Zigzag Brick Kiln Technology in Pakistan: Cost, Efficiency and Adoption among Brick Kiln Owners

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Abstract

This study analyzes the brick kilns sector of Pakistan, where two kiln technologies are mainly used for the production of bricks i.e. traditional fixed chimney brick kiln (FCBK) and advanced zigzag brick kiln (ZZBK). ZZBK is considered as environmentally friendly technology while FCBK is considered as the more polluting technology. Using private and social cost-benefit analysis, the study compares the economic and social benefits of the two technologies. In addition, the study also investigates the barriers to adoption of new advanced ZZBT for bricks production. The data for analysis was s collected from FCBKs and ZZBKs of Islamabad, Fateh Jangh, Tarnol, Rawat and Peshawar brick kiln sectors. In-depth interviews were conducted with different brick kiln owners and Head/President of Brick Kiln Association of Fateh Jangh, Tarnol and Peshawar. The analysis reveals that net private benefit of FCBK is 103.904 million rupees while the net private benefit of ZZBK is 195.548 million rupees, almost 92% higher than the net private benefit of FCBK. The CO_2 emissions were estimated at 7038.29 ton traditional FCBK, while 4575 ton of emissions are produced by ZZBK. The estimated social cost of CO_2 emissions is 2.49 PKR per brick for ZZBK, while 4.47 PKR per brick for FCBK. The estimated net social benefit of ZZBK is 170.5 million PKR and 62.92 million PKR, which is 2.7 times higher than net social benefit of FCBK. The private and social cost-benefit analysis revealed that ZZBK is economically and socially more beneficial than FCBK, and also considered as cleaner, environment friendly, productive and energy efficient than FCBK. A shortage skilled labors and workers, constructor, inputs like electricity and land, and financial and government support are the main reasons of failure in adoption of ZZBK. The government should also encourage brick kiln owners to adopt ZZBK for bricks productions by giving interest free or low interest rate loans to kilns owners for installing or retrofitting zigzag technology and long term loans for business progression. In addition, practical training sessions should be organized for kilns worker for better production.

Keywords: FCBK, ZZBK, brick kiln, CO_2 emissions, cost and benefit analysis.

1. Introduction

Brick production is one of the world's oldest industries. It is as old as the Indus Valley Civilization (2500-1500 BC) and fired bricks were used by ancient civilizations for construction of temples, tombs etc. in Egypt and Mesopotamia. The weight, size and shape of bricks have changed overtime while the bricks production process has undergone relatively few changes (Iqbal, 2006). Brick kilns are usually located in rural and peri-urban areas and often use traditional techniques for production of bricks. The presence of brick kilns in these areas contributes to improvement in the infrastructure and transportation facilities (Co et al., 2009).

Although brick kilns generate employment opportunities to the local and migrants, provide profit through brick sale and generate lease income for the farmers, these kilns also have some adverse effects like soil erosion, degradation of soil fertility and loss of agriculture land (Singh & Asgher, 2005). Bricks kilns are also responsible for increase in air pollution because the combustion of fuel like coal, wood, rubber or other plastic wastes produces different types of gas emissions. These emissions include CO, CO_2, particulate matters, nitrogen oxides, sulfur oxides, other heavy metals, raw materials of bricks and VOC's (volatilized from raw materials and phytotoxic compounds) (Khan et al., 2015; Co et al., 2009).

The major factor behind this negative externality is the use of such fuels during bricks production. Mostly coal is used as fuel for brick production, while wood is also used in large amount for

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combustion, which results in deforestation and causing different problems like air pollution, soil erosion, health disease and climate change (Khan et al., 2019). The extraction of soil for brick production contributes to soil degradation that leads to different environmental problems (R. Khan & Vyas, 2008). The process of bricks making has not changed since the first fired bricks were produced some hundreds of years ago. The steps used then are still used today, but with refinements. Some of the refined techniques used by developed and developing countries for the brick production are zigzag brick technology (ZZB), modified fixed chimney bull's trench kiln (MFBTC), hoffman kiln (HK), hybrid hoffman kiln (HHK), annular kiln (AK), tunnel kiln (TK) and vertical shaft kiln (VSK). A significant decline in the emissions of hazardous gases has been observed by using these modern techniques for bricks production (Blackman et al., 2006; Co et al., 2009).

Despite the use of these modern techniques, there are some other mitigation strategies used by developed and developing countries. These strategies include replacement of traditional open topped kiln with pairs of domed kilns, using natural gas instead of coal, rubber or propane, relocation of kilns from densely populated areas and introduction of no burns days or installing limestone scrubbing system in the kiln (Blackman et al., 2006; Co et al., 2009). It is evident from the literature that the traditional brick kiln technologies, although privately lucrative, impose substantial cost on the society, the environment and the human health which has prompted the large-scale application of the private and social cost-benefit analysis (CBA) frameworks. The initial analysis indicates the intensity of these externalities and thus creates the economic justification of switching to less pollutant technologies. One of the first systematic CBAs of brick kilns in Bangladesh done by (Croitoru and Sarraf, 2012), indicated that traditional fixed chimneys kilns are still profitable to entrepreneurs, although the social costs are very high in the form of negative health and environmental effects. The adoption of cleaner solutions like Hybrid Hoffman kilns and Vertical Shaft Brick kilns, the premature mortality decreases by 40-60 and move the sector towards the social optimum. (Eil et al., 2020) further expanded the private-social CBA framework to the regional scale by considering various measures of brick kiln technologies throughout Bangladesh, India, and Nepal where low-quality coal constitutes almost 91% of urban PM emissions. The analysis of the market-based prices and the disability-adjusted life years (DALY) method indicated that HHK and TK have the highest net private and social benefits as compared to other conventional technologies. The research also revealed that the health costs associated with PM in these three countries are over USD 4 billion annually.

Although Eil et al. (2020) focused on aggregate economic and health outcomes, (Rahman and Kazi, 2019) complemented the study by ranking the technologies of the brick kiln industry in Bangladesh with the help of the Analytical Hierarchy Process (AHP). Their findings supported the superiority of developed technologies, in that, TK performed better in terms of environmental performance and profitability followed by HHK and ZZBK, with VSBK being the least preferred since it is more expensive. This correspondence between technical efficiency and economic viability makes the argument of policy-based technological transition stronger. At the micro-level, (Bhattacharjya, 2018) assessed the process of converting the traditional kilns into Zigzag and Vertical Shaft technologies in Andhra Pradesh, India. The study revealed that that technological upgrading can bring large returns to individuals and high social benefits. Through DALY and Value of Statistical Life (VSL) methods, the study was able to estimate worthwhile mortality reduction brought about by lowering PM and CO_2 emissions. Thus, cleaner technologies yield welfare benefits that exceed the profitability of individuals.

The studies based on emissions also confirm the economic and health benefits of cleaner kilns. Guttikunda and Khaliquzzaman (2014) determined the health and fuel savings through the replacement

of inefficient fixed chimney bull trench kilns with cleaner technologies and estimated the cumulative health cost savings of USD 126-234 million and significant savings in fuel costs. On the same note, Imran et al. (2014) using IPCC emission guidelines proved that conventional kilns use a lot more fuel and produce a lot more CO_2 per unit output as compared to high-tech kilns like HHK and Zigzag kilns. According to evidence outside South Asia, these findings are more universally applicable. Blackman et al. (2006) demonstrated that net social benefits of investments in cleaner technologies in Ciudad Juarez, Mexico are greater than the net social benefits of pollution control measures against formal industrial polluters, as the health damages brought about by informal kilns are disproportionately large.

The studies based on emission provide better evidence regarding the magnitude and the composition of the pollutants emitted by the brick kilns. Rajarathnam et al. (2014) measured the emissions of various types of major technologies of brick kilns in India and found down-draft and fixed chimney kilns exhibited high emission levels, whereas zigzag and tunnel kilns performed better in terms of emissions. The results are supported by Nepal et al. (2019) which showed that the transformation of the fixed chimney to induced-draught zigzag kilns leads to the reduction of PM2.5 and black carbon emissions up to 40-55 %, which reveals the advantages of technological upgrading in the context of climate and air quality. Besides air pollution, the environment is also degraded in terms of soil, water, and trees. Fatima (2013) found that the levels of SO_2, NO_2, and particulate matter near brick kilns had been high in the area of Kashmir, leading to reduced chlorophyll levels in plants as well as low soil quality. Similarly, Khalid (2019) established that ground water in the areas surrounding traditional brick kilns in Pakistan was salty and contaminated with heavy metals that were potentially toxic to humans and exceeded the world health organization standards. These studies demonstrate that emissions of kilns produce multi-dimensional externalities in the environment. The evidence from impact on health also gives support to the argument against the traditional kiln operations.

Khan et al. (2015) demonstrated that the presence of brick kilns plays a very significant role in the causes of respiratory diseases, including asthma and acute respiratory infections in Punjab, Pakistan, especially during the high production seasons. Larsen (2016) reported similar findings for Dhaka, Bangladesh, where fine particulate emissions produced by the traditional kilns were associated with significant health losses. Larsen used the DALY and VSL techniques to prove that the social benefits of switching to cleaner technologies, including zigzag, VSBK, and HHK, are significantly higher than the private benefits, thereby providing an economic justification for technological transition. Although these impacts are well documented, however, the recent research has highlighted the role of behavioral and institutional factors in technology adoption. Hussain et al. (2021) using the Theory of Planned Behavior in Pakistan, discovered that the intentions of the kiln owners to use the zigzag technology are strongly associated with environmental concern, self-efficacy, and social norms. This suggests that the effective policy should address not only the economic incentives but also the behavioral factors influencing adoption decisions. This conclusion is further supported by the evidence from f\comparative technology assessments.

Pengoriya (2018) illustrated that VSBK and zigzag kilns use significantly less fuel and are more environmentally friendly as compared to the conventional clamp and fixed chimney kilns in India. Similar findings were reported by (Imran et al., 2014; Parvez et al., 2018), who highlighted the contribution of coal-based brick production to harmful emissions and poor ecologies. Policy oriented studies also highlighted the need to intervene through regulations. Co et al. (2009) showed that a combination of command-and-control and market-based tools, such as the emission standards, low-sulfur fuels, the financial incentives and the emission fees can help reduce pollution and encourage

cleaner technologies in the brick industry in Vietnam. These results are consistent with Blackman et al. (2006), who demonstrated that targeting informal brick kilns has very high social returns because they disproportionately contribute to the air pollution.

The health effects of the brick kiln emissions have been the focus of many studies, which have invariably found that the exposure to the pollutants of the traditional kilns has negative health effects on not only the cognitive development or respiratory health but also on the occupational health and overall health, especially in the developing countries. At the community level, Nasir et al. (2021) demonstrated that the higher levels of PM10 and PM2.5 in areas surrounding brick kilns production in Pakistan have a severe impact on physical well-being and academic achievement in children. Through field-based particulate monitoring and scores on the Raven test, the study established that children living close to kiln sites had lower cognitive ability as compared to children living farther away. Occupational pathway also augments health hazards in the course of the brick kiln workers. David et al. (2020) incorporated biochemical data and found that the consequences of long-term exposure to heavy metals in female kiln workers result in metabolic disorders, anemia, respiratory diseases, reproductive health problems, and oxidative stress. Khisroon et al. (2018) reported similar findings which observed a considerable increase in DNA damage in exposed workers, with age, smoking behavior, and working conditions as aggravating factors. These micro-level health effects are consistent with the industry-wide evaluation by Shaikh et al. (2012) which reported high prevalence of chronic respiratory illness, bronchitis and asthma among the kiln workers in Pakistan.

