. This software is a very important tool developing sustainable solutions for the industrial systems bringing negative impact to the environment

## 3.6. Economic Analysis

Economic analysis was performed on the three-brick kilns by collecting the data related to the yearly income, cash flow statements, and balance sheets. The primary purpose of this analysis was to provide the investors, a deeper insight of financial statistics and figure out which of the existing brick making technologies overtakes the other in terms of project start-up cost as well as annual net-income. The data was gathered by arranging in-person interviews directly with the brick kilns operators. Due to confidentiality concerns the management did not share the official written records related to their annual earnings.

## 3.7 PV system integration at Hoffman kiln using RETSrcreen

There were 9 different kinds of electrical equipments installed at the Hoffman kiln. All of them were 3 phase loads and had an annual electricity unit consumption of 48360 kWh. They all drew power from grid electricity which itself is a burden on the environment in terms of emitting harmful green house gases as fossil fuels have big share of overall electricity generated in the country. RETScreen software was adapted to perform a techno-economic analysis of PV integration into the Hoffman Kiln electrical systems. RETScreen is efficient and user-friendly software for performing analysis related to renewable energy projects. Several other researchers have used RETScreen software for clean energy system modeling [15]–[17]

### 3.7.1 About the RETScreen expert software

RETScreen is clean energy management software. It allows the professionals to perform simulations based on the actual data and assumptions to find the techno-economic viability of clean energy projects at different locations across the world. The data regarding the environmental aspects such as temperature and moisture is integrated in the software through NASA. The clean energy projects can be based on solar energy, wind energy and biofuels. This software also calculates the yearly emission reductions and cash flows that help the investors to take an informed decision.

### 3.7.2 Climate data location

The Hoffman kiln is located at district Sargodha, Pakistan. The data regarding the climate of the brick site as generated by NASA can be shown in the table 3-5.

**Table 3-5: Climate data of selected location of Sargodha district**

| Parameters | Values |
|---|---|
| Latitude | 32.1° |
| Longitude | 72.7° |
| Elevation (m) | 274 |
| Heating design temperature (°C) | 4.8 |
| Cooling design temperature (°C) | 38.0 |
| Earth temperature amplitude (°C) | 26.2 |

The climate related parameters are important for selecting the most suitable type of PV module for the location. Fixed type PV module category was chosen for the analysis. The modules were fixed to certain angle to deliver maximum electricity to the loads and export excess electricity to the grid. Moreover, monthly variation in effective sunshine hours and air temperature for the location is provided in Figure. 3-3. The data has been provided by NASA and is incorporated in the database of RETScreen.

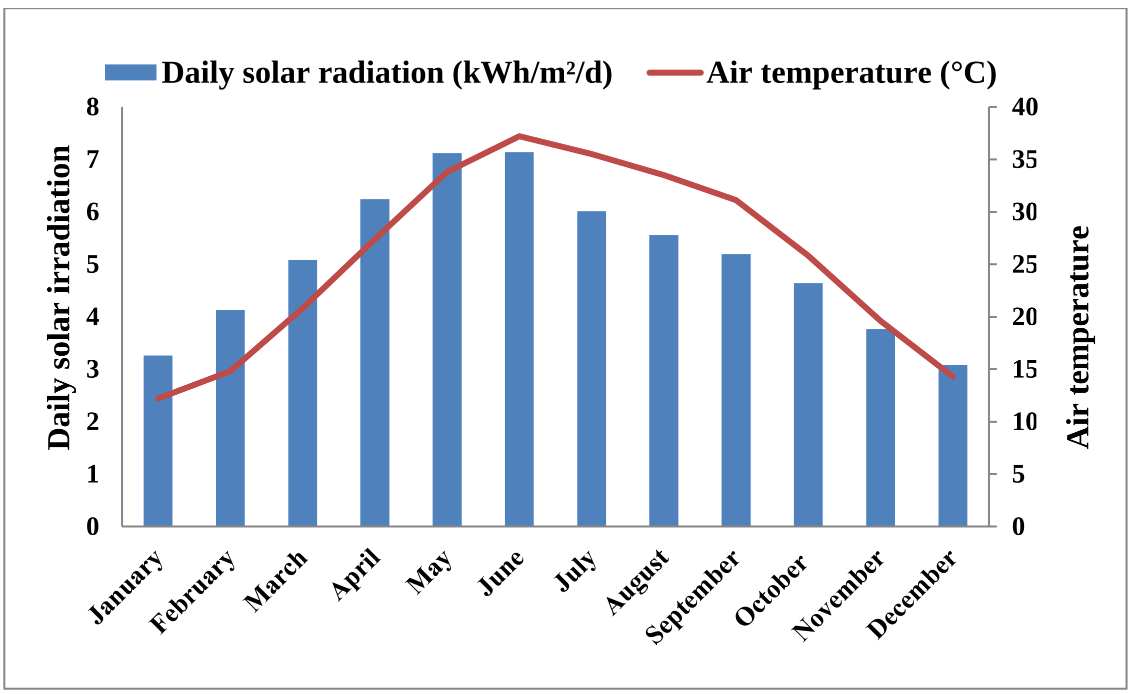


**Figure. 3-3. Solar irradiation and air temperature variation at district Sargodha**

### 3.7.3 System design

The on-grid PV system at Hoffman kiln consisted of PV modules to harness the solar energy during day-time to convert it into electrical energy and inverters to convert direct current (DC) generated by PV modules to alternating current (AC) to feed the loads. In the base case all the electrical loads at the Hoffman kiln were connected to the grid supply.

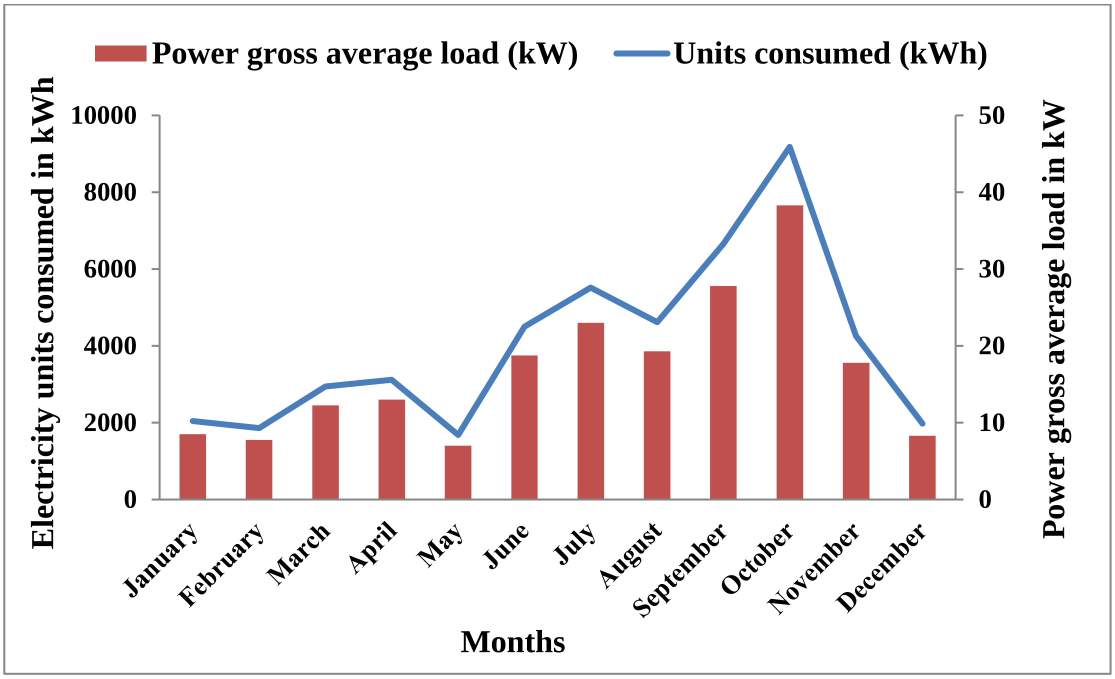


**Figure 3-4: Electricity consumption and average gross power at Hoffman kiln for the year 2020**

Our proposed PV system ensured the continuity of electrical power even during cloudy weather when solar irradiation falls below a certain level halting the power generation, because in that case the AC loads would still be able to get power from the grid. We did not use batteries to store energy because that would have made our system very expensive as batteries take up huge cost of PV system. However, all the loads at the brick kiln were operated during the day-time shift from 8 am to 4 pm so no power was needed to feed the loads at night [18]. The data regarding the consumption of electricity for the year 2020 at the Hoffman Kiln is already shown in the Figure 3-4

### 3.7.4 PV Module selection

The parameter for deciding the capacity of the PV modules at the brick kiln site was primarily based on power gross average load per month in KW that was calculated for the whole year to determine the peak annual load. This value was taken by the following formula given in Eq. 5 also used by Owolabi in a similar study [16].

*Power gross average load per month = Total units consumed in a month / (number of hours the load runs in a day × number of days in a month)………………………………….. (5)*

In denominator of above equation the number of days in a month was multiplied with 8 because all the loads at Hoffman kiln draw electricity only during the single morning shift for sharp 8 hours a day.

Figure 3-4: also shows that the peak annual load for the Hoffman kiln under study is 39 KW. PV module capacity can be calculated by the following formula given in Eq. 6

*PV module power output = Peak annual load (kW) × factor of safety…………………… (6)*

As in our case the factor of safety was 1.3 based on the electrical system losses. The optimal module capacity for our system turned out to be 47 KW. Longi Solar module type was chosen which was the most viable and recommended option for our system. The frame area and efficiency of each PV module unit based on RETScreen data base was 1.635m$^2$ and 17.12% respectively. A total of 168 units were required to meet the demand at the load side. The module slope was fixed at 15° to absorb the maximum solar energy. The electricity export rate to grid was fixed at PKR 11 in consultation with an electricity distribution company and from the guidelines of Ministry of Energy. The characteristics of the module used are given in the table 3-6

**Table 3-6: Characteristics of our selected PV module**

| Parameters | Values |
|---|---|
| Type of PV module | Mono-si |
| Model name | Mono-si-LR6-280W |
| Capacity per unit | 280W |
| Number of units | 168 |
| Efficiency | 17.12 % |
| Frame area | 1.635 $m^2$ |
| Nominal cell operating temperature | 45 °C |
| Temperature coefficient | 0.4 %/°C |
| Solar collector area | 275 $m^2$ |

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# Chapter 4

# Results and discussions

The results of brick production-based emission factors; life cycle assessment and modeling of on-grid photovoltaic system are analyzed in this section. The brick production-based emission factors actually give a general idea about the environmental footprint of each brick production technology by using which an inventory showing the approximate annual emission of each brick kiln type can be calculated. The primary variable in this case will be the number of the bricks produced in a year. Life cycle assessment give an in-depth information about the loopholes or leakages during entire brick making process. In this case all the possible inputs and outputs are considered to analyze their contribution on different impact categories related to marine, soil, forest and terrestrial ecosystems.

