Environmental Challenges 15 (2024) 100928

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Technologies, emission estimation, and feasibility of cleaner technologies in brick industry of Nepal

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ARTICLE INFO

Keywords:
Brick kilns
CO_2 emission
Emission factor
Brick firing technologies
Cleaner technologies

ABSTRACT

The brick industry is a significant contributor to economy of Nepal, but it is also a key source of greenhouse gas (GHG) emissions and air pollution. This study explores the current state of the brick industry in Nepal, the technologies used for brick production, and the feasibility of cleaner technologies using desk reviews, field surveys, and consultations. A total of 1.30 mT CO_2-e (million tons of CO_2 equivalent) emission is estimated from 1236 brick kilns in 41 districts of Nepal. The majority of brick kilns use traditional technologies, which are highly inefficient and produce large amounts of emissions. Several cleaner technologies are identified as viable alternatives, including Zigzag Kilns, Vertical Shaft Brick Kilns (VSBK), and Hybrid Hoffman Kilns (HHKs). Based on the evaluation of technological, environmental, financial, resource, and legal feasibilities, the zigzag and HHKs are identified as the most promising options for reducing emissions and improving environmental sustainability in the brick industry in Nepal. We conclude that while there are technical and economic barriers to adopting cleaner technologies in the brick industry, there are also opportunities for government support and private sector investment to drive more sustainable brick production in Nepal. A combination of policy incentives, financial support, and technical assistance help to accelerate the adoption of cleaner technologies in the brick industry, leading to significant environmental and economic benefits for the country.

1. Introduction

The brick industry plays a crucial role in the economy of Nepal, providing employment to thousands of people and supporting the construction sector; however, the production of bricks is highly energy-intensive and polluting, contributing significantly to the country's GHG emissions and air pollution (MoFE, 2021). In recent years, the negative impacts of the brick industry on our environment and public health have become a major concern, prompting calls for the adoption of cleaner technologies.

1.1. Brick kiln industry

The brick industry is growing rapidly in Nepal and has the potential to produce large amounts of CO_2 as a byproduct of a chemical conversion process; however, there are scant studies to estimate the emission from the current operation of these industries. Previous studies cover the brick kiln issue such as the environmental impacts of brick kilns (Shrestha and Jha, 2019; Khanal, 2018), emission characteristics of brick kilns (Shrestha and Shrestha, 2018) and mitigation options for reducing the impact of the brick industry on our environment (Singh and Singh, 2015).

The brick industry in Nepal faces challenges related to high emissions and inefficient technologies, primarily due to the excessive use of coal for firing bricks (Minergy, 2017). Introducing cleaner brick manufacturing technologies has the potential to significantly reduce CO_2 emissions in the long term, with estimates suggesting savings of up to 30% from 2019 to 2050 (Abbas et al., 2021). The feasibility of cleaner alternative technologies in the brick sector has been assessed in countries like Bangladesh, highlighting the importance of transitioning to

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https://doi.org/10.1016/j.envc.2024.100928
Received 18 March 2024; Received in revised form 22 April 2024; Accepted 29 April 2024
Available online 1 May 2024

more sustainable practices (Guttikunda and Khaliquzzaman, 2013). In South Asia, efforts have been made to mitigate emissions from brick kilns through various strategies and technologies, emphasizing the need for emission reduction in this industry (Seay et al., 2021). India's brick sector, characterized by traditional firing technologies and high emissions, underscores the importance of transitioning to energy-efficient and low-emission technologies (Greentech, 2012). Additionally, Nepal's long-term strategy for achieving net-zero emissions includes the adoption of electric tunnel kilns in the brick industry, further emphasizing the importance of cleaner technologies in reducing CO_2 emissions (GoN, 2021).

1.2. Emission from brick kiln

The brick kiln industry in Nepal is a significant contributor to ambient air pollution and greenhouse gases, with approximately 1000 operational brick kilns in the country (Nepal, 2019). Studies have shown that emissions from brick kilns can have a detrimental impact on the environment and human health (Guttikunda and Khaliquzzaman, 2013; Rajarathnam et al., 2014). For example, emissions from brick kilns can lead to the release of particulate matter, including heavy metals such as chromium and lead, which can affect soil quality in agricultural fields located near brick kilns (Bisht and Neupane, 2015). Additionally, emissions from brick kilns can contribute to the overall particulate matter levels in the atmosphere, with PM2.5 values potentially exceeding reported values (Jayarathne et al., 2018).