At the macro level, epidemiological and econometric research associates air pollution due to combustion-based activities such as brick production with broader population health outcomes. Husnain et al. (2016) and Fotourehchi (2016) concluded that PM and CO_2 emissions have huge adverse impacts on infant mortality and life expectancy, and they are not limited to their localized exposure. From a regional perspective, Junaid et al. (2018) reported persistently high levels of PM10 and PM2.5 in South Asia, which was linked to increased mortality and respiratory conditions. These effects are further compounded through environmental health pathways. Skinder et al. (2014) pointed that sulfur dioxide is one of the significant polluters of brick kilns, which contaminates the air, water, and soil. It causes serious respiratory illnesses and physiological damage to plants (Skinder et al., 2014), and indirectly, effects the food security and human health (Khan and Vyas, 2008). Finally, the social vulnerabilities exacerbate these health threats. Khattak et al. (2009) reported abject living and working conditions of the brick kiln workers, such as a shortage of sanitation, clean water, healthcare and education. These conditions imply that technological upgrading has the potential to generate multiple benefits by reducing emissions while simultaneously improving the welfare of the brick kiln workers.

1.1 Overview of world's brick kiln sector

In developing countries, the population growth, rural–urban migration, and regulation have spurred the rapid expansion of an urban informal sector comprised of low-technology microenterprises largely operating outside the purview of the state. Today, this informal sector accounts for over half of non-agricultural employment and contributes between a quarter and three quarters of gross domestic product in both Latin America and Africa (Schneider & Enste, 2000). On one hand it contributes to the Gross Domestic Product (GDP) and employment, improving individual's and country's economic and financial position while on other side this sector negatively effects human health, environment and economy, and produces negative externalities. These negative externalities include depletion of ozone layer, soil erosion, decrease in natural resources, animals and plants related diseases (Khan et al., 2019).

Despite of all its economic benefits, there are compelling reasons to believe that the expansion of this informal brick sector has significant impacts on the environment (Blackman et al., 2006).

This sector consists of a large number of informal firms that, although tiny, are exceptionally numerous, and a significant percentage are involved in highly polluting activities such as leather tanning, ceramics, metalworking, electroplating, and mining. These informal firms generally lack pollution control equipment, and often lack access to basic sanitation services. Also, such firms are typically labor intensive and situated in poor residential areas. Therefore, their emissions directly affect a considerable population of employees and neighbors (Khan et al., 2015). Increase in rural-urban migration, population growth and other regulations in developing countries have encouraged the spreading of the informal brick kilns. These brick kilns mostly operate in the rural and peri-urban areas using traditional techniques and practices (Co et al.,2009). Nevertheless, policymakers have so far paid little attention to informal polluters and the problem is not well-understood. In fact, policy makers lack information on the magnitude and incidence of the environmental damages caused by brick kilns, and the costs of mitigating these damages. These brick kilns have significant impacts on mortality and morbidity too. Brick kiln emissions are responsible for 14 premature mortalities per year (Blackman et al., 2006).

The pollutants produced by brick kilns in the presence of coal includes SO_2, CO, CO_2, NOx and PM (Skinder et al., 2014). Approximately 1.2% of global anthropogenic carbon dioxide (CO_2) emissions are contributed by brick kiln' fire (Lopez et al., 2012). In Ciudad Juarez, Mexico these kilns contributed to 16 per cent of all particulate matter pollution, and 43 per cent of all sulfur dioxide emissions (Blackman et al., 2006). The emissions from these brick kilns are among the main causes of the depletion of ozone layer and the acid rain. This, in turn, disturbs the environment and main components of ecosystem such as plants, animals, air, water and soil. When the harmful emissions in the atmosphere comes in contact with rain drops, it converts into weak acids that may harm the plant leaves and stem, and also the skin of animals. When these harmful emissions flow with water into the river or sea, it may harm the aquatic life. Moreover, these chemicals are absorbed by the soil, causing changes in its pH (Potential of Hydrogen) value (Fatima, 2013). Climate change is also apparent with the increasing amount of harmful emissions in the environment (Croitoru & Sarraf, 2012). In fact, there are both short and long term impacts of air pollution (Pokhrel & Lee, 2011). The short term impact includes the disturbed growth of vegetables and fruits, whereas the long-term impacts include the depletion of ozone layer, soil erosion, deforestation, smog and the lowering of groundwater level (Khan et al., 2019).

1.2 Overview of Pakistan's Brick kiln sector

In Pakistan different production sectors like ceramics, tiles, cement and marbles industries have adopted advance technologies for production purposes but unfortunately brick production sector is still using traditional, labor intensive and energy inefficient technologies. By adopting advance techniques these industries are making reasonable profit for their owners and also providing better environment for the labor force (Khattak et al., 2009). However, in Pakistan, the traditional techniques are mainly used for the production of bricks which produce harmful emissions on a large scale. These emissions are directly released in the environment and have negative impacts on the environment, human beings, animal and plants causing different type of diseases. The brick production sector is typically labor-intensive which results in high economic and social cost (Blackman et al., 2006).

Brick kilns are considered as one of the main sources of increased pollution. In many countries like China, India and Pakistan, the brick manufacturing is a fast-growing industry because of

infrastructural development. In Pakistan, emissions from brick kilns are still the most prominent causes of air pollution and health problems (Shaikh et al., 2012), and the harmful emissions from these brick kilns results in respiratory diseases and infections in the surrounding communities (Khan et al., 2015). This harmful emission contains Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NOx) and (PM) Particulate Matters (Kamal et al., 2014). Most of the developed countries are focusing on controlling and mitigating the harmful impacts of construction and brick kiln industry but unluckily some of the developing countries, like Pakistan, have not focused on these issues (Khan et al., 2019).

According to a report by the International Centre for Integrated Mountain Development (ICIMOD), there are a total of 20,000 brick kilns in Pakistan, mainly using the traditional technique i.e. fixed chimney technology for brick production. In 2017, ICIMOD in collaboration with Climate and Clean Air Coalition (CCAC) and Department for International Development (DFID), National Energy and Efficiency Conservation Authority (NECCA), Brick Kiln Owners Association of Pakistan (BKOAP) and Environment Protection Department, Punjab (EPD, Punjab) familiarized the brick owners and workers with cost efficient and environmentally friendly brick production technology i.e. Zigzag Technology. Following this, the Ministry of Climate Change (MOCC) strictly banned the construction of traditional kilns in July, 2018 and announced incentives for early adopters. As a result, eighteen new advanced brick kilns i.e. zigzag brick kilns were constructed for the first time (ICIMOD, 2018).

According to another report by CCAC, 2015 “These brick kilns are located around urban areas and contribute significantly to air pollution in Pakistan. Pakistan’s brick sector is highly unregulated and uncoordinated but is responsible for 1.5% of Pakistan’s Gross Domestic Product (GDP). Traditional brick production in Pakistan consists of hand-made bricks which are baked in FCBK, the most widely used brick firing technology in South Asia. It is one of the most contaminating technique used for brick production, resulting in a host of social and environmental impacts including air pollution, climate change, cardiorespiratory diseases, land use impacts and deforestation. The emissions mainly produced contain sulfur oxides, nitrogen dioxides, carbon monoxide and dioxide, forms of particulate matter including black carbon, and additional compounds by burning coal and other fuels”. The brick kiln industry is one of Pakistan’s most profitable sectors and is the third largest producer of bricks in South Asia. Pakistan’s brick sector employs 4.5 million people producing 45 billion bricks per year in 20,000 brick kilns. Almost, 13 million tons of coal is consumed by brick sector, which contributed nearly a quarter to the total CO_2 emissions from fossil fuel consumption in 2018-19 (198 million ton), in which 22% of CO_2 emissions are produced by brick kilns (ICIMOD, 2019: Butt et al., 2021). The brick production sector of Pakistan is considered as one of the most profitable sector and the emissions from brick kilns are still the most prominent causes of air pollution. After China and India, the brick production sector of Pakistan is considered as the largest brick producing sector in South Asia.

Despite the availability of the advance technologies, the brick kiln owners of Pakistan are still preferring the traditional, labor intensive and energy inefficient fixed chimney technology and are not willing to adopt these advance technologies for brick production The objectives of this research are to determine the private cost and benefits of Fixed Chimney Kiln and Zigzag Brick Kiln, social cost and benefits of FCBK and ZZBK, and to determine why brick kiln owners are not adopting the new ZZBK. Two technologies are mainly used for brick production in Pakistan i.e. traditional Fixed Chimney Kiln and advance Zigzag Brick Kiln. The study briefly explains the structure of these technologies and how it operates, and provides a detailed explanation of the different policies that govern the brick kiln sector.

Fixed Chimney Kiln dates back to 19th century. FCBK has a fixed chimney in the middle of the kiln at about 120-130 feet in height. The tall chimney provides a better and faster dispersion of the flue gas and its pollutants.

Table 1. Brick kiln sector overview

Number of brick kilns (2018)	18,000 – 20,000
Annual brick production (2018)	82.5 billion bricks
Annual domestic consumption	90% of production bricks
Annual brick demand	112 billion bricks
Animals utilized (2017)	115,000 animals
Number employed (2018)	1.3 million people
Men employed	77% men
Women employed	23% women
Admin and others	60,000 people
Moulding	9,00,000 people
GB transport	150,000 people
Firing	1,00,000 people
Fired brick transport	120,000 people
Sector investment (2018)	PKRs 240 billion i.e. (USD 2 billion)
Value of sales (2018)	PKRs 676.512 billion i.e. (USD 5.637 billion)
GDP contribution	Not available
Tax contribution	No sales tax; taxation on coal and income
Estimated avg. coal consumption for firing bricks per annum (2018)	13 million tons 60 – 70% of total fuel consumption by brick sector
Annual coal expenses (2018)	PKRs 179 billion/USD 1.49 billion
Other fuel consumption	Common biomass fuel – rice husk, cotton stalk, sawdust, biomass residue, baggase. About 30–40% of total fuel consumed by brick kilns. In some areas, bricks kilns exclusively use biomass fuel. Cost of biomass fuel varies between PKRs 6–10 per kg.

Source: *ICIMOD (2019)*

The Fixed chimney kiln is elliptical in shape and about 220 - 250 feet in length and 60-90 feet in width. Itis mainly operate in open large fields either over ground or partially underground. The bottom and sidewalls are lined with bricks. The shape, structure and size of zigzag brick kiln are almost the same as Fixed chimney brick kiln. However, the zigzag kiln has some modification i.e. the chimney is slightly shorter than that of FCK, rectangular in shape and an electric fan (blower) is installed in the bottom of the chimney to control the flow of the draft through the chamber. Furthermore, in ZZBK the workers stack raw bricks or green bricks in a zigzag or diagonal pattern, which forces the flow of heat to move in a zigzag path. Because of this zigzag pattern, the kiln is named as zigzag brick kiln. This

longer path taken by the draft increases the airflow in the firing section of the kiln, and this leads to the efficient combustion of coal. It also transfers greater amount of heat from the firing chamber to the pre-heating section, allowing more consistent baking of bricks. The combustion of fuel results in emissions of different types of gases like CO, CO_2, PM which flow with air from one chamber to another chamber. But due to zigzag pattern a large amount of these emissions stays at the bottom of the kiln and a very little amount comes out from the chimney.