## 4.1 Emission factors

**Table 4-1: brick production-based emission factors $EF_P$ for FCBTK, IDZZK and Hoffman kiln based on 1kg roasted brick**

| | **FCBTK** | **IDZZK** | **Hoffman Kiln** |
|---|---|---|---|
| Name of the kiln site | Rehman Bricks Company, Shah Alam | Anwar Bhatta Kasht Company | Saif Ur Rehman Bricks Company |
| Location coordinates | 31.98° N, 71.17° E | 31.60° N, 71.08° E | 32.07° N, 72.68° E |

The analysis of the brick production-based emission factors ($EF_p$) from Table 4-1 signposts that $EF_P$ for carbon monoxide (CO), $PM_{2.5}$ particulates and carbon dioxide ($CO_2$) were highest for FCBTK followed by IDZZK and Hoffman kiln. The emission factor for black carbon released by Hoffman kiln was higher compared to IDZZK as seen from Table 4-1. This could be due to the difference in the quality of coal used at Hoffman kiln compared to IDZZK. However, the coal was not used as the primary fuel in FCBTK and IDZZK as both of them used other fuel additives such as wood chips and sawdust to conserve the fuel-cost

**Table 4-2: Comparison of brick production-based emission factors $EF_P$ with other countries**

| Kiln Type | Country of study | Year of study | Brick kilns | n | Fuel used | $CO_2$ | $SO_2$ | $PM_{2.5}$ | BC | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Conventional | Pakistan | 2021 | FCBTK | 1 | **Coal, sawdust, wood chips, waste tires** | **131** | **1.9** | **1.06** | **0.043** | **Present study** |
| | Nepal | 2017 | FCBTK’s | 4 | Coal, rice husk, briquette | 96 | 1.2 | 0.2 | 0.03 | [1] |
| | | 2011 | FCBTK’s | 3 | Coal, tires, wood logs | 115 | 0.7 | 0.2 | 0.1 | [2] |
| | India | 2011-2012 | FCBTK’s | 3 | Coal and wood | - | - | 0.08-0.3 | 0.09-0.3 | [3] |
| | | 2011 | FCBTK’s | 5 | Coal and others | 179 | 0.5 | 0.9 | - | [4] |
| | Bangladesh | 2017-2018 | FCBTK’s | 10 | Coal and biomass | - | 1.8 | 0.4 | 0.03 | [5] |
| | Bangladesh | 2010 | FCBTK’s | - | Coal and biomass | 173 | 1.5 | 2.3 | 0.9 | [6] |
| | Vietnam | 2007 | Traditional | 2 | Coal | - | 1.5 | 0.5 | - | [7] |
| Improved | **Pakistan** | **2021** | **IDZZK** | **1** | **Coal, saw dust** | **101.6** | **0.41** | **0.24** | **0.02** | **Present study** |
| | | | **Hoffman** | **1** | **coal** | **93.4** | **0.79** | **0.19** | **0.04** | |
| | Nepal | 2017 | IDZZK’s | 3 | Coal, rice husk, sawdust | 82 | 0.9 | 0.1 | 0.01 | [1] |
| | Bangladesh | 2017-2018 | IDZZK’s | 6 | coal | - | 1.1 | 0.4 | 0.02 | [5] |
| | | 2017-2018 | Hoffman | 2 | Coal | - | 1.8 | 0.3 | 0.01 | |
| | India | 2011 | IDZZK’s | 2 | Coal | 103 | 0.3 | 0.1 | 0.04 | [2] |
| | | 2011 | IDZZK’s | 3 | Coal | 96 | 0.2 | 0.2 | - | [4] |
| | | 2011 | VSBK | 1 | Coal | 118 | 0.1 | 0.1 | - | |
| | | 2011-2012 | IDZZK’s | 3 | Coal | - | - | 0.03-0.05 | 0.02-0.004 | [3] |
| | | 2011-2012 | VSBK | 1 | Coal | - | - | 0.05 | 0.002 | |
| | Vietnam | 2011-2012 | DDK | 1 | Wood | - | - | 0.5 | 0.2 | |
| | | 2011-2012 | TK | 1 | Coal | - | - | 0.2 | 0.001 | |
| | | 2011-2012 | VSBK | 1 | coal | - | - | 0.1 | 0.001 | |

Table 4-2 shows the comparison of $EF_P$ with the previous studies conducted in different countries with the purpose to analyze the results from a global perspective. Most of the variations in the values of $EF_p$ of brick kilns across different regions are attributed to high dissimilarity in the consumption of the type of fuel used in the brick firing process. For example, the traditional FCBTK in this study used hard coal, sawdust, wood chips, and waste tires as fuel but on the other hand, Hoffman kiln used hard coal only. Moreover, the energy content of coal, the chemical composition of clay, and the amount of fugitive emissions released from kiln stacks highly vary from region to region. Consequently, the amount of fugitive emissions released highly depends on the leakages, cracks and aging of the kiln stacks. For traditional FCBTK in the present study the value of $EF_p$ for $CO_2$, $SO_2$, $PM_{2.5}$, and BC in the present study turned out to be 36%, 58%, 430%, and 43% greater than that evaluated by Nepal et al., [1] respectively. This is attributed to the use of other fuel additives along with coal such as wood chips and sawdust in FCBTK as Nepal et al., [1] , rice husk and briquettes were also being used alongside coal. $EF_p$ calculated for $SO_2$ in the current study was comparable to several other studies [5]–[7]. This is possible because of the similarity in the amount of sulphur content present in coal used as fuel. Although, $EF_p$ for $PM_{2.5}$ in this study was higher as compared to all the distinctive studies except [6]. This could be attributed to the use of plenty of wood chips and sawdust used in FCBTK as they are the major source of particulate matter emissions.

In the category of improved brick kilns in IDZZK and Hoffman kiln, the $EF_p$ values of $PM_{2.5}$ in all the studies including the present study turned out to be lower as compared to FCBTK because of the exclusion of wood chips as a fuel. $EF_p$ values for $CO_2$ in IDZZK in the present analysis were comparable to other countries [2], [4] with a very slight difference because of using combustion fuel of similar chemical nature. The same value for Hoffman kiln turned out to be slightly lower because they used fly ash along with clay as raw material for making green bricks. Increasing the quantity of fly ash lowers the amount of $CO_2$ released [8]. In this scenario, $EF_p$ value for $CO_2$ at IDZZK in the current analysis was preeminent as compared to the one evaluated by Nepal et al., (2019). This is attributed to the use of rice husk in varying quantities as fuel along with coal at IDZZK in Nepal. The $EF_p$ values for $SO_2$ from IDZZK in this investigation were lower in contrast to evaluations done by Haque et al., [5] and Ncube et al., [8] in Bangladesh and Nepal, respectively. This is because of the variation in the sulphur content present in the hard coal used as fuel. The results of $EF_p$ of $PM_{2.5}$ and Black Carbon (BC) from IDZZK and Hoffman Kiln followed a similar trend except that the values for BC were lower as opposed to the value calculated by Weyant et al., [3] in India. This is because of the considerable dissimilarity in the quality of the coal used in a completely different type of the kiln-Vertical Shaft Brick Kiln (VSBK)

## 4.2. Material and Energy flows

Figure 4-1 gives a generalized visual understanding of inputs, outputs, and wastage across each process in the production of bricks for a better interpretation of LCA outcomes. There are no GHG emissions as such during brick molding phase unless the extraction of clay is taken into account which is beyond the scope of the present analysis. Major emissions are released during roasting process and transportation of red bricks to the consumer end. Primary wastage at molding and roasting phase is of water and heat respectively. The brick wastage due to the transportation of green and red bricks is 8% and 2% correspondingly. Furthermore, the fuel type and green brick-making material may vary from one brick kiln to another depending on the location and operating methodology.

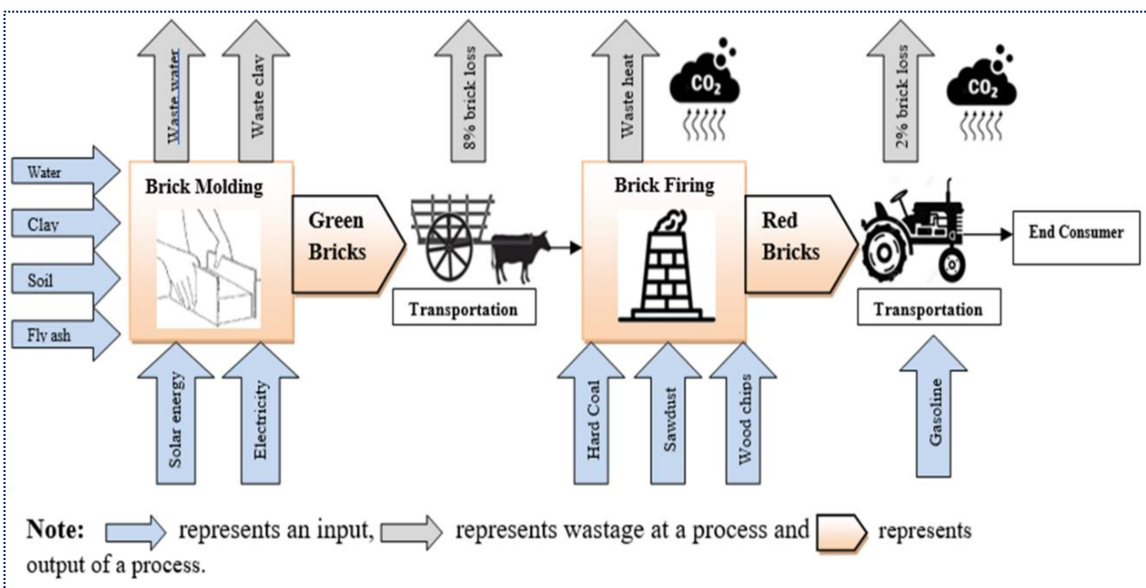


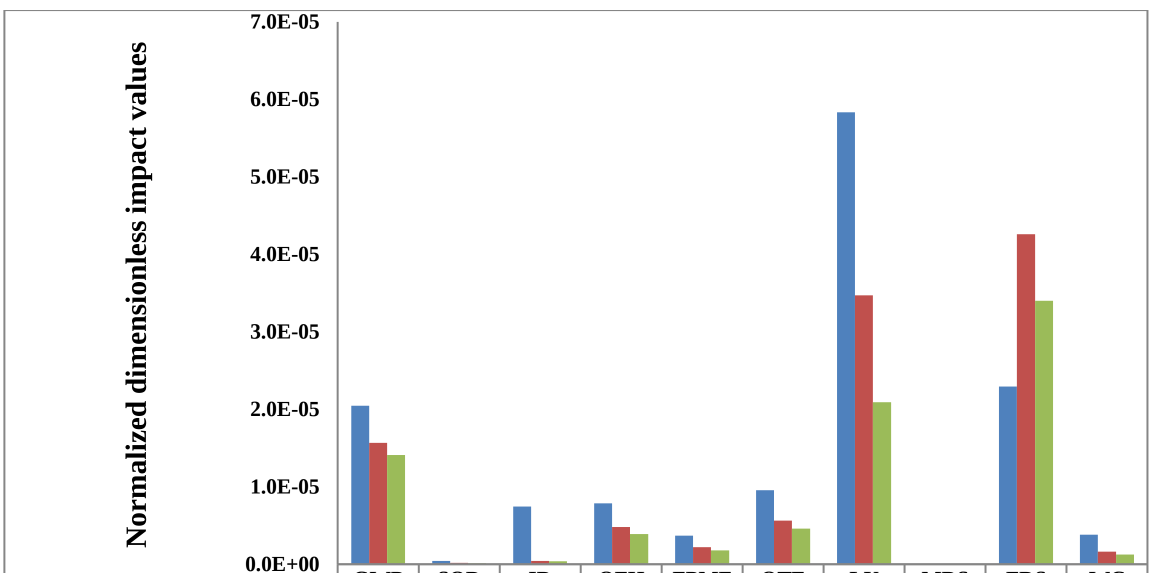

**Figure. 4-1. Generalized material and energy flows at brick kilns**

## 4.3 Life cycle Assessment (LCA) results

Life cycle assessment in SimaPro generates two types of results: preliminary normalized impacts and the characterized impacts.