As per the recent national GHG inventory of Nepal, brick manufacturing is one of the emission key categories of the country (MoFE, 2021). The estimation of emissions from these key categories was based on the Tier 1 approach by using default IPCC emission factors (EFs) due to the unavailability of the country-specific EFs (IPCC, 2006). An EF relates the quantity of emission released from a source to some activity associated with those emissions. Country-specific EFs are inevitable for a more accurate estimate of the emission (Stockwell et al., 2016).

Efforts have been made to assess and reduce emissions from brick kilns in South Asia, including Nepal. Studies have evaluated different brick-making technologies and their environmental performance, suggesting that the adoption of cleaner kiln technologies such as Zigzag or vertical shaft brick kilns can lead to improvements in environmental performance (Rajarathnam et al., 2014). Furthermore, research has highlighted the importance of transitioning to cleaner brick manufacturing technologies to achieve emission reductions and health cost savings (Guttikunda and Khaliquzzaman, 2013). Recent studies have also focused on monitoring emissions from brick kilns in Nepal, with a particular emphasis on stack emissions. The findings indicate that while some brick kilns have adopted cleaner technologies such as Vertical Shaft Brick Kilns (VSBK), the majority still use traditional technologies like Induced Draft BTK with Zigzag setting patterns for green brick stacking and fuel feeding (Sah et al., 2020). Efforts to improve energy efficiency and reduce pollution in brick kilns have shown promising results, with pollution reductions of over 70% for particulate matter and coal consumption reductions of around 30% at the individual kiln level (Khaliquzzaman et al., 2020).

To address the environmental and health impacts of emissions from brick kilns in Nepal, an integrated approach is needed. This approach should focus on improving working and living conditions in brick kilns, as well as promoting the adoption of cleaner technologies to transform the industry into a healthier and more environmentally responsible sector (Bajracharya et al., 2022). Regulatory measures and incentives may also be necessary to facilitate the transition to cleaner brick manufacturing technologies (Guttikunda and Khaliquzzaman, 2013).

The research gap lies in the lack of comprehensive studies that address the following aspects: i) While cleaner technologies like Vertical Shaft Brick Kilns (VSBKs) and Tunnel Kilns have been introduced in Nepal, there is a need for a detailed assessment of their suitability, operational requirements, and potential challenges in different regions of the country, ii) accurate and up-to-date estimates of emissions from the brick industry in Nepal are lacking. Quantifying the extent of air pollution, greenhouse gas emissions, and other environmental impacts is essential for establishing baselines and evaluating the potential benefits of cleaner technologies, iii) a comprehensive feasibility study is required to assess the economic, social, and environmental viability of cleaner brick kiln technologies in Nepal. This analysis should consider factors such as initial investment costs, operational expenses, potential cost savings, resource availability, and societal impacts.

Therefore, to mitigate the emission of the brick industry and provide recommendations for policy and research to promote sustainable development in the sector, it is inevitable to understand the current status and ongoing development of the brick industry in Nepal. This study aims to review the current state of technologies used in the brick industry in Nepal, estimate the emissions produced by the industry, and evaluate the feasibility of implementing cleaner technologies. The paper also discusses the challenges and opportunities associated with the adoption of cleaner technologies in the brick industry in Nepal.

2. Study area

The focus of this study is the brick industry of Nepal that has a long history of brick production, with an estimated 2 billion bricks produced annually, making it an important contributor to the country's economy; however, the brick industry in Nepal is also a significant source of GHG emissions and air pollution. The study considers the brick kilns located in all districts of Nepal.

3. Materials and methods

3.1. Data sources

The study uses a comprehensive review of the existing literature on the brick industry in Nepal, including studies on emission estimation and technological solutions. The study also draws on primary data collected from the rapid field survey, and phone and in-person interviews with industry experts and stakeholders, including brick manufacturers, government officials, and non-governmental organizations.

3.2. Data collection

The first step of the assessment was the desk review and identification of the data availability status and data gaps (Fig. 1). After the identification of the data gap from the review of the existing data sources, the data collection from the field was performed by sampling brick kilns. The number of brick kilns (National and Provincial) was collected from the Department of Industry, Ministry of Finance, Federation of Nepal Brick Industries (FNBI), Brick Manufacture Association of Nepal and other relevant agencies. Data regarding fuel consumption and brick production was collected from FNBI, physically from some selected brick kilns and other secondary sources.