Table 2. Brick kiln Technologies

Technology	Number (kilns with coal as the primary fuel)	Energy consumption (tons)	Number employed
Fixed Chimney Bull's Trench Kilns (FCBTK) (natural draft)	15,000	13 million tons of coal (excluding biomass)	1.3 million
FCBTK (forced/induced draft)			
Zig-zag FCBTK (natural draft)	150	0.0945 million tons of coal	45,000
Zig-zag FCBTK (forced/induced draft)			
VSBK		NA	
Hoffmann kiln		1	

Source: ICIMOD (2019)

The legal and institutional framework for regulating environmental protection, labor welfare, and industrial practices in Pakistan is based on various acts and policies. The industrial sector, including the brick kiln industry in Pakistan, has a wide range of environmental, labor, climate, and energy related legislations. Among these are the Environmental Protection Act 1997 and National Environmental Quality Standards (NEQS), which sets limits on the amount of industrial effluents and emissions that can be released. There is a well-developed set of standards, especially regarding gaseous emissions and particulate matter, but their implementation brick kiln sector has been feeble. The instruments used to provide labor protection include the Minimum Wages Ordinance (1961), the Employees Social Security Ordinance (1965), the Employment of children act (1991), and the Bonded labor (Abolition) act (1992) which are meant to protect the workers' rights as well as to prevent child and bonded labor and to improve the working conditions in risky industries. Besides local industrial mandates, the larger climate and energy policies, such as the Framework of Implementation of Climate Change Policy (2013), National Energy Efficiency and Conservation Act (2016), and National Climate Change Policy (2021), are the strategic guidelines towards climate resilience, energy conservation, and emissions reduction. These frameworks focus on low carbon development, ecosystem restoration, energy efficiency and sustainable use of resources, which directly apply to the energy-intensive industries like brick production. The government also introduced sector specific policies in an effort to curb the serious

environmental and social effects caused by the traditional brick kilns. The Punjab Prohibition of Child labor in Brick Kiln Act (2016) clearly prohibits the use of child labor in the kilns, recognizing that the working environment in the kiln is dangerous. Such technological reforms, especially the compulsory replacement of the conventional Fixed Chimney Bull Trench Kilns (FCBKs) with zig-zag firing technology can be viewed as a significant policy intervention aimed at enhancing fuel efficiency and reducing emissions. It is evident that zig-zag kilns significantly reduce the emissions of particle matter, black carbon and CO_2, while also increasing profitability through lower coal consumption and improved brick quality.

2. Methodology

The methodology provides a detailed explanation of the research design, questionnaire design and structure, study locale and sample size, data description and estimation techniques used for the Cost and Benefit analysis of traditional Fixed Chimney Brick Kiln Technology and new advanced Zigzag Brick Kiln Technology.

2.1 Questionnaire Design

A structured questionnaire was designed for this study which comprises four sections i.e. A, B, C and D. The details of each section are as follows:

Section A contains questions related to the demographic characteristics of the brick kiln owners and the technology used for the production of bricks while section B contains questions about the inputs used for the production of output. The information collected from this section was used to estimate the net private cost of the brick kiln. The cost comprises of the cost of the kiln structure, cost of the chimney, cost of coal, land lease cost, cost of machinery, taxes paid by brick kiln owners and other operating costs. Section C contains questions related to output of the kiln i.e. the total annual production of each kiln, different type of bricks produced and their market prices. The information collected from section C was used to estimate the economic or market value of the brick production which was further used in estimating the private and social benefits of both FCBK and ZZBK.

Section D contains questions related to the third objective of the study i.e. identifying the reasons for the failure to adopt the new advanced technology for brick production which were asked from brick kilns owners. This section has two subsections; the first contains questions asked from FCBK owners while questions in the second were asked from ZZBK owners during interviews with them. The information collected from this section was used to achieve the third objective of this study. Furthermore, the questionnaire contains both open ended and close end questions. The data from section B and C was used for quantitative analysis while the data from section D was used for qualitative analysis.

Table 3. Questionnaire Design Structure

Sections	Description	Variables
Section A	Demographic information	Name, age, education, gender, technology
Section B	Inputs info	Land, labor, machinery, coal, electricity, taxes, kiln structure, water etc.
Section C	Output info	Quantity of bricks, types, market price
Section D	Owners' viewpoint	FCBK, ZZBK

2.2 Working durations

Pakistan have two major seasons i.e. summer season and winter season. The brick kilns sector of Pakistan operates in both seasons, but during these seasons, there is a specific time period during which

the brick kilns stop production or operate at a very low level i.e. producing nearly 10 - 20% of bricks. The total time period of both seasons is 52 weeks i.e. 26 weeks for summer and 26 for winter. The duration of the summer season starts from 15th March and ends on 15th September i.e. a total of 26 weeks' time period. During these 26 weeks, brick kilns operate only 16 weeks, and this working period starts from 15th March and ends on 30th June. From 1th July, the off season starts and ends at 15th September i.e. 10 weeks' duration. The total duration of winter season is also 26 weeks. Its working season starts from 15th September and ends on 31th December i.e. 16 working weeks. After this the off season starts. Its total time period is from 2th January to 15th March i.e. 10 weeks and vice versa. Thus, the brick kilns sector operates according to this pattern throughout the year.

2.3 Data Description

For the analysis of brick kilns using private and social cost benefit analysis approach this study has used both primary and secondary data. The primary data was collected from two types of brick kilns i.e. FCBK and ZZBK using questionnaires and interviews with the Head/President of Brick Kilns Association and brick kiln owners. Secondary data was collected from different organizations and published articles. The brick kilns were selected by using the convenience sampling technique i.e. collection of data from conveniently available brick kilns, and stratified random sampling technique i.e. by selecting samples from two groups of brick kilns FCBK and ZZBKA structured questionnaire containing both open and close ended questions was used as a tool for collecting data related to brick kilns inputs and output. The questionnaire also included questions related to the third objective of this research, which helped in determining the reasons why the brick kiln owners are not willing to adopt ZZBT for brick production.

The collected data was used for the estimation of private costs and benefits of FCBT and ZZBT. Private costs comprised of investment cost, operation costs and input costs, while the private benefits include the total market value of output produced by the brick kilns. The social costs included direct cost of kiln i.e. private cost excluding taxes and environmental cost of CO_2 emissions, while the social benefits were equivalent to their private benefits. Direct costs comprised of total investment costs including the cost of kiln structure, kiln chimney, machinery and equipment used in kilns for brick production, Annual costs comprised of annual rent of leased land, operating cost i.e. cost of labor, coal, soil, clay, water, electricity and office expenses as well as taxes and illegal payments (bribe) made monthly or annually by the kiln owners.

2.4 Variables

This study has used CBA for estimating the total costs and benefits of two types of brick kilns i.e. FCBK and ZZBK. The total cost of brick kiln is divided into two cost components i.e. upfront investment and the annual costs.

Upfront Investment

Upfront investment includes the cost of kiln structure, cost of the chimney, cost of all the machinery and equipment used for production of bricks. These variables are also used by (Sharif & Nasim, 2020). However, this research has added some new variables such as the cost of construction of offices and labor rooms and the installment cost of water bores.

Brick kiln structure cost

Brick kiln structure cost includes total cost of kiln construction i.e. the firing chamber and chimney of the kiln. It is an important variable for estimation of CBA. Kiln structure cost is part of upfront investment i.e. one-time investment at the beginning of the kiln's construction. Following the existing literature, this research has also included the kiln structure cost in the upfront investment for PCBA and

has defined the variable using "S" symbol. Sharif and Nasim (2020) have also used kiln structure cost for the estimation.

Machinery cost

Machinery includes advanced technologies, tools and equipment used in the production of output. Different types of machinery are used in the brick sector i.e. mud machine, shovel or lifter, blower machine, generators, tractors and trolleys, coal crusher etc. This study has defined machinery with a symbol "M" and estimated its total cost using the market prices as a tool of measurement. Sharif and Nasim (2020) have also included machinery cost in their cost-benefit analysis.

Water cost

Croitoru and Sarraf (2012) have used total cost of water in estimation of operation cost of brick kiln which varies with water usage. However, this research has included water cost in the upfront investment of the brick kiln and defined it with the symbol "W". This is because each kiln has its own private water bores, which were installed at the time of construction of kiln.

Labor housing

Most of the brick kilns are located in the rural areas and don't have any proper transport system. Therefore, for convenience, the brick kiln owners have constructed shelter houses for labors and their families who are permanent workers at their kilns. This research has included this construction cost of these shelter houses in PCBA as an upfront investment. This study has defined the cost of labor housing with symbol "LH" symbol. The existing literature has generally ignored this cost in the estimation of PCBA.

Annual cost

Annual cost is composed of total land lease cost, operation costs (cost of labor, cost of fuel and cost of clay and soil), building costs (maintenance cost) and all taxes paid by kiln owners. Croitoru and Sarraf (2012) and Eil et al. (2020) have also included these costs in the estimation of annual cost. However, this study has also added electricity cost, plastic or protection cost and additional/office costs in its annual cost because these variables have significant contribution in the total cost of production.

Land lease

The land is one of the main factors of production of brick kiln sector. Brick kilns are constructed on large areas of land that contain sufficient amount of soil for brick production. Brick kilns are mostly located in rural areas where land is easily available and land lease rates are much lower as compared to urban areas. The lease rate of land depends on the geography of the land i.e. the area near urban centers have higher lease rate as compared to land in rural areas. Similarly, areas where land is scare have high lease rate too. Land having abundant and high quality soil has higher rent rates. Similarly, the land located near urban areas or road side has higher rent. This research has defined land lease cost with symbol "LL" and used Kanal as unit of measure. The lease rate of land is different in all four areas selected as study locale. The land lease rate ranges from 5000 PKR to 15000 PKR per Kanal per annum, and period of lease also varies across the selected study locations.

The lease agreement ranges from 5 years to 20 years. It also depends on the location and the behavior of land owner i.e. Islamabad has the highest rate as compare to other markets, while Rawalpindi has the lowest lease rate. Peshawar has the second highest lease rate followed by Fateh Jangh.

Labor cost

Labor is another important factor of production and can be defined as the effort that people contribute to the production of goods and commodities. Like agriculture and other industries, brick industry is also a labor intensive sector and labor is considered as the most important input for brick

production (Blackman et al., 2006). In each brick kiln nearly 100 to 150 laborer are working at a time performing different types of work at different positions such as "firer" who feeds coal to the kiln and maintains the fire of the kiln, the "moulder or tapeer" who prepares raw bricks, "Nikasi" who shifts fired bricks from kiln to stock house,the "kharkaar" brings raw bricks from field to kiln for baking, "pandre wala" who layeres the raw bricks up to 15 layers for drying purpose and "general labor" perform different tasks like driving, water management, office work etc. There is also a "manager and assistant of manager" who keep the record of all activities. Nearly 60 % of laborers are moulders, 8 % are firer, 10% are kharkaars while remaining 22 % are engaged in other types of work. This research has defined labor with symbol "LC" and the unit of measure for estimating the total cost of labors is their weekly wage rate.

Coal cost

Coal is another important input for the production of bricks and used as a source of fuel for baking bricks. There are also some other inputs i.e. rubber, wood, plastic etc., which are also used as fuel but in much smaller quantities as compared to coal. Thus this research has only included the cost of coal consumption in estimating the total cost of brick kiln. Same variable is also used by (Croitoru & Sarraf, 2012; Sharif & Nasim, 2020). The cost and quality of coal varies from region to region. The coal of Quetta is considered top-rated among different brick kiln markets because of its good quality and long burning period. Due to these qualities it is sold at high prices ranging from 23000 -26000 PKR per ton including taxes and transportation costs. The Quetta coal is followed by Dara Coal of KPK region which is highly flammable and burns at a high rate. Because of this quality, kiln owners also use it for strengthening the fire and its price ranges from 19000 – 22000 PKR per ton. The Punjab coal is also used to some extent and its price ranges from16000 – 20000 PKR per ton including transportation costs and taxes collected by minerals department. This research has defined coal consumption with the symbol "C" and its cost is included in total cost of inputs to estimate the private cost of brick kiln.

Clay and soil cost

Clay and soil are the main ingredients used in brick production. Brick kilns tend to operate in those areas where the availability of soil and clay is sufficient e.g. in rural areas as the clay and soil are more abundant there as compared to urban areas. The interviews reveal that some kilns have their own soil and clay while some bring it from the neighboring areas. Therefore, this research has used the clay and soil cost and added the total cost of clay and soil in the PCBA of brick kilns. This cost has been defined using the "CSC" symbol.