### 4.3.1 Preliminary normalized results

Preliminary normalized results give a basic visual indication about the impact categories that have been affected the most. These are dimension less values thus they can be summed up to get a total impact value for all the impact categories. The introductory results in Figure 4-2 show that out of 10 impact categories that have been chosen for the impact analysis 2 impact categories- land use and fossil resource scarcity are indicated to be heavily affected by the local emissions from the brick roasting process [9]. This is because green brick molding and roasting process require a lot of land. However the impact on fossil resource scarcity could be due to the fact that most of the coal used as the fuel in coal power plants and brick kilns in Pakistan is imported from South Africa and Indonesia because the coal currently exiting in Pakistan has quality issues that doesn't make it the most viable option to be used as a fuel [10].




| | GWP | SOD | IR | OFH | FPMF | OTE | LU | MRS | FRS | WC |
|---|---|---|---|---|---|---|---|---|---|---|
| FCBTK green brick roasting | 2.0E-05 | 4.4E-07 | 7.4E-06 | 7.9E-06 | 3.7E-06 | 9.6E-06 | 5.8E-05 | 5.6E-08 | 2.3E-05 | 3.8E-06 |
| IDZZK green brick roasting | 1.6E-05 | 1.9E-07 | 4.2E-07 | 4.8E-06 | 2.2E-06 | 5.6E-06 | 3.5E-05 | 5.5E-08 | 4.3E-05 | 1.6E-06 |
| Hoffman green brick roasting | 1.4E-05 | 1.6E-07 | 4.0E-07 | 3.9E-06 | 1.8E-06 | 4.6E-06 | 2.1E-05 | 5.0E-08 | 3.4E-05 | 1.3E-06 |

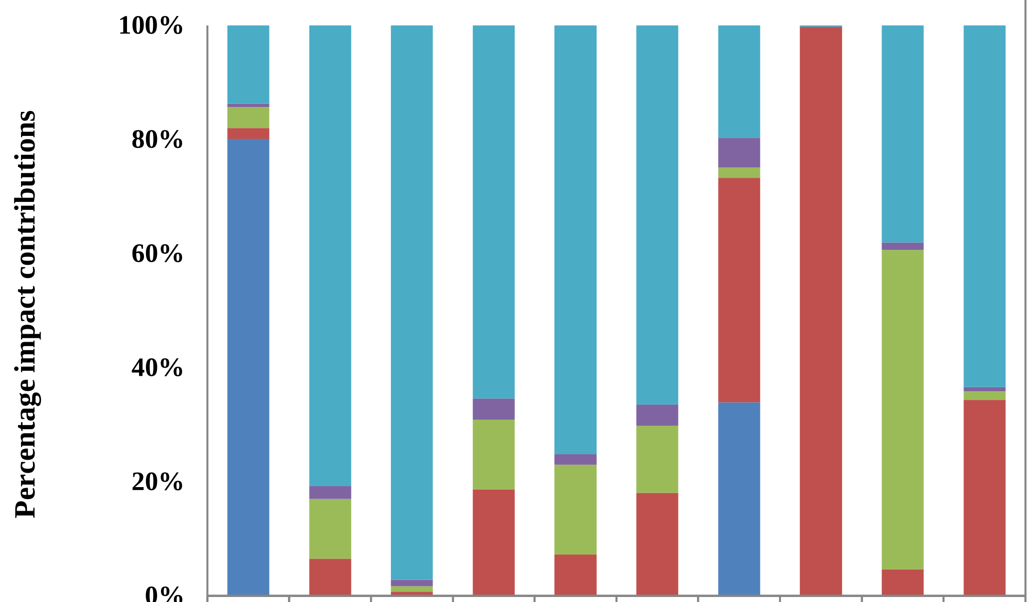
**Figure 4-2: Preliminary normalized results**

### 4.3.2 Characterized impact results

The results of characterized impacts have come with actual values with units for each impact category as shown in the Figure 4-2 thus the values of each impact category cannot be added but can only be analyzed individually.

### 4.3.3 Characterized impacts of FCBTK

Figure 4-3 shows the impacts of all the brick production phases at FCBTK on the 10 impact categories generated by SimaPro. X-axis shows the impact categories to be discussed along with their units based on IPCC equivalence protocols. On y-axis the percentage contribution of brick making stages to these impact categories are displaced. It is clear that the local emissions released from the brick roasting phase are the major contributor to the global warming (80.0983%). It is also noted that at FCBTK the fuel that is used for combustion consists of coal, sawdust, and dry wood chips. Wood chips in this case seemed to be adding huge burden on the environment especially in the case of stratospheric ozone depletion (80.75%), ionizing radiation (97.1742%), ozone formation (65.43%) and water consumption (63.37%). This is due to the fact that wood combustion produces particulate matter that are major cause of the formation of ground level ozone layer that poses serious health threats[11]. In lifecycle approach entire process of the production of wood is taken into account that begins with planting the seedlings for the wood biomass all the way to cutting the trees from heavy machinery and bringing the wood over to the site [12]. Some types of trees not only consume a lot of underground water thus not only decreasing the underground water table but also disrupt the availability of nutrients in the soil [13]. Figure 4-2 also indicates the actual ReCiPe Midpoint (H) generated impact values along with the units related to each category. Global warming and land use are the categories that are highly affected by the local emissions. Since the land required for brick molding is greater than land required for brick roasting thus as evident from the result that brick molding has a greater impact on land use 0.142 m2a crop eq. Hard coal that was used as a fuel heavily impacted the fossil resource scarcity which reflects that fact that Pakistan imports coal from other countries owing to its poor quality coal reserves and lack of financial constraints and technical expertise to find new and better quality reserves [14]. Sawdust had a very small effect on almost all the 10 impact categories.

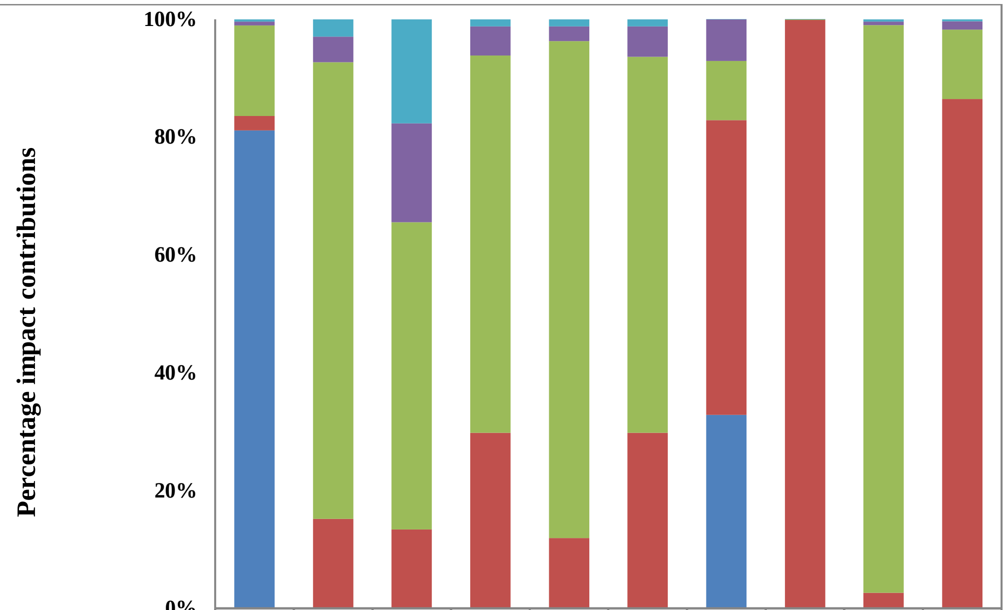



| | kg CO2 eq GWP | kg CFC11 eq SOD | kBq Co-60 eq IR | kg NOx eq OFH | kg PM2.5 eq FPMF | kg NOx eq OTE | m2a crop eq LU | kg Cu eq MRS | kg oil eq FRS | m3 WC |
|---|---|---|---|---|---|---|---|---|---|---|
| Wood chips | 2.2E-02 | 2.1E-08 | 3.5E-03 | 1.1E-04 | 7.1E-05 | 1.1E-04 | 7.1E-02 | 1.7E-05 | 8.6E-03 | 6.5E-04 |
| Saw dust | 9.8E-04 | 6.0E-10 | 4.2E-05 | 5.9E-06 | 1.7E-06 | 6.3E-06 | 1.8E-02 | 2.8E-07 | 3.0E-04 | 7.4E-06 |
| Hard coal | 6.0E-03 | 2.8E-09 | 3.3E-05 | 2.0E-05 | 1.5E-05 | 2.0E-05 | 6.7E-03 | 1.8E-06 | 1.3E-02 | 1.6E-05 |
| FCBTK green brick molding | 3.1E-03 | 1.7E-09 | 2.6E-05 | 3.0E-05 | 6.8E-06 | 3.1E-05 | 1.4E-01 | 6.8E-03 | 1.1E-03 | 3.5E-04 |
| FCBTK green brick roasting | 1.3E-01 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.2E-01 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

**Figure 4-3: Recipe Midpoint (H) characterized impacts calculated for FCBTK referred to a functional unit of 1 kg of produced brick**

### 4.3.4 Characterized impacts of IDZZK

The Figure 4-4 shows the impacts of IDZZK brick production processes on all the 10 impact categories. Hard coal which is used as main source of fuel seemed to be adding burden on several impact categories such as fine particulate matter formation, fossil fuel scarcity and ionizing radiation. As already discussed in the previous case of FCBTK that it has everything to do with all the processes involved from mining and extraction to enrichment and refining of coal which produce toxic chemicals also disrupting marine and fresh water ecology [14], [15]. The basic difference between FCBTK and IDZZK is the installation of a Zigzag fan in the chimney that artificially induces draught and improves combustion and fuel conversion efficiency. The zigzag fan at IDZZK under our consideration consumed 125 kWh per day and was the only electrical equipment used in the kiln. Unlike FCBTK the fuel used in IDZZK was composed of only hard coal and saw dust. Wood chips were not used as a fuel. Brick molding process had the highest impacts on water consumption, mineral resource scarcity and land use. This is consequent of water that is not only higher for each brick produced here compared to FCBTK, but also more land is required to produce green bricks. Figure 4-3 also shows that in IDZZK the impact value of local emissions (brick roasting phase) on global warming is lower in contrast to FCBTK. For FCBTK the value was 0.131 kg $CO_2$ eq. For IDZZK it is 0.1016 kg $CO_2$ eq. Since only a single fan is used in the kiln so the effect of electricity on all the impact categories is negligible.