To update and validate the number of brick kilns in each district, a rapid field survey and phone survey were conducted. A questionnaire and a checklist were designed to collect data. Interviews with representatives of stakeholders and actors were conducted. The range of stakeholders includes brick kiln entrepreneurs and their associations, government officials, and experts in the field of brick production and environmental sustainability. The qualitative information received from the interviews was used to substantiate the information collected from the desk review. The questionnaire/checklist was also utilized to carry out the field survey in the selected brick factories. About 10 % of the brick kiln numbers were sampled from each district to collect information related to the feasibility.

This study was carried out during the COVID-19 pandemic situation. In many instances, the data collections on brick factories from different

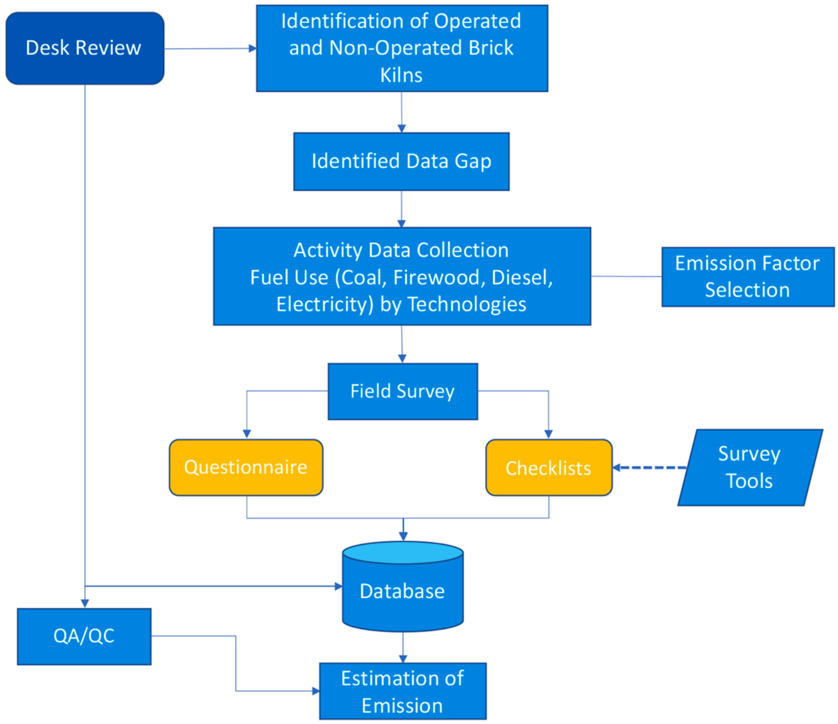

Fig. 1. Flow chart for determining emission from brick production.

districts were done using remote survey techniques and direct field visits. Telephone interviews and email surveys were used to address the limitations of the COVID lockdown. Some activity data that requires long-term monitoring was not possible to collect. Furthermore, during the rainy season, many of the brick kilns were shut down as they are seasonally operated.

3.3. Data analysis

3.3.1. Estimation of CO_2 emission from brick production

The net CO_2 emission from the brick kilns is the function of CO_2 emissions from coal, firewood, diesel, and electricity use. The CO_2 emission from coal consumption was determined by using Eq. (1).

$$Direct\ CO_2 = FC \times CEF \times f_o \times 44/12 \tag{1}$$

where, FC = total annual coal consumption in an energy conservation unit of the brick kiln during a year (TJ); CEF = carbon EF of coal (tC/TJ); f_o= carbon fraction of coal that has been oxidized during the combustion process; 44/12 = stoichiometric factor i.e. mass conversion factor of mass carbon to mass CO_2 generated during combustion processes (IPCC, 2006)

The CO_2 emission from firewood consumption was estimated using Eq. (2).

$$Carbon\ emission\ from\ firewood = Quantity\ of\ firewood \times Net\ Calorific\ value \times CO_2\ EF\ for\ the\ biomass\ fuel \tag{2}$$

where, Net Calorific value = 0.015 TJ/ton; CO_2 EF = 109.6 t CO_2/TJ. The EF for the firewood biomass is 1.644 t CO_2/ton of firewood (IPCC, 2006)

Similarly, the CO_2 emission due to diesel and electricity consumption was also estimated. The data regarding diesel and electricity consumption was collected from the field. For the EFs of diesel and electricity consumption, 2.69 kg CO_2/L and 0.82 kg CO_2/unit were used respectively (Maheshwari and Jain, 2017).

Finally, the net CO_2 emission of Bricks was determined by using Eq. (3).

$$Net\ CO_2\ emission = CO_2\ emission\ from\ Coal\ Consumption + CO_2\ emission\ from\ firewood\ Consumption + CO_2\ emission\ due\ to\ the\ Diesel\ and\ Electricity\ Consumption \tag{3}$$

The EFs for brick manufacturing for fuel consumption are given in Table 1.