Plastic cost or protection cost

It is another variable which is not included in the estimation of PCBA in different studies conducted by different researchers for the estimation of CBA of brick kilns. This study has included this cost in the estimation of total cost and defined it by the symbol "P". The kiln workers in Pakistan use plastic regularly during the production of raw bricks and also for protecting raw bricks during rainy season.

Electricity cost

This research has defined electricity with the symbol "E" and the cost of electricity has been included in private cost benefit analysis of both technologies i.e. FCBK and ZZBK. As compared to traditional FCBK, this new ZZBK consumes more electricity than traditional FCBK because of the installation of new advanced instruments like blower machine etc., in the brick kiln which run on electricity.

Additional cost

Additional cost is another variable added by this research to private cost-benefit analysis of brick kilns. Additional cost comprises of two different costs i.e. office cost which includes cost of food and stationary which is used in record keeping process. This research has defined additional cost by using symbol "AC", which has not been included in earlier studies.

Building cost

Building cost or kiln maintenance cost is also part of annual cost. Croitoru and Sarraf (2012) and, Sharif and Nasim (2020) have also added building cost in the PCBA of brick kilns. The building cost of a kiln is a variable i.e. it depends on the age of a kiln. If a kiln is newly constructed than the maintenance cost of the kiln is lower than that of old kilns where depreciation rate is higher.

Taxes and Bribe

Tax is defined as "A fee collected by government officials on income or commerce", while bribe is defined as "the money or any other valuable consideration given or promised with a view to corrupting the behavior of a person". Different types of taxes are also paid by brick kiln owners as a fee on their income earned from brick production. This research has added this variable in its cost benefit analysis and defined it by using symbol". The taxes paid by kiln owners include sales tax, income tax and value added tax while bribes constitute other illegal payments collected by government officials. The same tax variable is also used by (Eil et al., 2020).

2.5 Bricks production

Total output i.e. bricks is the only variable for estimating the total value of production of any brick kiln. Different types of bricks are produced during the production process, and each and every type of brick has its own market price. This research has used the market price as tool for estimating the total benefit of brick kilns by adding the market value of all types of bricks produced and this variable is defined by using symbol "BP". (Croitoru & Sarraf, 2012; Eil et al., 2020; Sharif & Nasim, 2020) have also used same approach for estimating the of output value/private benefit of brick kilns. Six types of bricks are produced by brick kilns i.e. A, B, C, K, T and D types. A-type brick which is called as "*Awal or Aik"* number bricks in local language are considered the top class brick and are produced in the middle layers. Because of their good quality they have the highest market value ranging from 10 - 14 PR per brick. The B-type which is known as "Doyem *or Dho"* number brick has market value ranging from 6 to 9 PKR per brick. These are bricks from the upper most layers which are partially fired bricks because of an insufficient supply of heat. The C type bricks are known as "*Soyem*" in local language and their market price ranges from 7 to 10 PKR per brick. Soyem are the bricks of second and third upper most layers and are generally well fired but slightly lighter in colour than A- type. Because of this lighter colour, they have a lower market value than A- type bricks.

The K- type or "*Kangher or Kanker*" bricks in local language are obtained from the bottom layers and have a blackish colour because of over firing. Their market price ranges from 6 to 9 PKR per brick. The T-typeover fired *Tora* bricks are the bricks that have burned due to overheating and their market value ranges from 4 to 6 PKR per brick. Pieces or *Dakra* are the bricks that are broken into fragments during heating process. These pieces were sold in form of trolleys and its price ranges from 3000 to 8000 PKR per trolley.

2.6 Sample Size

A statistically representative sampling technique is the one in which a sample is selected from a larger statistical population or group that adequately represents the larger population or group in its characteristics and qualities. In this study, stratified random sampling technique was used. Using this, a total of thirty samples were collected, 15 each from each brick kiln, for analysis.

2.7 Description of study area

For data collection thirty brick kilns were selected from five different areas i.e. Islamabad, Tarnol, Attock, Rawalpindi and Peshawar. Twenty-two kilns using FCBK and ZZBK technologies were selected from Islamabad, Rawat, Tarnol and Fateh Jangh areas, while eight kilns using FCBK and ZZBK technologies were selected from Peshawar brick kiln sector. Due to certain constraints like financial limitations, time limitations, and language barriers, the study was restricted to the nearest, feasible, and convenient areas.

2.7.1 Islamabad

Islamabad, the capital of Pakistan, is located on the Potohar Plateau. It is located at a distance of 9 miles from Rawalpindi. Islamabad was selected as the new capital in 1959, when the former Capital Karachi was considered unsuitable as the capital of the country. Islamabad covers nearly 65 square km of area, lying at an elevation ranging from 450 to 600 meters i.e.1500 to 1600 feet. The urban area of city is divided into eight zones i.e. diplomatic zone, industrial zone, commercial zone, residential zone, administrative zone, institutional zone, a greenbelt and national park. The planned capital area is nearly 350 square miles i.e. 906 square km and is composed of natural terraces and meadows, that surround the whole city. A further 1,400 square miles (3,626 square km) of hinterland, known as the Specified Areas, is subject to planning control, with the Margalla Hills, which are 3,000 to 5,000 feet (900 to 1,500 meters) high, in the north and northeast while the southern portion is an undulating plain. According to UN World Population Prospects (2021), the total population of Islamabad is reported as 1164000, showing a growth of 3.1%.

Islamabad has a humid subtropical climate , with five seasons: winter (November–February), spring (March and April), summer (May and June), rainy monsoon (July and August) and autumn (September and October). The hottest month is June, where average highs routinely exceed 38 °C (100.4 °F). The wettest month is July, with heavy rainfall and evening thunderstorms with the possibility of cloudbursts and flooding. The coolest month is January. There are nine sectors in Islamabad and each sector is dedicated to a specific zone. Sector I -9 is dedicated to the industrial zone and different types of industries i.e. IT, pharmaceutical industry, steel and iron industries etc. are located in this sector. Furthermore, the brick industry is also located in this sector. The main brick kiln operating zones located in Islamabad are Motorway market, Chabees (*26*) number market, Dokh Makhen and Noon market, and nearly 100 brick kilns are operating in these areas.

2.7.2 Tarnol

Tarnol is also an industrial area located three miles away from Islamabad on its north-west side. It's a small town in the vicinity of Islamabad. As compared to Islamabad, Tarnol is a backward area with poor transport system, limited infrastructure development and inadequate health and medical facilities etc. A large proportion of the population is working as laborers in different types of industries including formal and informal production units and work under harsh and risky conditions. A very small percentage of population is working in service sector in Islamabad and Rawalpindi areas. The industrial sector of Tarnol consists of pharmaceutical industries, food industries, agriculture industries, chemical industries, iron and aluminum industries, and bricks production industries. This research has only selected brick industry for analysis. The main brick production areas are Tarnol market, Mirchi market, and nearly 300 brick kilns are operating in these markets and produces up to 700,000 bricks per month per kiln on average.

2.7.3 Attock (Fateh Jangh)

Attock also known as Camlpur is a district in Pothohar Plateau, located in the northern part of Punjab province. Its boundaries are connected with the twin cities i.e. Rawalpindi and Islamabad (Capital of Pakistan) on the east side. It is also connected with Swabi and Haripur districts on the north side, with Chakwal and Mianwali on the south and southwest, with Kohat on east side and with Nowshera on northwest side. The Indus River flows along the western boundary of the district for about 130 which separates District Attock from the three bordering districts of Khyber Pakhtunkhwa (KPK) i.e. Nowshera, Swabi and Kohat. Attock district has a climate of hot summers and cold winters. The northern part is more humid and is more moderate in climate compared with the southern part of the district due to its higher altitude. Geographically, the district is mainly characterized with by hills, plateaus and dissected plains. After Haripur, the Haro River passes through the northern part of the tehsil of Attock where there is a flood plain with fertile soil. The district's average annual rainfall is 783 mm.

The total area of District Attock is 6857 square km and is divided into six tehsils i.e. Attock, Fateh Jangh, Hazro, Hassan Abdal, Jand and Pindi Gheb. The industrial sector of District Attock is composed of Oil and Gas refineries and industries, woolen and textile mills and industries, cement manufacturing industries, engineering goods and glass industries, agriculture and food related industries, and also brick production units. This study has only selected the brick kiln sector of District Attock. The brick sector of district Attock is spread across different tehsils. According to Punjab Brick Kilns Census there are nearly 100 brick kilns operating in district Attock and producing nearly 800,000 bricks per month on average. The highest numbers of brick kilns i.e. 65 are operating in Fateh Jangh tehsil because of the availability of large amount of land and other inputs, while 14 brick kilns are producing bricks in different areas of Pindi Gheb region. Up to 15 kilns are operating in Hazro and Hassan Abdal division, while the remaining brick producing kilns are operating in different areas of tehsil Attock. This research has selected Fateh Jangh as its study locale and has collected data from FCBK, ZZBK and partial ZZBK, which are producing bricks in different markets of Fateh Jangh such as Dokh Miskeen. It is considered the main hub of brick kilns.

2.7.3 Rawalpindi (Rawat)

Rawalpindi is a district of Punjab province and the fourth largest city in Pakistan after Karachi, Lahore and Faisalabad. It lies on the Potohar Plateau and nine miles (14 km) southwest of Islamabad, the current capital of Pakistan. The current area of Rawalpindi District is 5286 sq km. Before the formation of Islamabad (national capital), its total area was 6192 sq km 906 sq km of its area was allocated for the development of national capital. The average annual temperature is 21.5 °C or 70.8 °F in Rawalpindi. The average annual rainfall is approximately 1346.8mm (53.02 in), most of which falls in the monsoon season. The mean annual wind speed of Rawalpindi is roughly 10 km per hour (6.2 mph) at a height of 14 m.

Rawalpindi district is an industrial and agricultural area. The major crops of Rawalpindi district are wheat; barley, corn (maize) and millet. Furthermore, the industrial sector of Rawalpindi district is a hub of many formal and informal industries which include oil refineries, textile industries, iron industries and brick kilns. This study has only selected the brick kilns sector, where a nearly 300 brick kilns are operating in different Tehsils of Rawalpindi i.e. Gujar Khan town, Kahuta Town, Kallar Seydaan Town, Pothohar Town, Taxila Town and Rawalpindi Town. Nearly 200 brick producing kilns are operating in Gujar Khan and Pothohar town, while the remaining kilns are operating in Taxila Town, Kallar Seydaan, Kahuta and Rawalpindi town. This study has selected Rawalpindi town as a locale for

its analysis, where Rawat region is famous for brick production. Rawat is a village and union council of Rawalpindi Tehsil in the Rawalpindi District of Punjab, Pakistan. It is located in the north side of the country and in the hilly part of Punjab province, near to the border with Khyber Pakhtunkhwa and Kashmir at 33.4951° N, 73.1969° E. For the analysis this study has collected data from both advanced and traditional technologies of Rawat brick kilns market i.e. Chak Baily and Laoser Morh. Nearly 30 to 40 kilns are operating and most of the kilns are Fixed Chimney Brick Kilns or Partial Zigzag Kilns, while full Zigzag Brick kilns are very few in number.