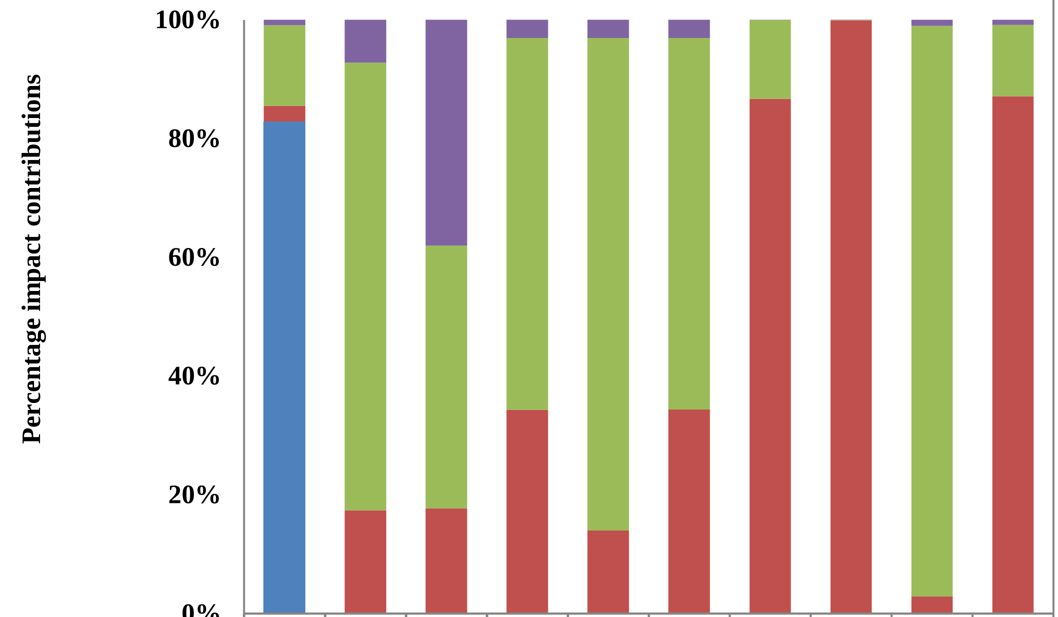



| | kg CO2 eq GWP | kg CFC11 eq SOD | kBq Co-60 eq IR | kg NOx eq OFH | kg PM2.5 eq FPMF | kg NOx eq OTE | m2a crop eq LU | kg Cu eq MRS | kg oil eq FRS | m3 WC |
|---|---|---|---|---|---|---|---|---|---|---|
| Electricity | 4.9E-04 | 3.3E-10 | 3.6E-05 | 1.2E-06 | 6.8E-07 | 1.2E-06 | 4.6E-06 | 3.4E-08 | 1.6E-04 | 1.4E-06 |
| Saw dust | 8.0E-04 | 4.9E-10 | 3.4E-05 | 4.8E-06 | 1.4E-06 | 5.2E-06 | 1.5E-02 | 2.3E-07 | 2.4E-04 | 6.1E-06 |
| Hard coal | 1.9E-02 | 8.8E-09 | 1.1E-04 | 6.3E-05 | 4.7E-05 | 6.4E-05 | 2.2E-02 | 5.8E-06 | 4.0E-02 | 5.1E-05 |
| IDZZK green brick molding | 3.1E-03 | 1.7E-09 | 2.7E-05 | 2.9E-05 | 6.7E-06 | 3.0E-05 | 1.1E-01 | 6.6E-03 | 1.1E-03 | 3.7E-04 |
| IDZZK green brick roasting | 1.0E-01 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 7.0E-02 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

**Figure 4-4: Recipe Midpoint (H) characterized impacts calculated for IDZZK referred to a functional unit of 1 kg of produced brick**.

### 4.3.5 Characterized impacts on Hoffman Kiln

This recently established brick kiln in Pakistan is only one and unique in terms of the fact that it uses electrical machinery in every stage of brick production. This not only reduces clay losses but also increases brick production efficiency. The Hoffman kiln turned out to be most environmentally efficient compared to FCBTK and IDZZK. Since hard coal was the only fuel that was used for combustion in the roasting area, its impact on the selected 10 impact categories can be seen in the Figure 4-5. The total land required for brick molding process is quite larger as compared to roasting process. Therefore, molding has 86.7043% impact on the land use. Also, the green brick production in molding process requires a lot of water so impact of molding process on water consumption turned out to be (87.12%). Here electricity consumption seemed to have a minimal effect on fine particulate matter formation (3.032%) as a considerable portion of grid electricity being consumed in Hoffman kiln also includes the electricity generated from coal in coal power plants. Some coal power plants contribute to particulate matter production due to the lack of efficient methods for filtering eco-toxic chemicals before getting released into the atmosphere [16] Figure 4-4 also shows the actual characterized impact values of impacts of Hoffman kiln brick making process along with the units. It is evident that the effect of local emissions on global warming in case of Hoffman kiln is 0.0934 kg $CO_2$ eq. which is smaller as compared to FCBTK (0.131 kg $CO_2$ eq.) and IDZZK (0.1016 kg $CO_2$ eq.).




| | kg CO2 eq<br>GWP | kg CFC11 eq<br>SOD | kBq Co-60 eq<br>IR | kg NOx eq<br>OFH | kg PM2.5 eq<br>FPMF | kg NOx eq<br>OTE | m2a crop eq<br>LU | kg Cu eq<br>MRS | kg oil eq<br>FRS | m3<br>WC |
|---|---|---|---|---|---|---|---|---|---|---|
| Electricity | 9.9E-04 | 6.7E-10 | 7.3E-05 | 2.4E-06 | 1.4E-06 | 2.5E-06 | 9.3E-06 | 6.8E-08 | 3.3E-04 | 2.8E-06 |
| Hard coal | 1.5E-02 | 7.0E-09 | 8.5E-05 | 5.0E-05 | 3.8E-05 | 5.1E-05 | 1.7E-02 | 4.6E-06 | 3.2E-02 | 4.0E-05 |
| Hoffman green brick molding | 3.0E-03 | 1.6E-09 | 3.4E-05 | 2.8E-05 | 6.4E-06 | 2.8E-05 | 1.1E-01 | 6.0E-03 | 9.6E-04 | 2.9E-04 |
| Hoffman green brick roasting | 9.3E-02 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

**Figure 4-5: Recipe Midpoint (H) characterized impacts calculated for Hoffman kiln referred to a functional unit of 1 kg of produced brick.**

### 4.3.6 Green Brick Roasting Comparison

Figure 4-6 indicates that out of total 10 impact categories as generated by SimaPro there are 9 categories in which the local emissions that are released from the roasting process in FCBTK have highest effect compared to IDZZK and Hoffman kiln. Only one impact category that is the fossil resource scarcity turned out to be more burdened by IDZZK. This is because of more coal per 1kg brick is used as a fuel for roasting green bricks in IDZZK compared to FCBTK and Hoffman Kiln. Since SimaPro takes into account all the stages regarding bringing the coal from underground reserves to the brick kiln site and FCBTK also uses sawdust and wood chips are fuel along with the coal, so FCBTK has least impact on fossil resource scarcity.

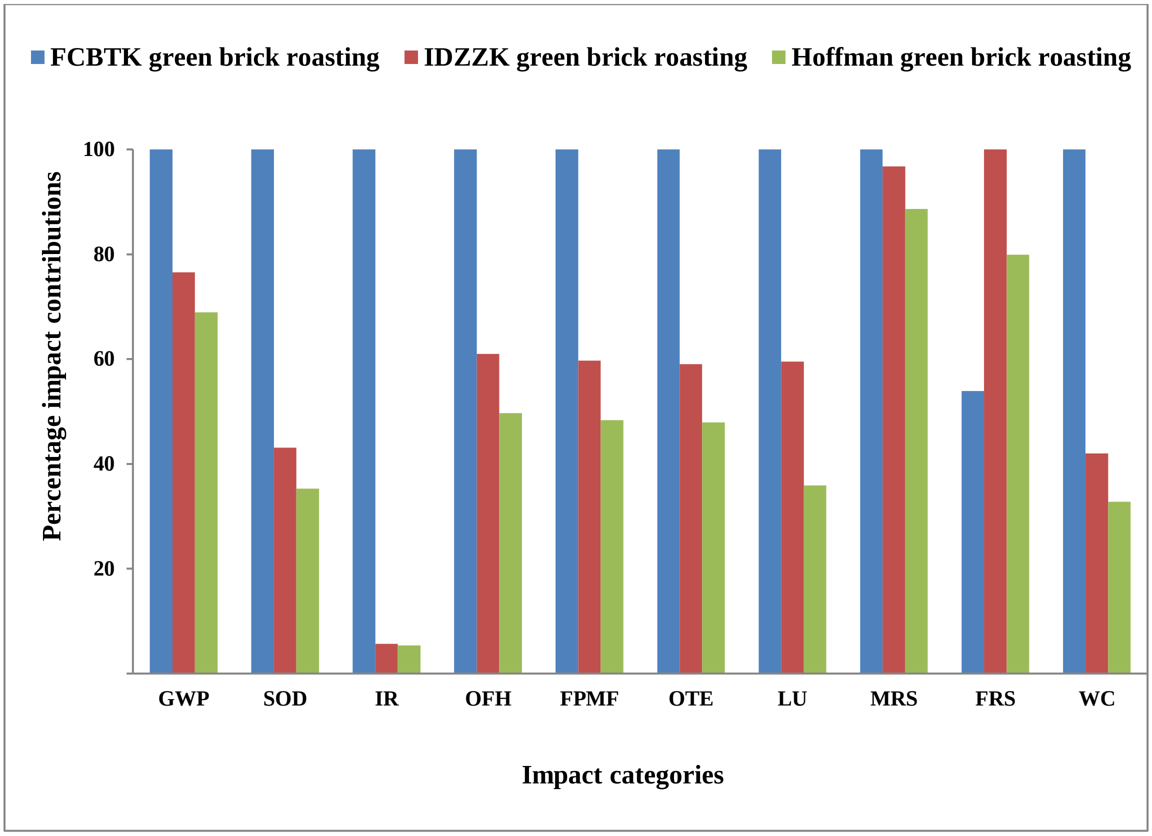



**Figure 4-6: Comparison of the characterized impacts of roasting phase of all the three brick kilns**

### 4.3.7 Green brick molding comparison

Figure 4-7 shows that global warming; fine particulate matter formation and 4 other impact categories are affected highest by FCBTK and least by Hoffman kiln in green brick molding process. In other impact categories such as ionizing radiations where Hoffman kiln caused more impact compared to FCBTK could be due the use of fly ash along with the clay for making green bricks.