3.3.2. Feasibility evaluation of cleaner technologies

To evaluate the feasibility of the cleaner technologies for brick production in Nepal by the private sector to reduce emissions in terms of policies, finance and incentive mechanisms, the following five viability components were considered: *Legal, Technology, Environment, Finance, and Resources* (Fig. 2) that could impact the adoption of cleaner technologies, as well as the potential benefits and challenges of transitioning to these technologies. The feasibility of using cleaner technology to reduce emissions was determined using the data obtained from the field survey and the review of existing literature, including the review of the policies, acts, guidelines, and standards.

Table 1
Default EF for coal in the brick manufacturing industry (kg of GHG per TJ on a Net Calorific basis).

GHG Emission	EF (kg/TJ)*	Global Warming Potential (GWP)**
CO_2	94,600	1
CH_4	10	28
N_2O	1.5	265

* IPCC (2006).
** GHG Protocol (https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf).

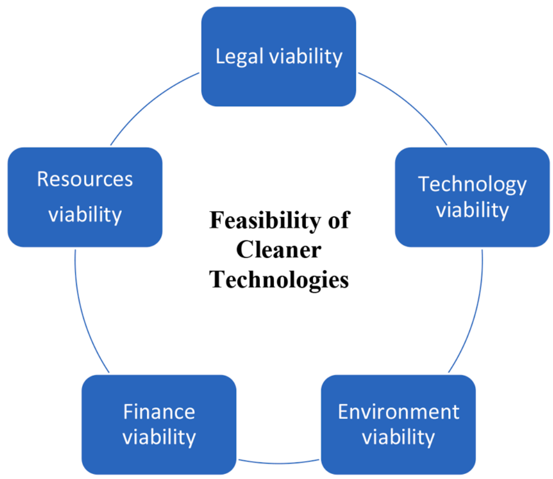

Fig. 2. Different components to be considered for the feasibility evaluation of the cleaner technologies in brick industry.

4. Results and discussion

4.1. Distribution of brick kilns

Brick kilns are an important part of the construction industry in Nepal, providing the main source of bricks for building homes, schools, and other infrastructure; however, these kilns have been a source of controversy due to the negative environmental and health impacts associated with their operation. Our result shows that a total of 1236 brick kilns were operating in 41 districts of Nepal in 2020 (Fig. 3). Most of the brick kilns were found in Madhesh province followed by Lumbini, Bagmati and Koshi Province (Table 2).

This estimation is lower than the estimates made by the National Brick Kiln Monitoring Committee (NBKMC). According to the study by the NBKMC in Nepal, there are over 1500 registered brick kilns in the country, with an estimated annual production capacity of 9.6 billion bricks (Khadka et al., 2019). However, it is also estimated that there are many more unregistered kilns, making the total number of brick kilns in Nepal difficult to determine.

Table 2
Province-wide distribution of brick kiln numbers.

Province	FNBI	% FNBI	Non-FNBI	% Non-FNBI	Total
Koshi	56	7.7	26	5.1	82
Madhesh	291	40.0	299	58.7	590
Bagmati	162	22.3	35	6.9	197
Gandaki	5	0.7	21	4.1	26
Karnali	0	0	2	0.4	2
Lumbini	164	22.6	97	19.1	261
Sudurpaschim	49	6.7	29	5.7	78
Total	727	100	509	100	1236

The operation of brick kilns in Nepal has significant environmental impacts. The use of coal and other fossil fuels as the main source of energy for firing the kilns releases large amounts of CO_2, SO_2, and particulate matter into the air, contributing to air pollution and global warming. In addition, the extraction of clay for making bricks can cause soil erosion and deforestation (Bhuju et al., 2016). Brick kilns have also negative impacts on the health of workers and nearby communities. The burning of coal and other fossil fuels produces hazardous emissions that cause respiratory problems, including asthma and lung cancer. In addition, the use of child labour in brick kilns is a persistent problem in Nepal, with many children working long hours in hazardous conditions (Bhandari et al., 2016).