2.7.4 Peshawar

Peshawar district is the capital of KPK province, located in the northern part of Pakistan. It is the sixth largest city of Pakistan and it is about one-tenth of the total province in size but has nearly 50 % of the province's population. Peshawar city lies to the west of the Bara River, a tributary of the Kabul River, near the Khyber Pass. The rainfall in Peshawar is significant, even the driest month of the year has some level of precipitation. The temperature averages 22.3 °C or 72.1 °F. Precipitation ranges from 817 mm to 32.2 inches per year. Peshawar is the habitat of about 2.2 million individuals nearly 56 % of the total population of the province while total area is 1257 sq km. Peshawar district is an agricultural area as well as hub of different industries like sugar mills, textile mills, fruit canning, leather and shoe industries, glazed pottery, wax and embroidery work, copper utensils, *lungi*s (a type of sarong), turbans, carpets, ornamental woodwork and furniture, ivory work, knives, and small arms. Besides these different industries, brick production industries of Peshawar play an important role in the industrial sector. According to the report of Environmental Protection Agency of KPK, there are nearly 800 brick kilns operating in different districts of KPK i.e. in district Mardan, Peshawar, Nowshera, Swabi, Dera Ismail Khan, Bannu etc. This research has selected Peshawar district for the collection of data from brick kilns. Nearly 300 brick kilns are operating in different area of Peshawar, using the traditional technique for brick production. Compare with Punjab province, nearly 1% kilns have adopted the latest zigzag technology for brick production. These 300 kilns are operating in Pandu Market, Urmar Market, Matha Bachee Market, Bagh Banan bricks market and Jalozai (*och neer*) market.

2.8 Estimation techniques

This section explains the private and social cost benefit analysis which has been used for the economic valuation of two types of brick kilns technologies.

2.8.1 Private Cost-Benefit Analysis

Private cost and benefit analysis is the economic analysis of FCBK and ZZBK technologies from the entrepreneur's view point. In PCB analysis this research is estimates the total cost of brick producing technologies and the total private benefit of each technology. The market prices are used as the basis for calculating total private costs and benefits of FCBK and ZZBK (Croitoru & Sarraf, 2012; Eil et al., 2020).

2.8.1.1 Empirical Model

Private cost = Upfront investment + Annual cost

$$\mathbf{PC = UI + AC} \qquad \mathbf{(1)}$$

Upfront investment = kiln structure cost+ cost of chimney+ cost of machineries + cost of shelter houses for labors + cost of water

$$\mathbf{UI = KSC + MC + LHC + WC} \qquad \mathbf{(a)}$$

Annual cost = Land lease + all types of taxes paid + and operation cost

$$\mathbf{AC = LL + T + OC} \qquad \mathbf{(b)}$$

Operation cost = cost of labors + cost of fuel(coal) + cost of clay and soil + building cost+ electricity cost + plastic cost + additional cost

$$\mathbf{OC = LC + CC + CSC + PC + EC + AC + BC} \quad \textbf{(c)}$$

$$\mathbf{AC = LL + T + LC + CC + CSC + PC + EC + AC + BC} \quad \textbf{(d)}$$

So

$$\mathbf{PC = KSC + MC + LHC + WC + LL + T + LC + CC + CSC + PC + EC + AC + BC} \quad (2)$$

While

Private Benefit = Value of total bricks produced

$$\mathbf{PB = VB} \quad (3)$$

2.8.2 Social Cost and Benefit Analysis

Social cost and benefit analysis is also known as economic analysis from a social viewpoint. The SCB analysis of FCBK and ZZBK includes the private costs and benefits assessment as well as the social costs and benefit assessment (Croitoru & Sarraf, 2012; Eil et al., 2020; Sharif & Nasim, 2020).

2.8.2.1 Direct Cost

Direct costs and benefits include the cost and benefits which is calculated by the private cost-benefit analysis excluding all types of taxes i.e. income tax, sales tax and value added tax paid by the owner of brick kilns. Market prices are used as a tool for calculating direct costs and benefits of brick kilns and these market prices are known as real prices or economic prices because these prices are not subsidized by any government organization (Croitoru and Sarraf, 2012).

Direct cost = private cost – taxes

$$\mathbf{DC = PC - T} \quad \textbf{(1)}$$

$$\mathbf{PC = UI + AC} \quad \textbf{(a)}$$

$$\mathbf{PC = KSC + MC + LHC + WC + LL + T + LC + CC + CSC + PC + EC + AC + BC} \quad \textbf{(b)}$$

$$\mathbf{DC = (KSC + MC + LHC + WC + LL + T + LC + CC + CSC + PC + EC + AC + BC) - T} \quad \textbf{(c)}$$

$$\mathbf{DC = KSC + MC + LHC + WC + LL + LC + CC + CSC + PC + EC + AC + BC} \quad (2)$$

Direct benefit = Market or Economic value of total bricks or Private Benefit

Where,

$$\mathbf{PB = VB} \quad \textbf{(d)}$$

So,

$$\mathbf{DB = VB} \quad \textbf{(3)}$$

2.8.2.2 Cost of CO_2 emissions

The cost of the effect of CO_2 emissions on environment is one of the major components in estimating the social cost of brick production technologies. Bhattacharjya (2018), Croitoru & Sarraf (2012), Eil et al. (2020) and, Sharif & Nasim (2020) have used the international market price of CO_2 for estimating the social cost of brick kiln technologies. Following these studies, this research is also using international market price of CO_2 for estimating the total cost of CO_2 emissions. To estimate the total cost of CO_2 emissions, the total quantity of CO_2 emissions produced is multiplied with the price of CO_2 emissions (Croitoru & Sarraf, 2012; Eil et al., 2020; Sharif & Nasim, 2020). The equation used for estimating the cost of CO_2 emissions is given below:

$$\mathbf{CO_2 \text{ emissions} = TP * SEC * CEF * CF}$$

Where,

TP = total brick production (kg of bricks per year),

SEC = specific energy consumption (TJ per kg of bricks),

CEF = IPCC default carbon-emissions factor for fuel used (tC per TJ), and
CF = carbon to CO_2 conversion factor

Social Cost = Direct Cost + Environmental Cost

Where,

Direct cost = PC – T **(a)**

DC = KSC + MC + LHC + WC + LLC + LC + CC + CSC + PC + EC + AC + BC **(b)**

Environmental Cost = Cost of CO_2 emissions **(c)**

So,

SC = DC + EC + HC **(1)**

Table 4. Valuation Methods

Types of analysis	Types of costs and benefits	Valuation method
Private	**Costs:** Investment, land, buildings, operating costs, taxes	Market prices
	Benefits: Value of bricks	Market prices
Social	**Costs:** Investment, land, buildings, operating costs	Real prices
	CO_2 emissions	Price on the carbon market
	Benefits: Value of bricks	Real prices

Source: Croitoru and Sarraf (2012).

3. Results and Discussion

3.1 Descriptive Analysis of Variables and the Market Prices

This section provides a detailed discussion of the descriptive statistic of the all input used for estimating the initial cost i.e. kiln cost, machinery cost, water cost and labor housing cost; and the annual cost which comprises the cost of land, labor, coal, clay, electricity, building, taxes and protection cost or the cost of plastic used for protection or raw bricks, clay and the mud used for making raw bricks. Table 5 presents the average or mean value of all variables along with the minimum and maximum values of each variable or input.

Table 5. Descriptive Statistics of Variables/Inputs (rupees)

Inputs/Variables	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Kiln cost (Millions)	7.01	10	3	5.91	12	1.8
Machinery cost (Millions)	7.45	13.2	4	4.53	7	2
Water cost (Millions)	0.35	1	0.1	0.25	0.6	0.1
Labor Houses Cost (Millions)	4.27	10	2.5	2.33	3.5	1
Land Cost (Millions)	2.29	4.5	0.8	2.25	5.2	1.2
Coal cost (Millions)	27.46	54	9.6	27.04	62.4	14.4
Clay cost (Millions)	3.63	9.4	0.4	5.96	12.4	1.2
Electricity cost (Millions)	2.14	4.2	0.72	1.30	2.4	0.24
Building cost (Millions)	0.77	1.2	0.3	0.48	1	0.2

Taxes and Bribe (Millions)	0.18	0.36	0.06	0.15	0.6	0.04
Office cost (Millions)	1.09	2.52	0.22	0.98	1.44	0.4
Protection Cost (Millions)	1.04	1.8	0.15	0.56	1.2	0.2
Labor Cost (Millions)	30.15	57.6	20.76	23.58	32.4	19.2
(Technology)	**ZZBK**	**ZZBK**	**ZZBK**	**FCBK**	**FCBK**	**FCBK**

Source: *Authors' calculation*.

3.2 Economic Analysis

This section discusses the results of economic analysis of two type of kilns i.e. FCBK and ZZBK, and compares their private costs and benefits as well as their social costs and benefits. The results are estimated using private cost-benefit analysis and social cost-benefit analysis method, based on the data collected from ZZBK and FCBK.

3.2.1 Private Cost

Tables 6 and 7 provide a detailed explanation of annual cost of all inputs used in the production of bricks by both technologies i.e. FCBK and ZZBK.

Table 6. Initial Cost/Upfront Investment (rupees)

Variables	FCBTK	ZZBK	Grand Total
Sum of Kiln cost (Millions)	88.6	105.2	**193.8**
Sum of Machinery cost (Millions)	68	111.7	**179.7**
Sum of Water cost (Millions)	3.77	5.2	**8.97**
Sum of Labor Houses Cost (Millions)	35	64	**99**

Source: Authors' calculation.

Table 7. Annual operating cost(rupees)

Variables	FCBK	ZZBK	Grand Total
Sum of Land Cost (Millions)	33.8	34.32	68.12
Sum of Coal cost (Millions)	405.6	411.84	817.44
Sum of Clay cost (Millions)	89.4	54.5	143.9
Sum of Electricity cost (Millions)	19.51	32.04	51.55
Sum of Building cost (Millions)	7.14	11.52	18.66
Sum of Taxes and Bribe (Millions)	2.292	2.635	4.927
Sum of Office cost (Millions)	14.63	16.322	30.952
Sum of Protection Cost (Millions)	8.4	15.55	23.95
Sum of Labor Cost (Millions)	353.76	452.28	806.04

Source: Authors' calculation.

The private cost analysis shows that ZZBK has a higher initial cost which is 286 million PKRs while the FCBK initial cost is 195 million PKR. The private cost of ZZBK is almost 33% higher than that of FCBK as shown in figure 1. This is because of use of modern technologies and machinery for the production of bricks by ZZBK. Similar results have been reported by (Eil et al., 2020; Sharif &

Nasim, 2020). Furthermore, a detailed discussion on initial cost/upfront investment of both technologies i.e. ZZBK and FCBK is presented in figure 2. Figure 3 presents the results of the estimation of total annual operating cost of ZZBK and FCBK. The results show that the annual operating cost of ZZBK is 9.5% higher than that of FCBK. This increase in annual operating cost is attributed to the use of more labor and coal for the production of bricks by using ZZBK. The annual operating cost is 1031 million PKR for ZZBK and 934.5 million PKR for FCBK. Similar results have been reported by (Croitoru & Sarraf, 2012; Eil et al., 2020). Furthermore, figure 4 provides a comparison of the estimated annual costs of inputs such as labor, coal, clay etc.