Fly ash has mostly been collected as a waste that is left after burning of coal in coal power plants, so its impact is indirectly linked to the consumption of coal. The impact of IDZZK is highest in the impact category of water consumption because the quantity of water used per 1 kg brick to produce green bricks is highest in case of IDZZK

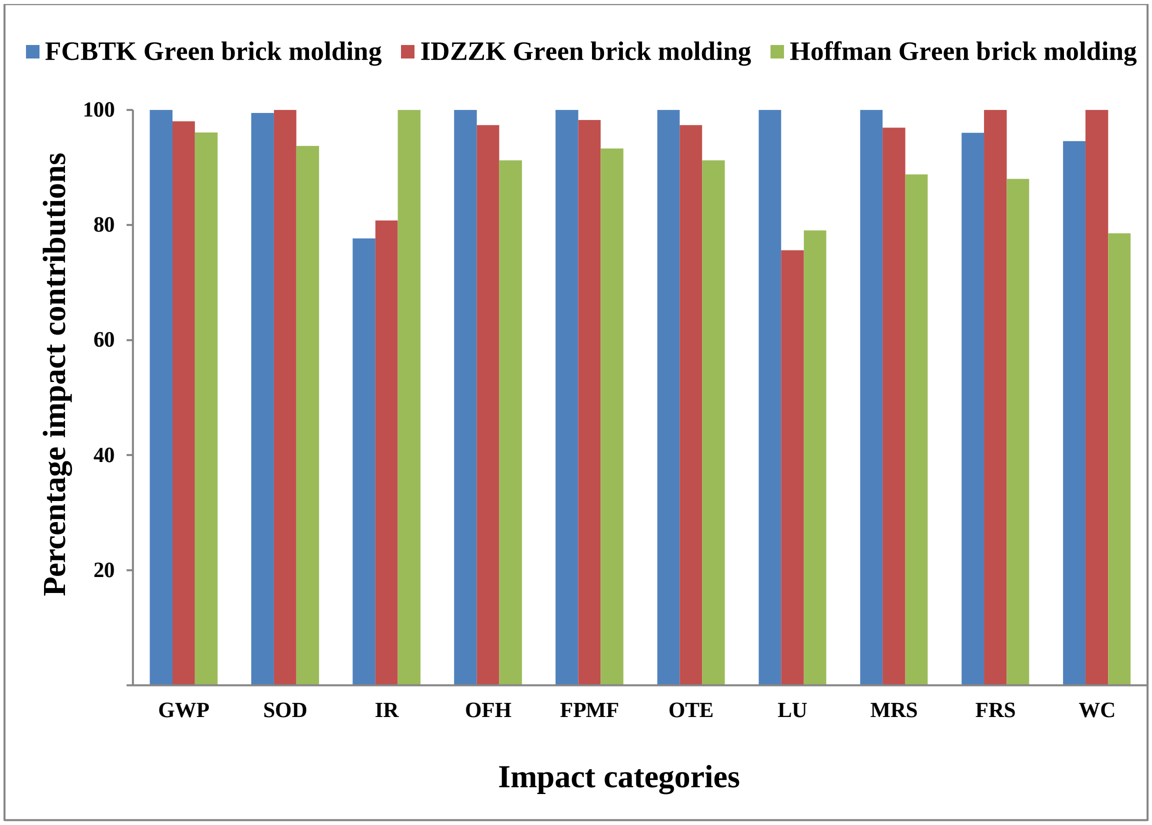



**Figure 4-7: Comparison of the characterized impacts of molding phase of all the three brick kilns**

### 4.3.8. Endpoint Impacts

The overall impact of the selected impact categories is expressed into endpoint environmental impacts: resources; ecosystems and human health. It is evident from Figure. 4-8 that the FCBTK brick kiln technology has the highest overall environmental impact due to the extraction of virgin resources such as clay and sandy soils leading to the destruction of natural ecosystems. Human health impacts are due to release of dust particles into the atmosphere causing respiratory problems. Overall, the Hoffman kiln has least environmental impact compared to other kilns namely FCBTK and IDZZK.

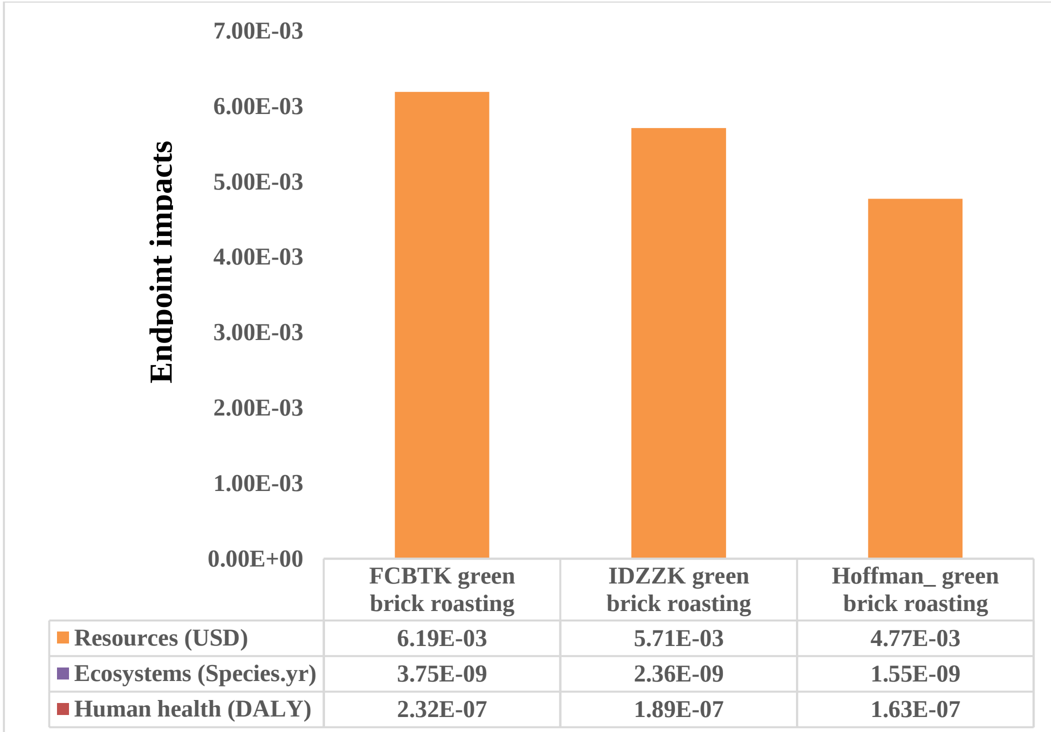



**Figure 4-8. Endpoint impacts of the selected brick kilns**

### 4.3.9. Sensitivity and Uncertainty analysis

Several factors can influence the quality of data which may affect the overall results of the LCA study [17]. In this context, a Monte Carlo uncertainty assessment at the 95% confidence interval was performed using the SimaPro software to test the reliability and robustness of the results (Table 4-3). FCBTK has the highest impact on the environment primarily due to the use of coal and other cheap fuels such as waste tires. The proposed case scenario for the replacement of such fuel at FCBTK is biomass. Table refers to the uncertainty analysis of 1 kg roasted brick produced by FCBTK with biomass (A) vs. the FCBTK based on coal (B). The analysis indicates the values of mean, standard deviation (SD), coefficient of variation (CV, defined as the ratio between the SD and the mean), and standard error of the mean (SEM, defined as the standard deviation of the sampling distribution of the mean). CV ranges of 5–51% are regarded as lower variations and it included the following impact categories: FPMF, FRS, GWP, LU, MRS, and WC. SOD and those much higher than 51% which shows a higher uncertainty range require additional refinement through further checks and studies.

**Table 4-3**

**Results of Monte Carlo uncertainty analysis related to upgrading FCBTK with biomass (A) vs. the coal-based kiln (B)**

| Impact category | A >= B | Mean | Median | SD | SEM | CV% |
|---|---|---|---|---|---|---|
| FPMF | 100 | 7.79E-05 | 7.61E-05 | 1.47E-05 | 4.66E-07 | 18.90% |
| FRS | 0.2 | -5.51E-03 | -5.55E-03 | 1.27E-03 | 4.00E-05 | 23.00% |
| GWP | 100 | 4.51E-02 | 4.33E-02 | 8.87E-03 | 2.81E-04 | 19.66% |
| IR | 100 | 1.32E-03 | 7.25E-04 | 1.90E-03 | 6.02E-05 | 143.93% |
| LU | 100 | 7.79E-01 | 7.71E-01 | 6.77E-02 | 2.14E-03 | 8.69% |
| MRS | 100 | 1.68E-04 | 1.64E-04 | 1.67E-05 | 5.27E-07 | 9.94% |
| OFH | 100 | 1.17E-04 | 8.69E-05 | 9.67E-05 | 3.06E-06 | 82.64% |
| OTE | 100 | 1.19E-04 | 8.89E-05 | 9.67E-05 | 3.06E-06 | 81.26% |
| SOD | 100 | 5.04E-07 | 4.08E-07 | 2.94E-07 | 9.28E-09 | 58.30% |
| WC | 100 | 1.44E-02 | 1.45E-02 | 2.84E-03 | 8.99E-05 | 19.72% |

## 4.4. Economic statistics

All the three brick kilns under analysis marginally differ in terms of proportions of brick production qualities with A-Grade being the premium and C-Grade being the lowest priced brick with the most undesirable quality based on the consumer demand. The quality of brick is evaluated by the uniformity of firing and even distribution of heat.

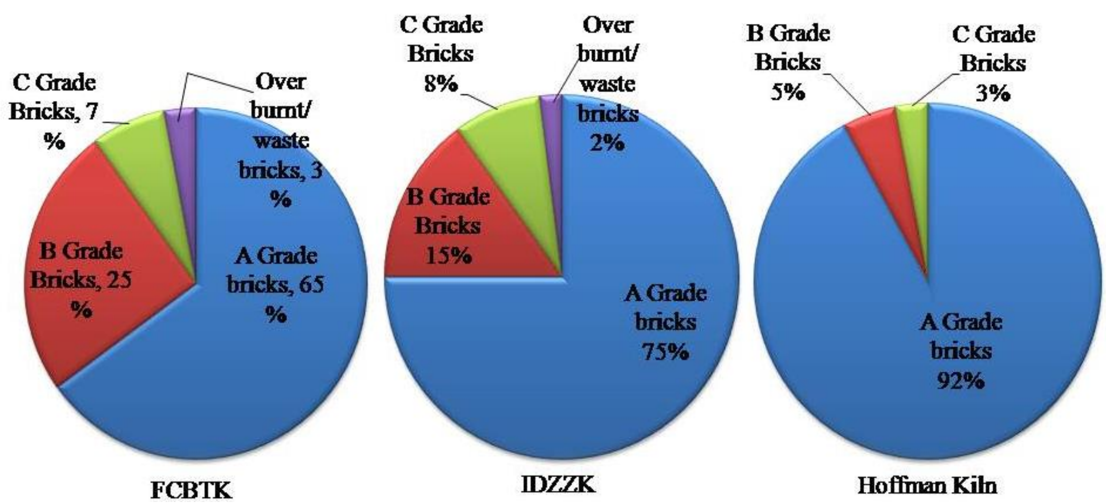



**Figure 4-9. Comparison of the percentage of different brick qualities**

For an equal number of bricks produced by all the three kilns, the largest chunk of premium quality bricks-A Grade bricks is produced by Hoffman kiln which ultimately results in their high-profit margins compared to FCBTK and IDZZK (Figure. 4-9). The improved combustion technologies at Hoffman kiln led to uniform distribution of oven temperature and even roasting of bricks. Consequently, there is negligible red brick wastage at Hoffman Kiln which is 3% and 2 % at FCBTK and IDZZK, respectively.