Efforts have been made to mitigate the negative impacts of brick kilns in Nepal. In 2019, the government of Nepal issued regulations requiring brick kilns to switch from coal to cleaner-burning fuels, such as natural gas or liquefied petroleum gas (LPG), by 2025 (Ministry of Industry, Commerce and Supplies, 2019); however, the implementation of

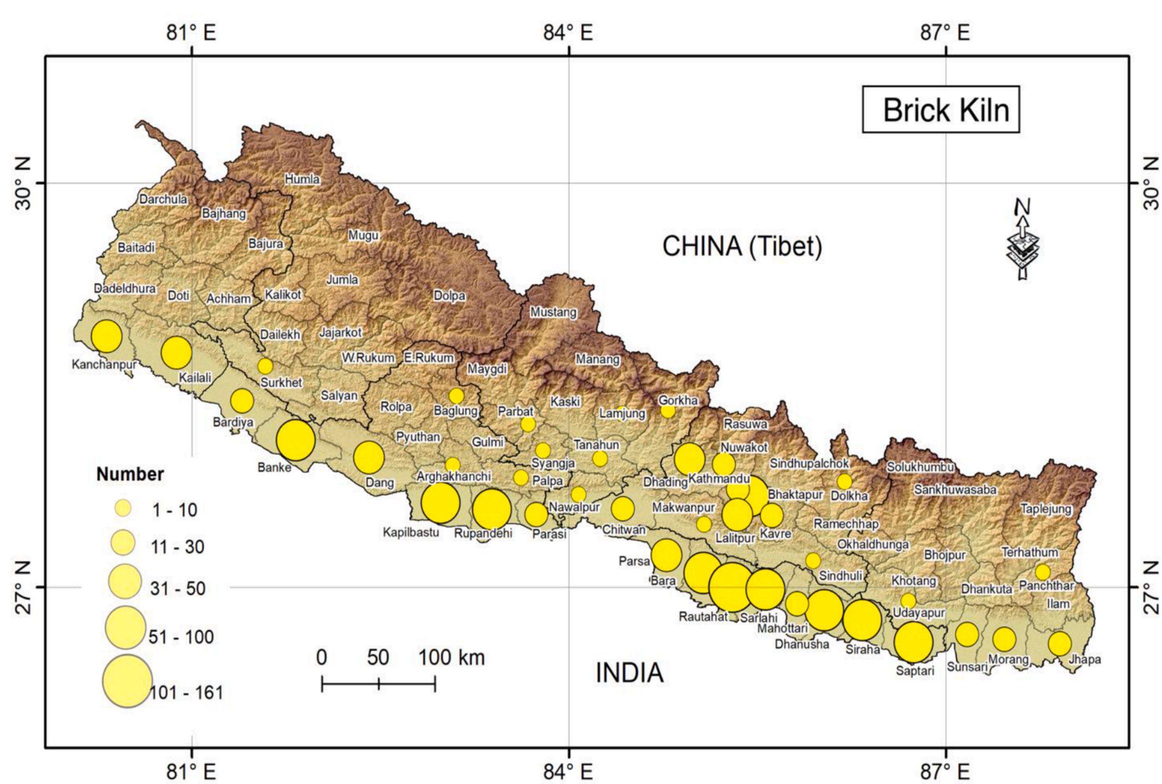

Fig. 3. Map showing the location of Brick Kilns in Nepal.

Table 3
Available brick kiln technologies and the number of brick kilns in Nepal.

SN	Brick Firing Technology	Characteristic	Number of Brick Kiln (in 2020)
1	(a) Straight-line FCBTK (natural draft) (b) Straight-line FCBTK (forced/ induced draft)	Permanent and fixed chimney, 100–120 ft tall Forced or natural type	817
2	(a) Zig-zag FCBTK (natural draft) (b) Zig-zag FCBTK (forced/induced draft)	Similar to (1), but with zig-zag flow, Forced zig-zag type energy efficient and high environmental performance than other FCBTKs	263
3	Vertical Shaft Brick Kilns (VSBK)	Energy-efficient, environment-friendly, invented in China, in Nepal since 2003, 30% reduction in energy consumption & 80% reduction in pollutant emissions	25
4	Hoffmann kiln (HK)	FCBTK, closed structure, all year round in operation	6
5	Tunnel kiln (TK)	Metallic fences, ageing warehouse, tunnel dryer, Drying and firing in tunnel kiln	3
6	Hybrid Hoffman Kilns (HHK)	Mix of pulverized coal and clay, use natural gas, or coal, combines fuel injection and external firing in insulated kiln, high quality brick with reduced emission	2
7	Clamp kiln	Traditional, mostly in hilly regions	114
8	Movable Chimney Bull's Trench Kiln (MCBTK)	Continuous firing, 6–10 m metal sheet chimneys Surface heat loss significant (energy inefficient & polluting)	6
	Total		1236

these regulations has been slow, and many brick kilns continue to operate using coal.