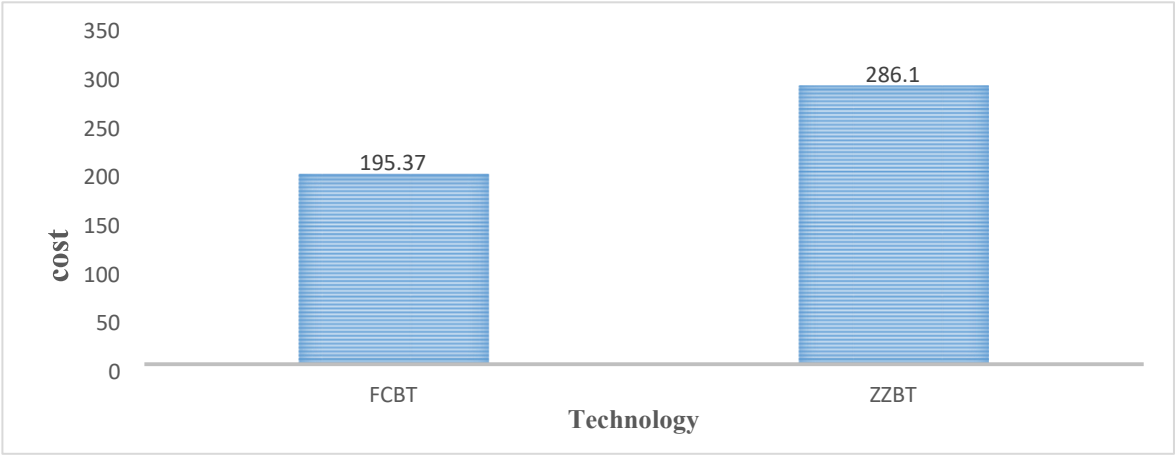


Figure 1. Total Initial cost/Upfront investment(rupees)

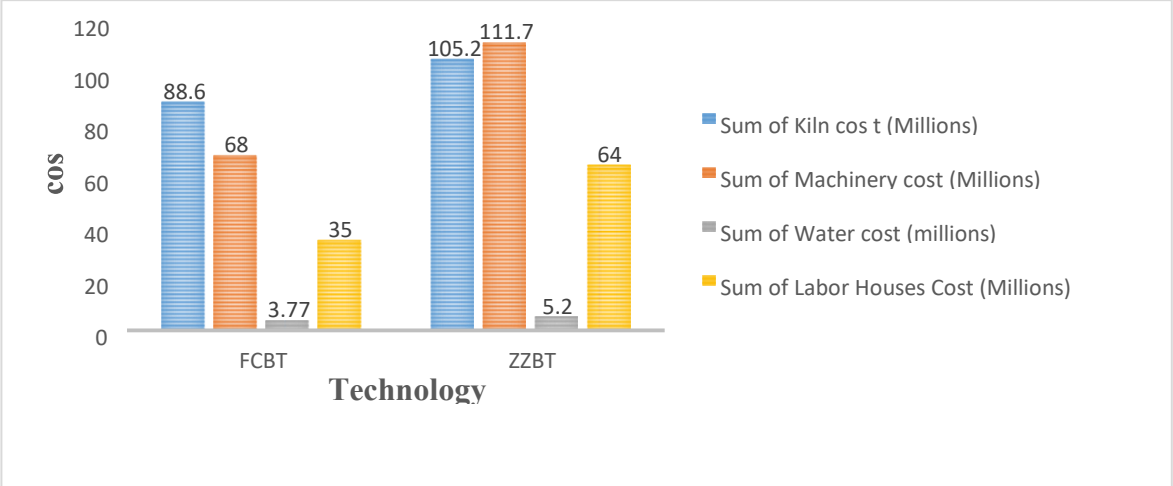


Figure 2. Initial cost/Upfront investment(rupees)

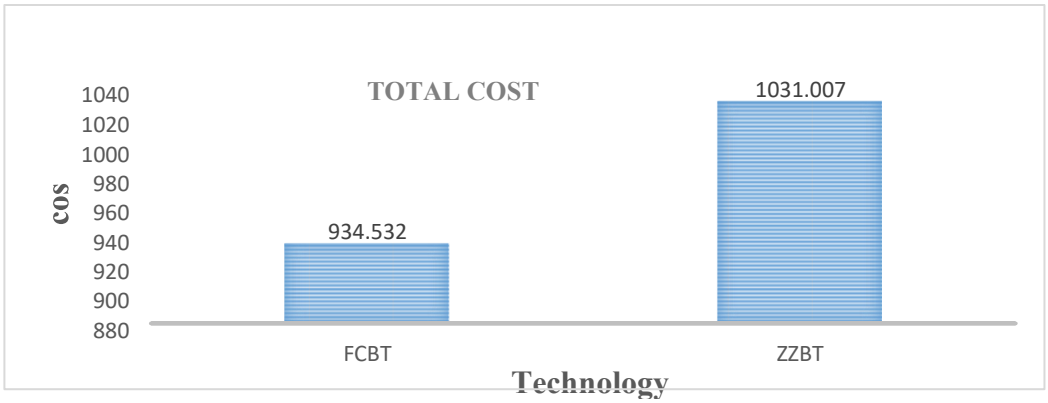


Figure 3. Total Annual Operating Cost (Rupees)

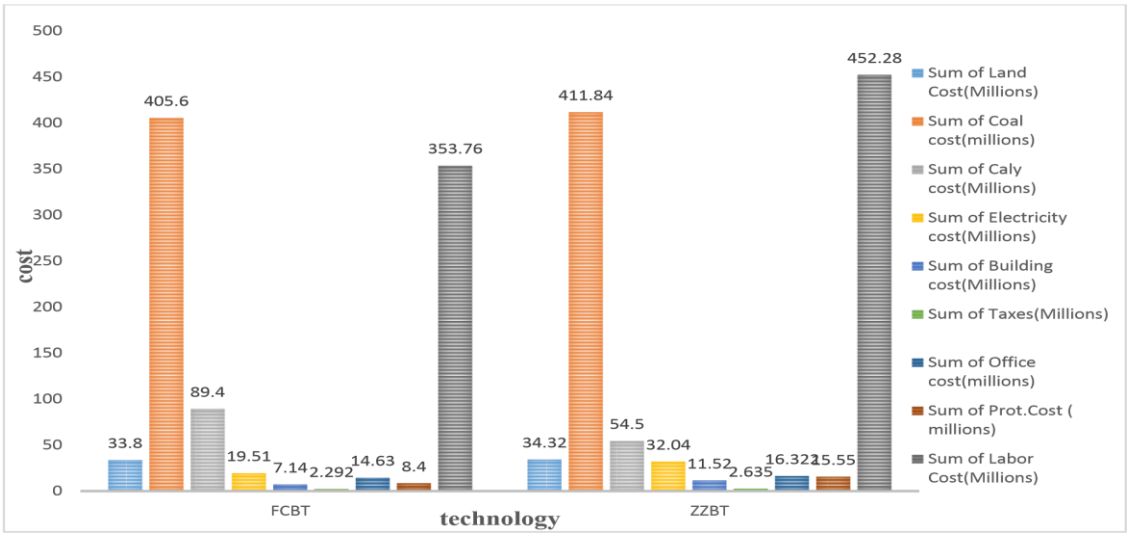


Figure 4. Annual operating cost of FCBK and ZZBK (rupees)

3.2.2 Private benefit

Private benefit includes the total market value of bricks produced by FCBK and ZZBK. Table 8 provides a detailed explanation of the price level of each type of bricks.

Table 8. Price level of Different types of bricks(rupees)

Brick Types	Average Price	Maximum Price	Minimum Price
A	9.7	12	8
B	5.9	8	4
C	7.4	10	5.5
K	7.7	10	6
T	7.1	8	5
D	4967	8000	3000

Source: Authors' analysis.

This study has also analyzed the total brick production of both technologies and has estimated that a total of 315 million bricks are produced annually by both brick producing technologies. Of these, almost 169.8 million bricks are produced by ZZBK while 145.2 million bricks are produced by FCBK

as shown in table 9. These bricks produced by ZZBK and FCBTKare classified into six different types i.e. **A** (*Awal*) **B** (*Doyem*), **C** (*Soyem*), **K** (*Kanger*), **T** (*Tora*) and **D** (*Dakra*).

Table 9. Total bricks production(million)

Technology	Monthly bricks production	Annual bricks production
FCBTK	12.1	145.2
ZZBK	14.15	169.8
Grand Total	**26.25**	**315**

Source: Authors' analysis.

Figure 5 shows different types of bricks produced annually by ZZBK and FCBK. The results show that A level bricks are produced on a large scale by both technologies i.e. 121.2 million bricks by ZZBK and 102.85 million by FCBK. ZZBK produces almost 15% more of A level brick than traditional FCBK, and this is because of the use of advanced and energy efficient technology for brick production. A similar pattern is observed in B and C level bricks which are produced in higher quantity. However, the situation reverses for T type bricks which are produced in greater quantities by FCBK and in smaller quantities by ZZBK. Furthermore, Table 10 explains the total annual production of each type of brick produced by both technologies i.e. traditional FCBK and advanced ZZBK. Similar results have been reported by (Darain et al., 2016; Sharif & Nasim, 2020).

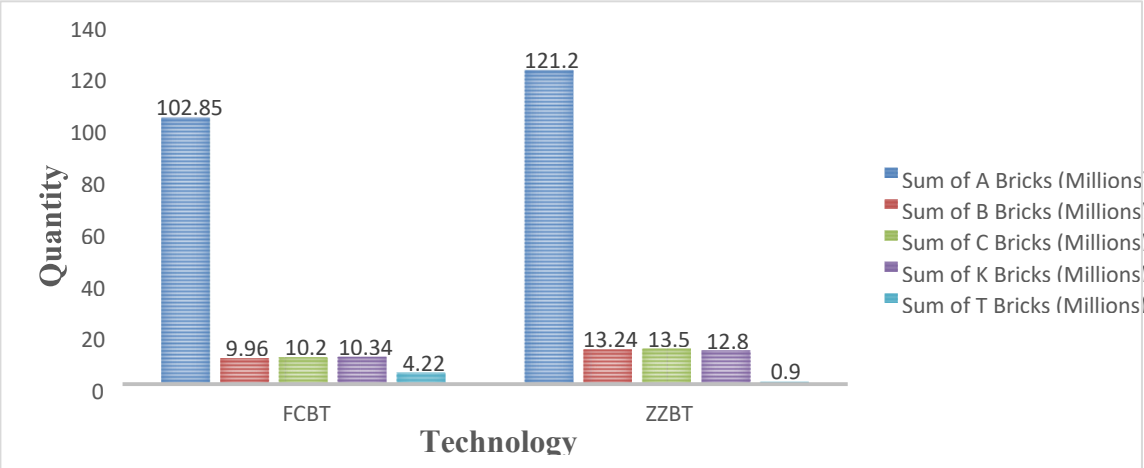


Figure 5. Total production of different types of bricks

Table 10. Total annual production of all types of bricks

Row Labels	Sum of A Bricks (Millions)	Sum of B Bricks (Millions)	Sum of C Bricks (Millions)	Sum of K Bricks (Millions)	Sum of T Bricks (Millions)	Sum of D bricks (Trolleys)
FCBK	102.85	9.96	10.2	10.34	4.22	828
ZZBK	121.2	13.24	13.5	12.8	0.9	927
Grand Total	**224.05**	**23.2**	**23.7**	**23.14**	**5.12**	**1755**

Source: Authors' analysis.

Figure 6 and 7 show the percentage wise production of different types of bricks produced by each FCBK and ZZBK respectively. The results show that 74.8% of bricks produced by FCBK are A level bricks and remaining 25.2% are other types of bricks. In comparison 75% of bricks produced by ZZBK are A level bricks and remaining 25% are other types of bricks.