The Hoffman kiln overtakes FCBTK and IDZZK in terms of annual profit margins owing to the higher price of the production of 92% A-Grade bricks. This helps them recover their initial start-up costs in a shorter span of time. FCBTK and IDZZK largely rely on both A and B-Grade bricks to generate revenue. The variations of price per brick concerning brick quality for all the kilns are shown in Figure. 4-10.

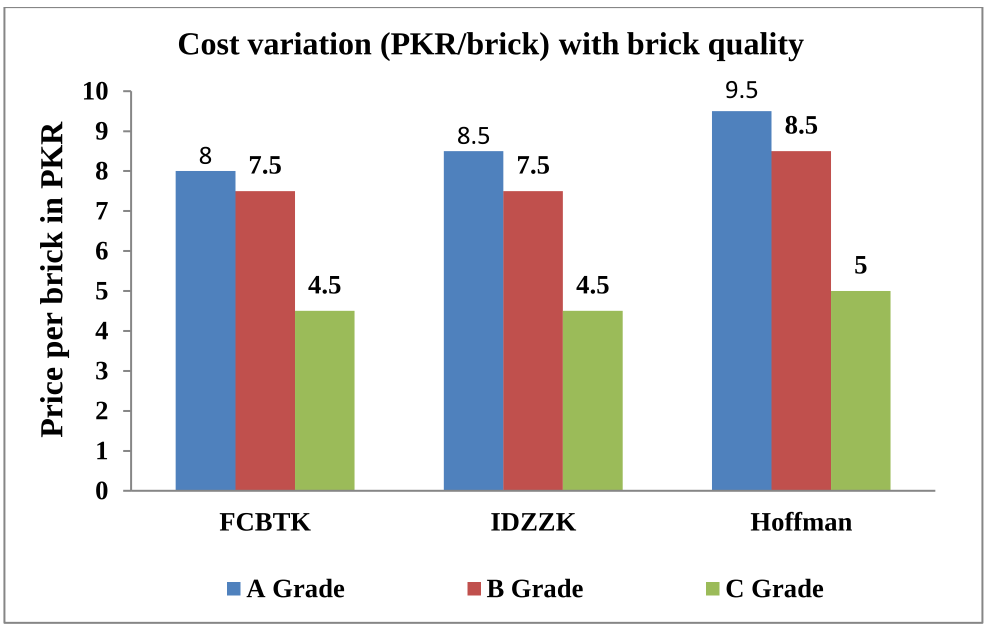



**Figure 4-10. Comparison of the cost of different brick qualities**

Figure 4-11 shows the initial project costs for the three kilns under analysis in Pakistani Rupees (PKR). The initial cost is subdivided into capital cost and working capital. Hoffman kiln overtakes FCBTK and IDZZK in terms of total project start-up cost. Capital cost is the added cost of land, electrical machinery, and infrastructure. The major proportion of capital cost in case of IDZZK is the land cost because hand-molded bricks require ample space for sun-drying, but in Hoffman kiln cost of imported electrical equipment takes up a big chunk of capital cost. FCBTK in this scenario requires the least capital cost (PKR 18 million) in contrast to the other two kilns. Working capital includes the cost of equipment spare parts and raw materials to be used for the foregoing year. FCBTK requires more than PKR 4 million worth of working capital followed by IDZZK and Hoffman kiln that require PKR 5.79 million and PKR 7.82 million respectively.

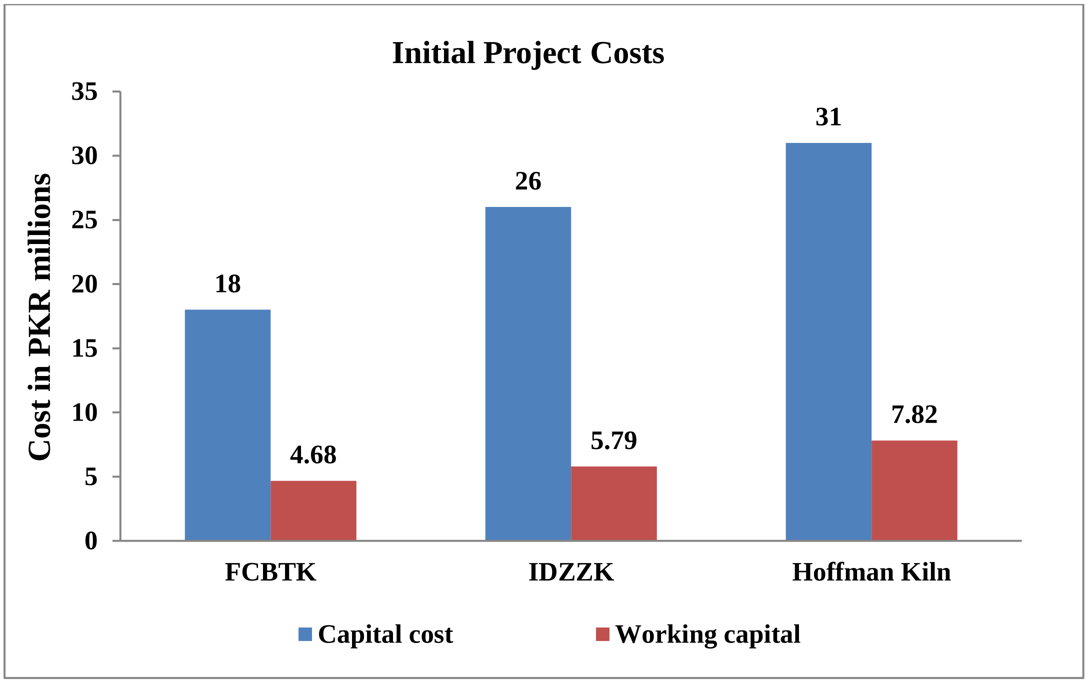



**Figure 4-11. Comparison of the initial project costs**

Figure 4-12 shows the comparative information related to the profit margins of the existing brick kilns technologies. Hoffman kiln, owing to more than 90% production of A-Grade bricks results in the highest profit margins with a net income of PKR 11.2 million. Figure 4-12 compares the values of annual sales revenue, gross profit and net income generated by FCBTK, IDZZK, and Hoffman kiln. Gross profit (GP) is annual revenue minus cost of sales which mostly includes the cost of raw material and advance payment of labor hired on contract. Net income is GP minus all applied taxes. However, these annual costs are subject to variations in the type and cost of equipment, raw material and fuel even across different kilns operating with similar technology. These figures just give an overview and only represent the economic statistics of kilns taken under analysis and thus cannot be generalized to all the FCBTKs and IDZZKs currently functional in the country.

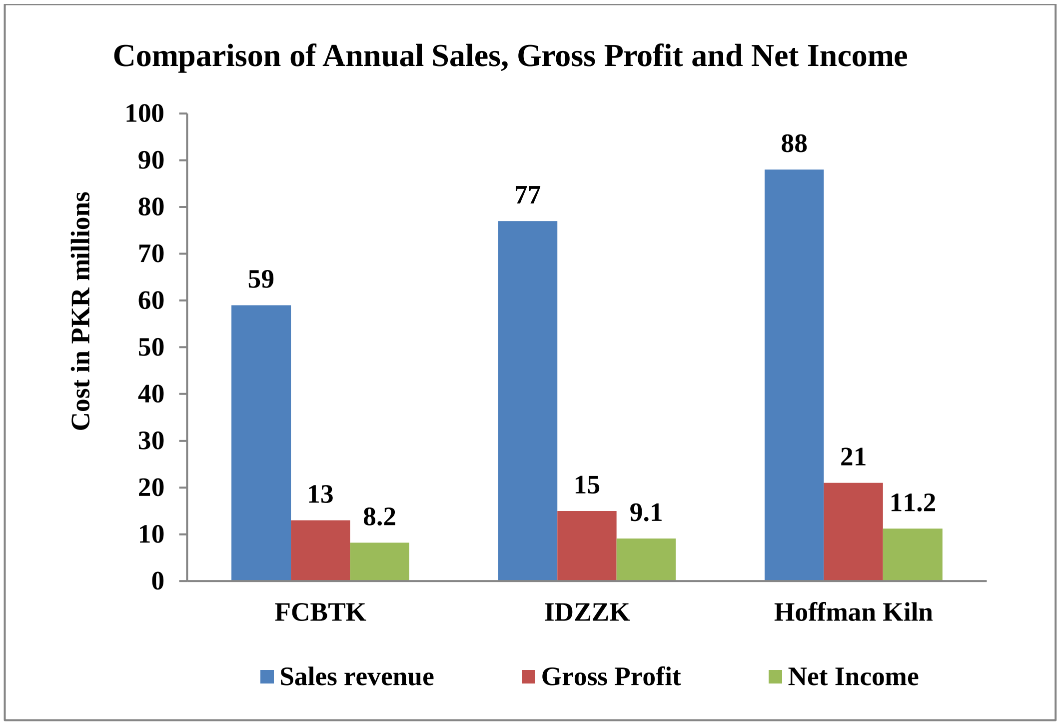



**Figure 4-12. Comparison of annual sales, gross profit, and net income**

## 4.5 Photovoltaic Project viability

All the loads at the Hoffman kiln were connected to the electricity generated by the PV modules. The table 4-4 shows that not only the electricity delivered to the loads is more than the calculated average demand per month (4030 kWh) but also considerable amount of electricity is exported to the grid.

It is also evident from the Table 4-4 those daily solar radiations are the highest in the months of May and June. The electricity delivered to the load and exported to the grid also increase with increasing solar radiation. The total units delivered to the load annually are 64284.083 kWh. This value is higher than the units consumed by the load when connected to only grid electricity (48360 kWh). The net electricity exported to the grid with export rate of PKR 11 per kWh is 260.627 kWh.