4.2. *Brick firing technologies*

Eight different brick-firing technologies are reported from Nepal (Table 3). Out of 1236 brick kilns operated in 41 districts of Nepal, 6 were illegally operated with MCBTK, 817 with straight-line FCBTK, 263 Zig-zag FCBTK and 25 have adopted VSBK Technology. The adoption of new technologies such as Tunnel Kilns and HHK was also introduced in Nepal.

Clamp kiln (114) is the most traditional brick technology and available in the hilly regions of Nepal. Movable Chimney Bull's Trench Kiln (MCBTK) was the most common brick technology used in Nepal, but due to its air quality impacts and energy inefficiency, it was legally banned from Kathmandu Valley from 2004 and outside the valley in 2012; however, in some parts of Terai region, it is still reported operating illegally. New technologies, such as the VSBK, Tunnel Kilns, and HHK are considerably cleaner than currently used Fixed Chimney BTK (FCBTK). These enhanced technologies utilize reduced energy and emit lower levels of pollutants and GHGs.

The VSBKs are a type of kiln that is designed to be more efficient and environmentally friendly than traditional kilns. According to the United Nations Industrial Development Organization (UNIDO) report, VSBKs can reduce coal consumption by up to 50 % and reduce emissions of particulate matter and other pollutants by up to 90 % (UNIDO, 2012). Another study (Beard et al., 2022) found that the levels of gaseous air pollutants and respirable crystalline silica (SiO_2) were low and often undetectable both inside and outside the homes of brick kiln workers in Bhaktapur, Kathmandu Valley, Nepal.

HHKs are a type of kiln that combines elements of traditional Hoffman kilns with more efficient zigzag kilns. According to the International Finance Corporation (IFC), HHKs can reduce coal consumption by up to 35 % and reduce emissions of particulate matter and other pollutants by up to 50 % (IFC, 2018). Similarly, the study by the Ministry of Population and Environment shows that zigzag kilns can reduce coal consumption by up to 30 % and reduce emissions of particulate matter and CO by up to 50 % and is effective for pollution reduction (MoPE, 2017). Another study shows that adoption of Zig-Zag Kiln (ZZK) technology leads to a substantial reduction in several environmental impact categories. Specifically, it decreases particulate matter formation (PMF) by 63%, photochemical oxidant formation (POF) by 93%, and terrestrial acidification (TA) by 95% when compared to the conventional brick kiln technologies (Bashir et al., 2023).

Efforts to promote these technologies in Nepal are ongoing. For example, the UNDP is supporting the adoption of VSBKs and HHKs through its Clean Brick Production in Nepal project, which provides technical assistance and financing to brick kiln owners (UNDP, 2018). In addition, the IFC has launched a program to promote the implementation of cleaner technologies in brick kilns in South Asia, including Nepal (IFC, 2018).

4.3. *Fuel consumption*

A total of 465,220 tons of coal equivalent per year is used as the fuel for the brick sector in Nepal. The most widely used fuel for brick production is coal (82 %) followed by diesel (8.9 %) and firewood (8.7 %). Furthermore, wood chips, petroleum, bagasse, and rice husk are also used as the energy source in operating the brick kilns. Fig. 4 represents the major fuel types in the brick industry of Nepal. According to a study, rice husk can be used as a fuel in brick kilns, reducing the need for coal and other fossil fuels (Shrestha et al., 2017). In addition, the use of rice husk as a fuel can reduce GHG emissions and improve the livelihoods of local rice farmers by providing an additional source of income.

According to the International Centre for Integrated Mountain Development (ICIMOD) study, brick kilns in Nepal consume an estimated 1.5 mT of coal and biomass per year (ICIMOD, 2019). The high fuel consumption of brick kilns is due to several factors, including the use of inefficient technologies, poor combustion practices, and the low quality of the fuel used. Inefficient technologies such as traditional fixed chimney kilns and clamp kilns have low thermal efficiency and require large amounts of fuel to produce bricks. Poor combustion practices, such as incomplete combustion and inefficient use of combustion air, also contribute to high fuel consumption and emissions.