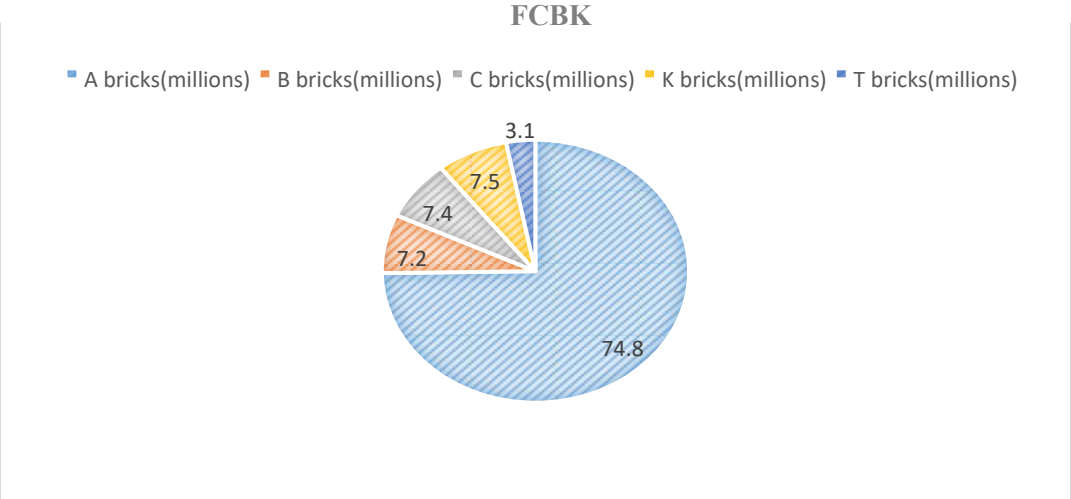


Figure 6. Bricks production (Percentage)

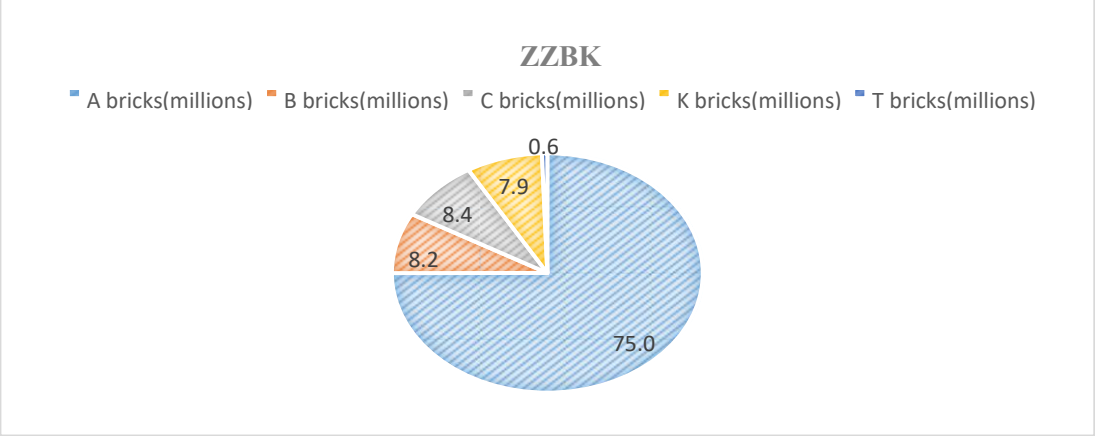


Figure 7. Bricks production (Percentage)

Furthermore, the results of the Private cost-benefit analysis have shown that the total private benefit or the market value of bricks produced by FCBK and ZZBK is 2746.46 million PKR of which the total value of bricks produced by ZZBK is 1512.65 million PKR, while the total market value of bricks produced by FCBK is 1233.8 million PKR. The private benefit of ZZBK is almost 19% greater than the private benefit of FCBK as shown in figure 3.8. This increase in the private benefit of ZZBT is attributed to the higher production of A level brick resulting from the use of new advanced technology. Similar results have been reported by (Croitoru & Sarraf, 2012; Eil et al., 2020). Further explanation of the market value of different types of bricks produced by FCBK and ZZBK is given in figure 9, while table 11 shows the total market value of each type of brick.

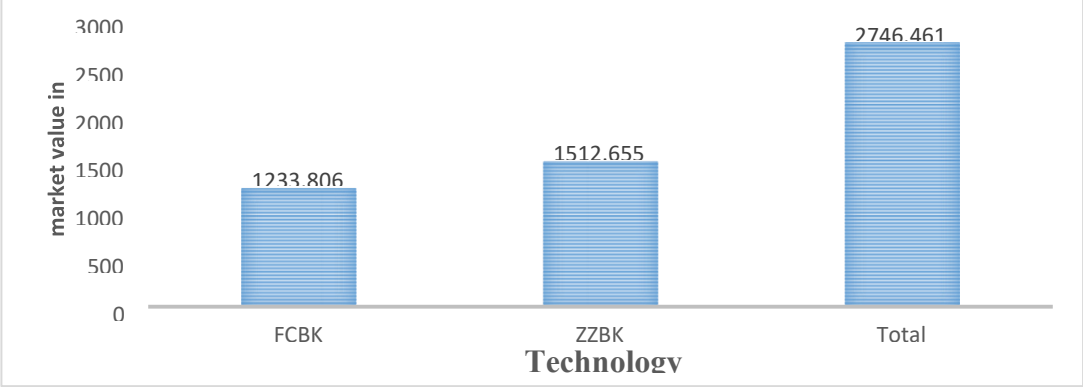


Figure 8. Total Private Benefit

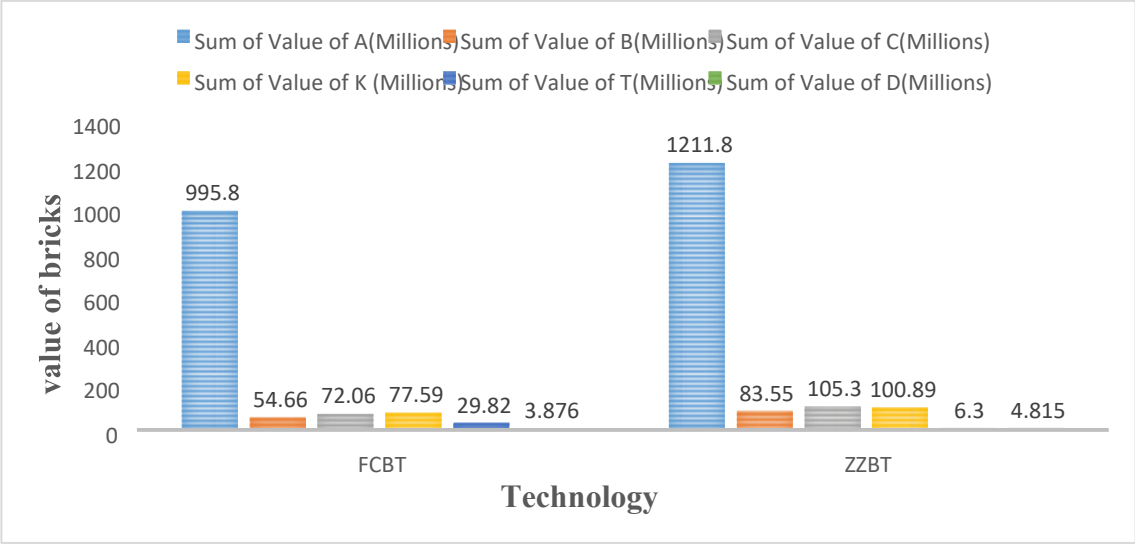


Figure 9: Private benefit/total market value(rupees)

Table 11. Total market value of bricks(rupees)

Brick types	FCBT	ZZBT	Grand Total
Sum of Value of A (Millions)	995.8	1211.8	**2207.6**
Sum of Value of B (Millions)	54.66	83.55	**138.21**
Sum of Value of C (Millions)	72.06	105.3	**177.36**
Sum of Value of K (Millions)	77.59	100.89	**178.48**
Sum of Value of T (Millions)	29.82	6.3	**36.12**
Sum of Value of D (Millions)	3.876	4.815	**8.691**

Source: *Authors' analysis.*

For estimating the net private benefits of FCBK and ZZBK, this study has calculated the difference between the total cost of production of FCBK and ZZBK i.e. 1129.902 million PKR and 1317.107 million PKR respectively, and from the total annual revenue of FCBK and ZZBK i.e. 1233.806 million PKR and 1512.65 million PKR respectively. The estimated result show that the net private benefit of FCBK is 103.904 million PKR while the net private benefit of ZZBK is 195.543 million PKR. Figure

10 shows that the net private benefit of ZZBK is almost 88.2% higher than the net private benefit of FCBK because of the use of new technology which is more productive and energy efficient. Similar results have also been reported by (Croitoru & Sarraf, 2012; Eil et al., 2020; Sharif & Nasim, 2020).

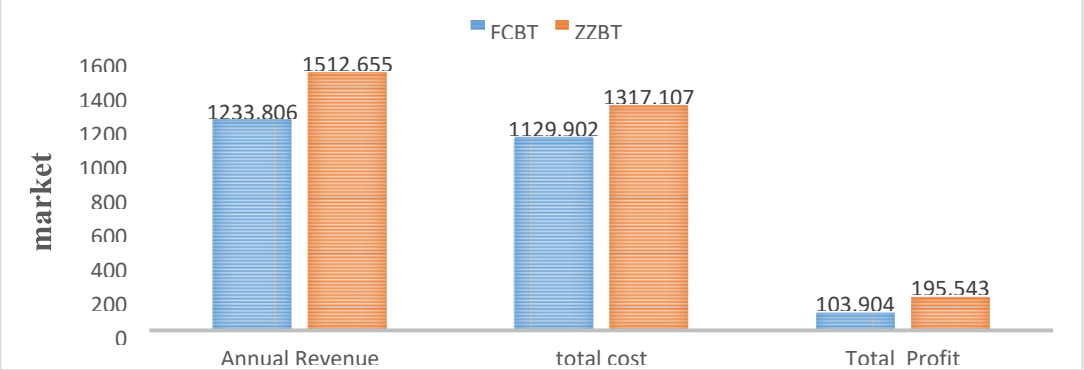


Figure 10: Net Private benefit/total market value(rupees)

3.3 Social Cost

Social cost-benefit analysis is an analysis of brick kilns from social view point. The total estimated direct cost of both brick kilns is 2242.08 million PKR in which 1314.4 million PKR is the total direct cost of ZZBK, while 1127.61 million PKR is the direct cost of FCBK as shown in figure 11.

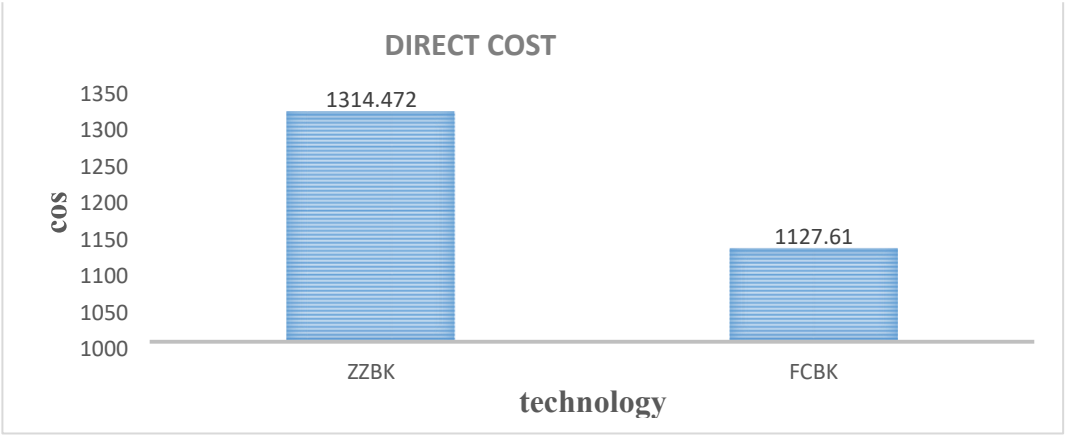


Figure 11: Direct Cost

3.3.1 Cost of CO_2 emissions

This study has estimated the environmental cost of CO_2 emissions by analyzing the cost of CO_2 emissions through the social cost-benefit analysis The result shows that 11613.29 tons of CO_2 emissions are produced annually of which 4575 tons are produced by ZZBK. The remaining 7038.29 tons of CO_2 emissions are produced by FCBK. The estimated CO_2 emissions produced by ZZBK and FCBK are 0.000404 and 0.000727 tons per brick respectively. Using the international market price of CO_2, the social cost of CO_2 emissions is estimated as 2.49 PKR per brick for ZZBK, while it is 4.47 PKR per brick for FCBK. Due to its lower social cost, ZZBK is considered as cleaner technology as compared with traditional FCBK. (Bhattacharjya, 2018; Larsen, 2016; Pengoriya, 2018) have also reported similar results in their analysis. Further details of CO_2 cost estimations are given in table 12.