**Table 4-4: PV module summary of electricity delivered to load and exported to grid**

| **Months** | **Daily solar radiation (horizontal) (kWh/m$^2$/day)** | **Total Electricity production (kWh)** | **Electricity exported to grid (kWh)** | **Electricity delivered to load (kWh)** |
|---|---|---|---|---|
| January | 3.26 | 4415 | 18 | 4397 |
| February | 4.13 | 4598 | 19 | 4579 |
| March | 5.08 | 5696 | 23 | 5673 |
| April | 6.24 | 6164 | 25 | 6139 |
| May | 7.12 | 6710 | 27 | 6683 |
| June | 7.14 | 6294 | 25 | 6268 |
| July | 6.01 | 5642 | 23 | 5619 |
| August | 5.56 | 5452 | 22 | 5430 |
| September | 5.19 | 5239 | 21 | 5218 |
| October | 4.64 | 5367 | 22 | 5345 |
| November | 3.76 | 4719 | 19 | 4700 |
| December | 3.08 | 4249 | 17 | 4232 |
| **Annual** | **5.10** | **64545** | **261** | **64283** |

### 4.5.1 Cost Analysis

Table 4-5 below shows the cost input parameters for financial analysis. The total life of the project was assumed to be 2 years [18]. Total initial costs included the cost of the inverter, electricity cables, structure cost and the cost of the civil works and labor. O&M cost was PKR 75000 and was to be paid annually. Electricity export escalation rate was taken 2% considering the economic situation of the country.

**Table 4-5: Financial input parameters**

| Input parameters | Values |
|---|---|
| Fuel cost escalation rate | 3% |
| Inflation rate | 8.4% |
| Discount rate | 7% |
| Reinvestment rate | 9% |
| Project life | 25 yr. |
| Dept ratio | 70% |
| Dept interest rate | 10% |
| Dept term | 15 years |
| Electricity export rate | PKR 11/kWh |
| Electricity export escalation rate | 2% |
| Total initial cost (one time) | PKR 4737200 |
| Yearly operation and maintenance (O&M) cost | PKR 75000 |
| Dept payment | PKR 387411/year |

In the software modeling of a PV system, it is highly critical to take into account the economic sustainability of the proposed project. RETScreen contains a worksheet designed for financial analysis of the project. The financial parameters incorporated in the 'finance' worksheet that take values as input variables from the user include initial cost as well as operation and maintenance (O&M) cost. The values of the other input parameters such as debt ratio, discount rate and inflate rate are directly taken from RETScreen software. The financial output parameters and yearly cash flows for the proposed case of PV module as shown in Table 4-6 and Figure 4-13 respectively, show that our proposed project is financially viable considering the fact that the simple payback is in 3 years and benefit to cost (B-C) ratio is 12.2. The minimum B-C ratio that makes a project financially viable to the investors is 1.0. It can be seen that if all the electrical loads convert at our Hoffman Kiln are converted into solar power, we cannot not only save cost and taxes to be paid to grid electricity distribution company but can also reduce ample $CO_2$ emissions at the grid side that are being discussed in the section 4.5.2

**Table 4-6: Financial output parameters**

| Financial output parameters | Values |
|---|---|
| Pre-tax internal rate of return on equity (IRR) | 84.8 % |
| Pre-tax modified internal rate of return on equity (MIRR) | 19.5 % |
| Simple payback | 3yr |
| Equity payback | 1.2yr |
| Net present value | PKR 15962270 |
| Annual life cycle savings | PKR 1369731 |
| Benefit cost (B-C) ratio | 12.2 |
| Debt service coverage | 3.7 |

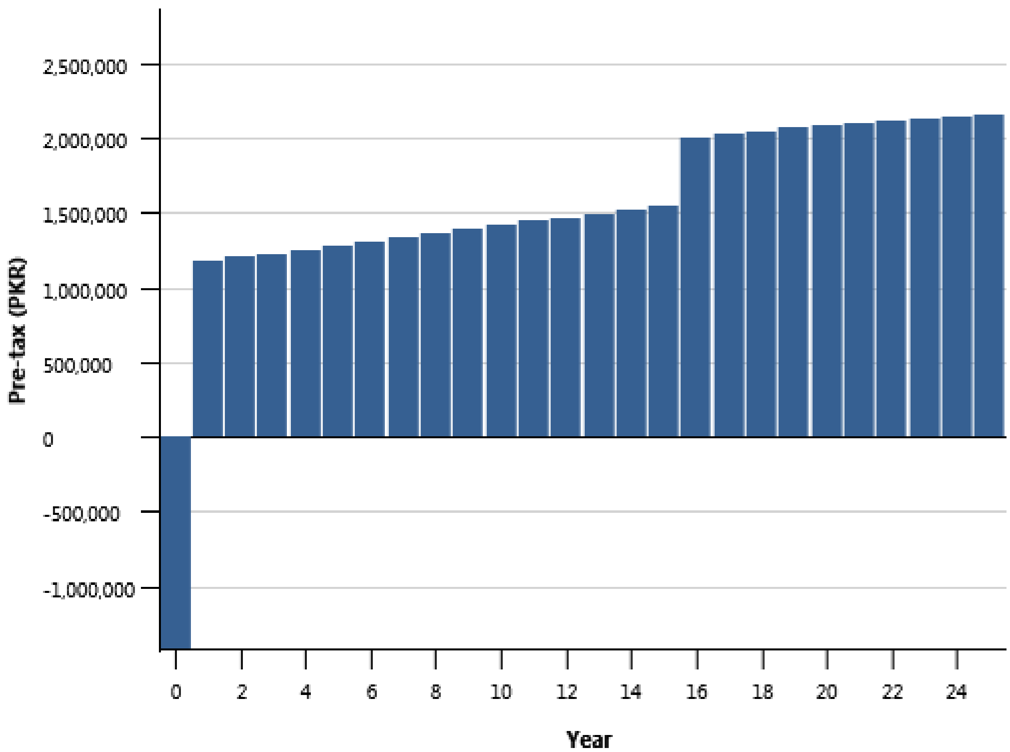



**Figure 4-13: Yearly cash flows of proposed case of PV module**

### 4.5.2 Emission Analysis of proposed PV project

The Figure 4-14 shows that our proposed project does not emit $CO_2$. The base case emissions were 66 tons of $CO_2$ per year which now after the integration of PV system have reduced down to 0. When the system is only connected to the grid it is called base case. As our proposed life of the project is 20 years, by that time 1326 tons of $CO_2$ could be saved at the grid side which will be one step of contribution towards achieving sustainable development goals (SDG's) as framed by United Nations [19], [20]

| **GHG emission** | | |
|---|---|---|
| Base case | $tCO_2$ | 66.3 |
| Proposed case | $tCO_2$ | 0.0 |
| **Gross annual GHG emission reduction** | $tCO_2$ | 66.3 |

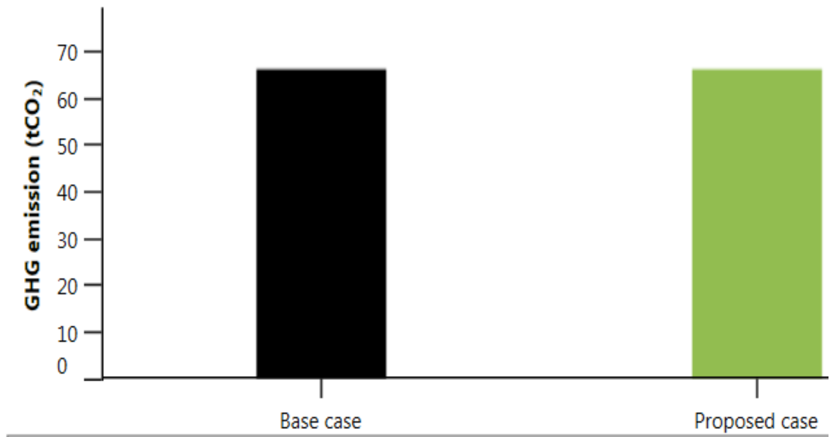



**Figure 4-14: $CO_2$ emissions due to base and proposed case**

RETScreen analysis also showed that the amount of $CO_2$ (66.3 tons) reduced in a year at the grid side by our proposed case of PV integration at just one Hoffman brick kiln is equivalent to the following changes in one year

- 12.1 cars and trucks not being used
- 28468 liters of gasoline not being used
- 154.1 barrels of crude oil not being consumed
- 15.1 Acres of forest absorbing carbon
- 22.8 tons of waste recycled

We did not consider the revenue generated in terms of carbon credits by the reduction of $CO_2$ emissions due to some data constraints.

## Summary

In this section it has been concluded that Hoffman kiln has turned out to be the most environmentally friendly technology compared to FCBTK and IDZZK. We performed Life Cycle Assessment on SimaPro on all the three brick kilns to analyze the detailed environmental impacts. 10 impact categories were chosen based on the relevance to the environmental issues of our country. PV modeling at Hoffman kiln on RETScreen resulted in the reduction of 66 tons of $CO_2$ per year at the grid side. From the cash flow analysis, it has also been concluded that the project is financially viable.

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# Chapter 5

# Conclusions and Recommendations

## 5.1 Conclusions

The LCA of three different technology brick kilns in Pakistan demonstrates that FCBTK is not sustainable technology for the environment. It releases harmful pollutants in quantities that can pose a serious threat to the health of humans, animals, and plants in the vicinity. IDZZK produces fewer amounts of pollutants but still the emissions altogether cannot be eliminated until the main source of emissions i.e., hard coal is replaced with some clean and renewable fuel. Hoffman kiln is the most suitable in all the three brick kiln types as the pollutants released into the environment are lowest, the losses of clay at green brick production stage are also reduced and process efficiency at every production step is high. Among the three kilns, Hoffman kiln turned out to be the most environmentally efficient kiln in contrast to FCBTK and IDZZK where green brick production is done by hand labor by molders that results in clay losses and poor brick production efficiency. Hoffman kiln has well-structured electrical machinery that makes the production process more efficient and effective. However, the number of roasted bricks produced in Hoffman kiln is less than number of roasted bricks produced in IDZZK. But this number could be increased by increasing the plant capacity to double shift as during the study the kiln was only working on single 8-hour shift. To make the brick production process sustainable it is necessary to replace coal in all the kilns with a fuel that does not emit harmful greenhouse gases in the atmosphere. Shifting all the 3 phase electrical loads at Hoffman Kiln on solar energy can reduce the emissions on the grid side to generate considerable environmental benefits. For this we performed an analysis on RETScreen software which showed that constructing Hoffman brick kilns in the future and converting all the electrical loads on the solar energy can contribute a lot towards sustainability of the brick kiln making industry. Conclusively, our study analyzed Hoffman kiln technology as the best performing technology among three brick kiln types currently operating in Pakistan. However, in order to further reduce the emissions, the replacement of coal with some cleaner fuel such as biomass is required

## 5.2 Future recommendations

To make the brick production process sustainable it is necessary to replace coal in all the kilns with a fuel that does not emit harmful greenhouse gases in the atmosphere. One such potential fuel can be non-wood agro-based biomass produced from specifically developed "Arundo Donax" plants. It is bamboo like cane that can grow up to 10 meters [1]. It also has a wide adaptability and resistant to flood, fires, and cyclones. It has a high heating value HHV of 18 MJ/Kg and growth rate of 4 to 6 meters per year. The various simulations on replacement fuel were not considered but it is under investigation by many private sector organizations to use it as a renewable fuel in cement kilns, brick kilns, thermal power plants and other industries running on coal [2]. Based on the research conducted by the previous literature it can be deduced that growing algae around the brick kilns can sequester the $CO_2$ released by the brick kilns and can improve the safety of the workers[3]. However, the actual software-based simulation for replacing it with coal for all the brick kilns was left for future research considerations.