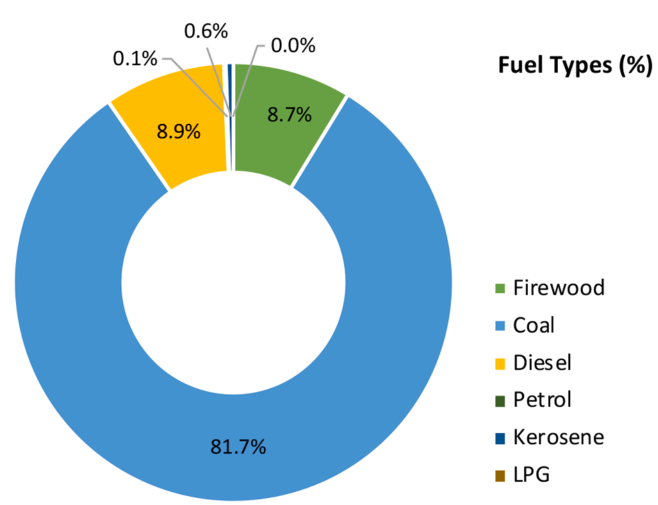

Fig. 4. Use of different fuel types in brick kilns in Nepal.

Table 4
GHG emissions from brick kilns in Nepal.

Technology	Number	Coal consumption (ton)	Emission (ton)			
			CO_2	CH_4	N_2O	CO_2-Eq
Straight-line FCBTK (natural draft) Straight-line FCBTK (forced/induced draft)	817	330,644	916,711	96.9	14.5	923,276
Zig-zag FCBTK (natural draft) Zig-zag FCBTK (forced/induced draft)	263	77,487	214,832	22.7	3.4	216,370
VSBK	25	5714	15,842	1.7	0.3	15,956
Hoffmann kiln	6	10,624	29,455	3.1	0.5	29,666
Tunnel kiln	3	7139	19,793	2.1	0.3	19,935
HHK	2	2266	6282	0.7	0.1	6327
Clamp kiln	114	27,386	75,929	8.0	1.2	76,473
MCBTK	6	3962	10,984	1.2	0.2	11,063
Total	1236	465,222	1,289,828	136	20	1,299,065

4.4. GHG emissions from the brick industry

Emission from the brick kiln is from the fuel used during its operation. CO_2, CH_4, and N_2O are the main GHGs emitted from the brick industry like other industrial emissions (Thakuri et al., 2021). The estimation of these direct gases using the 2020 fuel use (activity data) and default EF from the IPCC database (Table 1) shows a total emission of 1.30 million tons of CO_2-equivalent (Table 4). CO_2 is the main GHG in the brick production process.

The brick industry in Nepal is a significant source of GHG emissions, primarily due to the high fuel consumption and poor combustion practices of traditional brick kilns (Bhandari, 2017). According to a study by the ICIMOD, the brick industry in Nepal is responsible for an estimated 5.1 mT of CO_2 emissions per year (ICIMOD, 2019). The use of inefficient technologies, poor combustion practices, and the low quality of the fuel used contribute to the high GHG emissions of the brick industry.

We compared the emissions computed based on the EFs provided in Sadavarte et al. (2019) for CO_2, CH_4, and N_2O for different brick kiln technologies. The emission estimated by using those EFs were significantly (8–60 %) lower than computed in this study, marking the role of country-specific EFs in the emission computation.

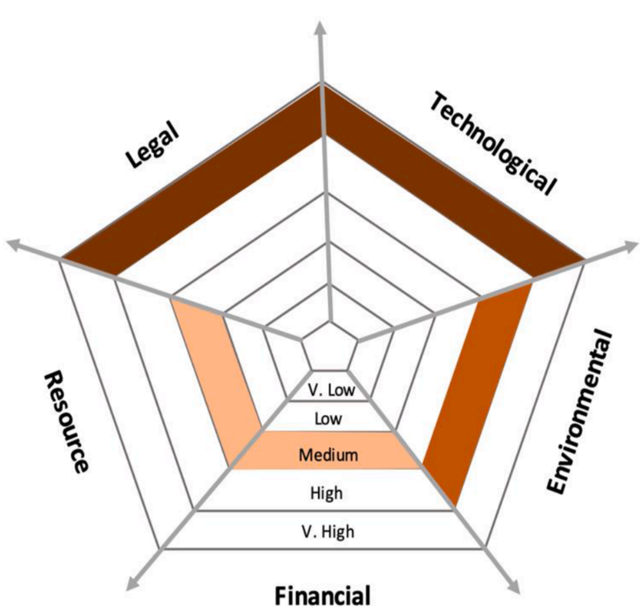

Fig. 5. Feasibility assessment based on five indicators (technological, environmental, financial, resource, and legal viability) for the clean technologies in the brick industry in Nepal.

4.5. Viability of cleaner technologies in the brick industry

Reducing GHG emissions from the brick industry in Nepal is essential to mitigate the impact of climate change and improve air quality. The adoption of cleaner technologies can not only reduce GHG emissions but can also result in long-term cost savings through reduced fuel consumption and improved productivity. Fig. 5 summarizes the feasibility of cleaner technologies in the brick industry based on five indicators. The result shows medium resource and financial feasibility, high environmental feasibility and very high technological and legal feasibility.