Table 12. Social Cost of CO_2 emissions

Technologies	ZZBK	FCBK
Total Brick Production ($million\ bricks$)	11.32	9.68
Total Weight of a Brick (kg)	2.9	2.9
Total Weight of Bricks (t)	32,828	28,072
Total Coal Consumption (t)	1740	1660
Total Coal Consumption (t/100,000 $bricks$)	15.37	17.14
Coal Consumption per Brick ($kg/brick$)	0.1537	0.1714
Specific Energy Consumption per Brick ($MJ/brick$)	4.28	7.7
Carbon Emissions Factor (C/MJ)	25.8	25.8
Carbon to CO_2 Conversion Factor	3.66	3.66
Annual CO_2 Emissions (t)	4575.00	7038.29
Annual CO_2 per Brick (t/100,000 $bricks$)	40.41	72.70
Price of CO_2 Emissions (\$/t)	34.99	34.99
Annual Cost of CO_2Emissions (\$)	160079.21	246269.61
Annual Cost of CO_2 Emissions per Brick (\$/$brick$)	0.014	0.025
Annual Cost of CO_2 Emissions per Brick ($Rs./brick$)	2.49	4.47

Source: *Brick weight is taken from domestic brick sector, Carbon emissions factor, Carbon to CO_2 conversion factor and Specific energy consumption taken from (Croitoru & Sarraf, 2012; Eil et al., 2020; Sharif & Nasim, 2020). Price of CO_2 emissions has taken for International market (year-2021).*

Table 13 provides a detailed explanation of the estimation of annual cost of CO_2 emissions in domestic currency i.e. rupee. The results show that the total annual cost of CO_2 emissions produced by traditional FCBK is 35% i.e. 15.15 million PKR higher than the annual cost of CO_2 emissions produced by advanced ZZBK. (Eil et al., 2020; Larsen, 2016; Lopez et al., 2012) have reported similar results in their analysis.

Table 13. Cost of CO_2 emissions(rupees)

Technology	FCBK	ZZBK
Annual CO_2 emissions (tons)	7038.29	4575
Cost of CO_2 per ton	6148.79	6148.79
Annual cost of CO_2 emissions (million)	43.28	28.13

Source: *Author's calculation and Current exchange rate i.e. 1USD = 175.73 PKR.*

3.4 Net social cost and benefits

Table 14 shows the net social cost and benefits of traditional FCBK and advanced ZZBK. The results show that the net total social cost of FCBK and ZZBK is 1170.89 and 1342.60 million PKR respectively. The higher social cost of ZZBT is due to its higher direct cost rather than cost of CO_2 emissions i.e. the environmental cost. Furthermore, the net social benefit of ZZBK is 171% higher than that of FCBK i.e. 170.5 million PKR and 62.92 million PKR respectively. This higher net social benefit is attributed to the use of advanced ZZBK for brick production. Similar results have also been reported by (Bhattacharjya, 2018; Lopez et al., 2012; Sharif & Nasim, 2020)

Table 14. Net social costs and benefits(rupees)

Technology	FCBK	ZZBK
Direct cost (million)	1127.61	1314.47
Cost of CO_2 (million)	43.28	28.13
Total social cost (million)	1170.89	1342.60
Social benefit (million)	1233.806	1512.655
Net social benefit (million)	62.92	170.05

Source: Author's analysis.

3.5 Environmental and Energy-efficiency

Table 15 shows the comparison of coal consumption and CO_2 emissions between both technologies. The results show that 17.14 tons of coal is consumed by FCBK for baking 100,000 bricks, while ZZBK consumes 15.37 tons of coal for baking 100,000 bricks. Furthermore, total 72.7 tons of CO_2 emissions are produced by FCBK, while 40.14 tons of CO_2 emissions are produced by ZZBK for baking 100,000 bricks. ZZBK produces 32.56 tons less CO_2 emissions than FCBK and this is because of the use of new advanced and environmentally friendly technology for bricks production. It has also been estimated that by adopting new advanced ZZBK, CO_2 emissions can be reduced by an average of 0.3256 kg per brick. Similar results have also been reported by (Croitoru & Sarraf, 2012; Larsen, 2016; Rahman & Kazi, 2019; Sharif & Nasim, 2020).

Table 15. Energy consumption and CO_2 emissions

Technology	FCBK	ZZBK
Coal consumption (tons/100,000 bricks)	17.14	15.37
CO_2 Emissions (tons/100,000 bricks)	72.7	40.14
CO_2 Reduction(tons/100,000)	Na	32.56
CO_2 emissions reduction (kg/ brick)	Na	0.326

Source: *Author's calculation.*

3.6 Factors Hindering the Adoption of Zigzag Brick Kiln Technology

To achieve the third objective, this study conducted in-depth interviews with the brick kiln owners and the Head of Brick Kilns Association of Fateh Jangh and Peshawar. The following reasons were highlighted by the respondents:

3.6.1 High Initial and Transition Costs.

The additional cost associated with converting existing FCBK into ZZBK emerged as one of the major barriers to adoption. Most kiln owners reported that they already have fully operational kilns generating satisfactory revenues. So shifting towards ZZBK will be a substantial financial burden. Also, they would have to shut down the business for 3 -4 months during the reconstruction process, resulting in significant income losses. Nearly 70% of respondents stated that shifting to ZZBK would l cost huge amount of additional finances. The installation of new technology requires a huge amount of additional investment or financial support. As for the installing of new ZZBT or retrofitting current FCBT to ZZBK technology needs modification of shape of kiln walls i.e. changing from round shape to square shape and modification of old chimney into new one, and installation of machinery such as blower machine, dynamo or electric motor and other associated devices.

3.6.2 Increased Input Requirements and Production Risks

For production of bricks through ZZBK, the brick kiln owners need double inputs mainly land, labor, capital, clay and coal which results in an increase in the cost of production. This is because ZZBKs are larger in size and shape as compared to FCBK and also produce more bricks than FCBK. Almost 90% of brick producers have said that ZZBK requires double the input requirement as compared to FCBK. Furthermore, those who have adopted ZZBK have faced a huge amount of loss due to the increase in production of low quality bricks. This is because their current workers have no knowledge and expertise in the use of ZZBK which results in increased production over burned or half fired bricks and the inefficient use of coal.

3.6.3 Shortage of Skilled Labor and Technical Expertise

So for producing good quality of bricks through ZZBK, the brick kiln owners need highly skilled workers and skilled labor force. Almost all ZZBK owners have stated that they had faced a huge amount of loss in the beginning of ZZBK installation due to lack of expertise. Furthermore, ZZBK will be fuel efficient if it runs properly and in the presence of skilled workers with relevant expertise, otherwise it will be inefficient in fuel consumption. Because if the workers have no experience in firing system of ZZBK, then it will lead to over consumption of coal or the coal will stay unburnt in the kiln and convert to waste

ZZBT is a new advance technology that uses few electrical devices and machines like a blower machine and a temperature maintaining device. The workers of FCBK have no knowledge or experience in the use of these machines and devices. All respondents have said that due to the lack of skilled labors and workers they don't want to install ZZBT. Moreover, the skilled constructors of ZZBK are not available in domestic brick kiln sector. One hundred percent of respondents have expressed that due to the lack of skilled constructors and mechanics, they don't want to shift towards ZZBT.

Moreover, the workers of brick kilns need 3-5 months of practical training in different ZZBK to gain experience and knowledge about the use of new technology. The workers are uneducated or have only primary education. Therefore, it's too difficult for them to gain knowledge and experience about the use of ZZBT in only t 2-3 weeks of training.

3.6.4 Inadequate and Unreliable Electricity Supply

ZZBK has some electrical devices and motors which need 24 hours of electricity for operation, otherwise ZZBK will not operate in the absence of electricity. But unfortunately they hardly receive 5-15 hours of electricity on a daily basis. Therefore, the government needs to assure the reliable supply of 24 hours of electricity for brick kiln owners. One hundred percent of the respondents have agreed that if they can get a reliable electricity supply from government, they will happily shift towards ZZBT.

3.6.5 Uncertainty regarding Land Tenure and Future Relocation

Respondents are not willing to shift to ZZBT due to lack of certainty about the existence of their kilns at the same place in future years because the government can issue them a notice for removing or shifting their kiln at any time. Furthermore, some brick kilns need 1-3 years of extension of the dead line of shifting towards ZZBK. This is because they have a minimum period of time left in their land lease agreement and they are not sure about the renewal of land lease agreement with land owners.

3.6.6 Limited Government and Financial Support

Furthermore, the government has just issued notice to shift towards ZZBT to brick kiln owners without conducting any pilot test of the new technology or developing any plat form at the ground level for introducing new technology. They added that they will shift to ZZBK, if government provides them financial support in terms of subsidies, long term loans, interest free or low interest loans for shifting

towards the new technology. According to the respondents, the amount of loan should not be less than five million PKR because two or three million PKR are not enough for installing ZZBT.

4. Conclusion

The private cost and benefit analysis demonstrates that although ZZBK requires higher initial and operating costs than FCBK due to the use of its modern technology, machinery and greater input requirements, it provides greater economic and environmental benefits. ZZBK has higher production capacity and produces a slightly higher proportion of A –type bricks, which contributes to its higher private benefits and substantially greater net private benefits compared with FCBK.

From a social perspective, ZZBK also performs better than traditional FCBK. Despite its higher direct cost, ZZBK generates substantially low levels of CO_2 emissions and consequently incurs lower social and environmental costs. The lower emissions demonstrate the environmental advantage of ZZBK and supports its classification as a cleaner and more efficient brick production technology.

Overall the findings indicate that ZZBK is socially, environmentally and economically more beneficial than FCBK. Therefore, the adoption of ZZBK can provide greater overall benefits to brick kiln owners and society, provided that the technology is properly installed, operated and supported by the necessary technical and institutional facilities.

4.1 Policy Recommendations

- Before introducing new technology, local authorities in collaboration with brick kilns association should establish an appropriate support system at ground level, conduct a pilot test of a new technology and arrange practical training sessions for brick kiln owners and workers to develop the knowledge and experience required to operate the advance technology. Trainings should also be provided to kiln constructors to develop their capacity to construct and install new technology.
- The installation of new technology or retrofitting of existing kilns requires substantial additional investment. Therefore, the brick kilns association, in cooperation with financial institutions should facilitate access to interest free, long-term loans and low interest loans for brick kiln owners to install or retrofit the new technology. In addition, the underplay financing system in the brick kiln sector should be brought into the formal financial system.
- The findings of this study highlight the critical importance of a reliable electricity supply for the adoption of ZZBK. To enable the brick kiln sector to adopt ZZBK and to reduce the CO_2 emissions up 40%, the brick kiln sector should be provided with a reasonable continuous supply of electricity as ensured to other formal sectors.
- The official authorities should consider brick kiln sector as a formal sector and develop appropriate policies and regulations for its effective regulation and implementation. This should include a proper taxation, licensing and registration system, a copy right system for their trademarks, a formal agreement system between labor and kiln owners that clearly defines labor rights, kiln owner rights and wage rates.
- The Brick Kilns Association along with the owners of successful ZZBK should organize awareness workshops and practical demonstration events in different brick clusters. This is particularly important as almost 90% of the brick kilns owners are unaware about the economic and social benefit of ZZBK. The findings also indicate that that many kiln owners believe that FCBK and ZZBK produces same emissions and that the only difference is the color of emissions. Their understanding of the private and social cost-benefit analysis of the two technologies is limited. Awareness programs should provide evidence-based information on the differences in emissions, energy efficiency, production, private benefits and social costs associated with FCBK and ZZBK

4.2 Suggestions for Further Research

This is first study in Pakistan which has analyzed the brick kilns sector of Pakistan in depth. Further research can extend the social cost analysis by incorporating the health costs associated with brick kiln emissions, which were not included in our study because of financial and time constraints The survey can be expanded to the district level to generate more comprehensive evidence and improve awareness of the brick kiln owners and policymakers.

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