The government of Pakistan should offer a favorable ecosystem by facilitating and incentivizing the owners of Hoffman kilns to establish new kilns and conveniently import the equipment. Moreover, converting currently operating old and inefficient kilns into Hoffman kiln technology can benefit particularly the low-and middle-income countries by providing them the opportunity to reduce the number of harmful greenhouse gases in the atmosphere with suitable returns on the initial investments. A regulatory authority should be established that can inspect the fuel quality and set a standard for good quality fuel used in kilns. The use of wood chips and waste tires should be banned. The use of fly ash for making green bricks should be promoted. Using fly ash at the brick kilns can be an opportunity to solve the global problem of disposal of waste fly ash [4]. Social campaigns need to be organized specifically in rural settings demonstrating the menace of using poor quality fuel in kilns to vitalize suitable technology transfer to modern-day efficient kilns

The future scope of this study is to analyze the replacement of clay with such green brick production materials that release fewer emissions on combustion such as fly ash and scrap plastic as both materials can not only reduce the production cost but are also eco-friendly when transformed into useful construction materials for green fields.

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# Appendix 1

# Prospects Towards Sustainability: A Comparative Study to Evaluate the Environmental Performance of Brick Making Kilns in Pakistan

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## Abstract

For years the brick kiln industry has been perceived as the main stationary source of environmental pollution. Life cycle assessments (LCA) are necessary to comprehend and improve process leakages and environmental risks associated with the expansion of this sector. The present study offers a comparative approach to analyze economic statistics and environmental impacts of three different brick-making technologies in Pakistan. Emission factors for various pollutants were calculated from the three brick kilns followed by determining the concentration of various pollutants. Simard software was used to perform LCA analysis on all stages of brick making at selected brick kilns sites. At the Hoffman kiln, the brick production-based emission factors for CO, PM2.5, CO2, and $SO_2$ resulted in 33%, 82%, 29%, and 58% reduction compared to the Fixed Chimney Bull's Trench Kiln (FCBTK) technology. The characterized impacts indicated that woods chips burdened 9 out of 10 impact categories at FCBTK while at Induced Draught Zigzag Kiln (IDZZK) and Hoffman kiln, the hard coal turned out to have a major negative influence on the environment. An on-grid photovoltaic (PV) system of 47 kW at Hoffman kiln was modeled on RETScreen expert software generating a total of 64544 kWh units of electricity, delivering 64284 kWh to the kiln load, and exporting 260 kWh back to the grid on annual basis. The system generated substantial financial and environmental benefits with the payback time of 3 years, benefits to cost ratio of 12.2, and reduction of 66.3 tons of $CO_2$releasedper year thus reducing the problem of harmful emissions being released at power generation end. The outcome of this study highlights that Hoffman kilns in Pakistan can result in lesser emissions, better resource efficiency, increased sustainability, and better quality of bricks.

## Keywords

Emission factors; life cycle assessment; impact categories; increased sustainability; brick kilns; photovoltaic

## Journal and Status

Environmental Impact Assessment Review (EIA), Impact Factor 4.59, Category $Q_1$, Accepted.

# Appendix 2

# Raw data of the brick kilns taken into study

## Raw data of FCBTK

| | |
|---|---|
| **Number of Human Resources** | |
| Munshi (Secretary) | 2 |
| Barhai wala (Filler man) | 2 |
| Jamadar (Janitors) | 2 |
| Naqasi wala | 3 |
| Pathers (One who makes brick molds) | 45 |
| Jalai wala (One who looks after the entire brick roasting process) | 4 |
| Barhai Rerhi | 12 |
| Coal man (The one who carries coal powder in hand-driven carts and take it for combustion) | 2 |
| **Quantity/cost of fuel, water** | |
| No of green bricks (molds) made by pathers in a single day | 40500 |
| Quantity of water used to make one brick | 160 ml |
| Water used per day to make 40500 green bricks | 6450 liters |
| Water used to make 972000 green bricks in 26 days (One month as Fridays are off) | 168480 liters |
| No of green bricks that Barhai Wala (Filler) puts in for baking in one day<br>**10% of the green bricks (molds) get wasted while putting them on carts and taking them for burning* | 23100 |
| No of baked bricks produced per day | 20000 |
| No. of Green bricks wasted per day | 2310 |

| | |
|---|---|
| No of baked bricks produced per month | 600000 |
| Quantity of coal that is required to bake 600000 bricks/ month | 40 Tons |
| No. of Trucks that carry coal to the brick kiln area | 4 |
| Cost on coal along with the fuel of 4 trucks (to bake 600000 bricks/month) | 560000 PKR |
| No of trucks that carry sawdust (another fuel) | 8 |
| Quantity of sawdust in one truck | 9600 Kg |
| Total Quantity of sawdust in 8 trucks | 76800 Kg<br>\ |
| Cost on sawdust along with the fuel of one truck | 45000 PKR |
| Cost on sawdust along with the fuel of eight trucks | 360000 PKR |
| Quantity of wood required (another fuel)<br>**Wood is placed as 11th row after every 10 rows of coal and sawdust in combustion area* | 320000 kg |
| Cost on 320000 kgs of wood | 200000 PKR |
| Cost on total fuel (coal+sawdust+wood) per month | 1120000 PKR |
| Cost on fuel per day | 37333 PKR |
| Cost of fuel to bake 1000 bricks | 1866 PKR |
| Total area of land allocated for a brick kiln chimney | 2.5 acres (10117 $m^2$) |
| Total area of land allocated for pathers to make green bricks (molds) | 28 acres (113312 $m^2$) |
| Rent of one truck to carry clay to the brick kiln | 2500 PKR |
| Quantity of clay used to make 1000 bricks | 2500 Kg |
| Quantity of clay used to make 1 brick | 2.5 Kg |
| Quantity of fuel consumed/day by water pump | 5 liters |
| Quantity of fuel consumed in water pump per month | 130 liters |
| Distance the truck covers from clay mining area to the brick kiln | 20 Km |

## Raw data of IDZZK

| **Number of Human Resources** | |
|---|---|
| Munshi (Secretary) | 2 |
| Barhai wala (Filler man) | 3 |
| Jamadar (Janitors) | 4 |
| Naqasi wala | 3 |
| Pathers (One who makes brick molds) | 67 |
| Jalai wala (One who looks after the entire brick roasting process) | 7 |
| Barhai Rerhi | 18 |
| Coal man (The one who carries coal powder in hand-driven carts and take it for combustion) | 5 |
| **Quantity/cost of fuel, water** | |
| No of green bricks (molds) made by pathers in a single day | 58500 |
| Quantity of water used to make one brick | 370 ml |
| Water used per day to make 40500 green bricks | 21645 liters |
| Water used to make 972000 green bricks in 26 days (One month as Fridays are off) | 359640 liters |
| No of green bricks that Barhai Wala (Filler) puts in for baking in one day<br>**approx. 8% of the green bricks (molds) get wasted while putting them on carts and taking them for burning* | 44500 |
| No of baked bricks produced per day | 42000 |
| No. of Green bricks wasted per day | 2500 |
| No of baked bricks produced per month | 1092000 |
| Quantity of coal that is required to bake 600000 bricks/ month | 75 Tons |
| No. of Trucks that carry coal to the brick kiln area | 9 |
| Cost on coal along with the fuel of 4 trucks (to bake 600000 bricks/month) | 1145000 PKR |
| No of trucks that carry sawdust (another fuel) | 8 |
| Quantity of sawdust in one truck | 8700 kg |

| | |
|---|---|
| Total Quantity of sawdust in 11 trucks | 95700 kg |
| Cost on sawdust along with the fuel of one truck | 49500 PKR |
| Cost on sawdust along with the fuel of 11 trucks | 544500 PKR |
| Cost on fuel per day | 37333 PKR |
| Cost of fuel to bake 1000 bricks | 1866 PKR |
| Total area of land allocated for a brick kiln chimney | 3.2 acres (12949 $m^2$) |
| land allocated for pathers to make green bricks (molds) | 35 acres (141640 $m^2$) |
| Rent of one truck to carry clay to the brick kiln | 2250 PKR |
| Quantity of clay used to make 1000 bricks | 2310 Kg |
| Quantity of clay used to make 1 brick | 2.31 kg |
| Quantity of fuel consumed/day by water pump | 8 liters |
| Quantity of fuel consumed in water pump per month | 130 liters |
| Distance the truck covers from clay mining area to the brick kiln | 14 KM |

# Raw data of Hoffman kiln

| **Number of Human Resources** | |
|---|---|
| Munshi (secretary) | **2** |
| Barhai wala (filler man) | **2** |
| Jamadar (janitors) | **2** |
| Pathers<br>*At Hoffman kiln the brick molding process is automated so a smaller number of pathers are required. | **10** |
| Jalai Wala (One who looks after the entire brick roasting process) | **5** |

| **Details of Electrical Equipment** | | | |
|---|---|---|---|
| **Names of electrical Equipment** | **Units consumed per 1Kg brick per day** | **Machine weight; Life span; material composition** | **Mass of equipment per kg green brick per day** |
| Box Feeder | 0.0003 kWh | 2 tons; 25 years; mild steel | 2.4×10^-6 kg |
| Roller Crusher | 0.00189 kWh | 6 tons; 25 years; mild steel | 7.32×10^-6 kg |
| Clay Mixer | 0.00183 kWh | 3 tons; 20 years; iron | 5×10^-6 kg |
| Extruder | 0.00252 kWh | 5 tons; 25 years; iron | 6×10^-6 kg |
| Vacuum | 0.00101 kWh | 0.4 tons; 20 years; iron | 6.62×10^-7 kg |
| Brick Cutter | 0.0000252 kWh | 0.5 tons; 20 years; iron | 8.3×10^-7 kg |
| Fan to induce draught | 0.0020 kWh per 1kg brick | 2.2 tons; 20 years; mild steel | 3.67×10^-6 kg |

| **Details of bricks produced fuels and production materials** | |
|---|---|
| Green bricks produced | 24000 bricks per day |
| water consumed to make green brick | 180 ml per 1 kg green brick |
| total land to make green bricks | 0.15329 $m^2$ per 1kg green brick |
| Fly ash | 0.133 kgs per 1 kg green brick |
| clay used | 0.688 kgs per 1 kg green brick |

| | |
|---|---|
| Amount of electricity consumed/day by motor of water pump | 0.000253 kWh per 1kg green brick |
| Water bore-hole | 0.0370 $m^3$ (4.67e-7 $m^3$ per 1kg green brick) |
| Conveyer belt (0.8m/s Length:10m) | 0.000160 kWh per 1kg brick |
| Hammer Crusher | 0.000136 kWh per 1kg brick |
| Total area allocated for a kiln stack | 1 acre (4046 $m^2$)/ 0.0649 $m^2$ per 1kg brick |
| Green bricks put for baking | 21000 per day |
| Coal | 0.056 kgs per 1 kg brick |