4.5.1. Technological viability

In the brick industry, multiple technologies are available and already tested and practiced in Nepal. This study identified 1236 Brick Kilns operated in 41 districts of Nepal. Technology such as MBTK, straight-line FCBTK, Zig-zag FCBTK and VSBK have been operated in Nepal. The adoption of new technologies such as Tunnel Kilns and HHK was also introduced in Nepal. The VSBK exhibits the lowest energy consumption, as evidenced by its specific energy consumption (SEC) in Mega Joules per kg of fire bricks, as shown in the table below, compared to other commonly used technologies. Specifically, the SEC of VSBK is 28.5 % lower than that of FCBTK and 33.6 % lower than that of MCBTK. Additionally, the enhanced FCBTK, featuring the Forced Draught Zigzag stacking pattern, demonstrates superior energy efficiency compared to other methods within FCBTK and MCBTK. (Manandhar and Dangol, 2013). These environmentally friendly technologies have demonstrated success and feasibility in Nepal.

4.5.2. Environmental viability

Within the brick industry, VSBK exhibits superior environmental performance compared to all other technologies. VSBK produces 28.5 % less Suspended Particulate Matter compared to FCBTK and 33.6 % less compared to MCBTK. Likewise, VSBK emits 84.2 % less toxic gas Sulphur Dioxide (SO2) than FCBTK. Moreover, the environmental performance of the Forced Draught Zigzag Stacking method within FCBTK surpasses that of other FCBTK technologies. (Manandhar and Dangol, 2013). New technologies such as Tunnel Kilns and HHK are considered substantially cleaner than the currently used FCBTK. These enhanced technologies decrease fuel consumption, utilize less energy, and emit lower levels of pollutants and greenhouse gases (GHGs), aligning with the country's priorities (MoFE, 2020).

4.5.3. Financial viability

Even if the VSBK technology is energy efficient and low emitter, higher initial investments and lower returns of VSBK compared to FCBTK have been one of the key issues to be widely accepted by entrepreneurs in Nepal. Hoffmann Kiln was introduced in Nepal since long time ago, but due to the high investment cost, it has also not received considerable acceptance in Nepal. Financial constraints in the brick sector entrepreneurs have affected the efforts to introduce lower-emission and higher-efficient kilns like, HHK and Tunnel Kilns that cost about 10 times higher than that of FCBTK. Financial institutions and banks typically do not categorize brick kilns as industries, resulting in a lack of access to commercial or industrial loans with competitive interest rates. As a result, many brick entrepreneurs' resort to private lending and investment, which discourages investment in energy-efficient technologies.

The initial investment required for upgrading or establishing cleaner brick kilns can be substantial, which may be a barrier for small-scale brick manufacturers; however, in the long run, cleaner technologies can provide cost savings through improved energy efficiency and lower fuel costs, potentially offsetting the initial investment. Access to financing options, such as loans or government incentives, can facilitate the adoption of cleaner technologies.

4.5.4. *Resource viability*

Nepal has access to alternative fuels like natural gas and biomass, which can be used in cleaner brick kilns, reducing dependence on traditional fuels like coal or wood. However, the availability and consistent supply of these alternative fuels may vary across different regions, posing challenges for some brick manufacturers.

The brick industry also requires management or administrative, skilled, semi-skilled and unskilled human resources. Management and administrative staff are quite sufficient but the supply of technical staff is limited and is an issue to the industry. About 22 % of workers in the brick industry are Nepalese and the rest are Indian. Skilled technicians for installations, operations and maintenance of the plants are unavailable in the country for the brick industry (ILO, UNICEF and CBS, 2020).

4.5.5. *Legal viability*

The legal viability of cleaner technologies in the brick industry in Nepal has been addressed in various policies and regulations (Table 5). The government of Nepal has implemented several policies and initiatives to promote the adoption of cleaner technologies in the brick industry and reduce the environmental impact of brick production. One of the key initiatives is the Brick Clean Production Campaign, launched in 2013 by the Ministry of Industry, Commerce and Supplies. The campaign aims to promote the adoption of cleaner technologies in the brick industry and improve the environmental performance of brick kilns. As part of the campaign, the government has provided financial incentives and technical assistance to brick manufacturers to adopt cleaner technologies such as VSBKs and HHKs. In addition to the Brick Clean Production Campaign, the government has also implemented regulations to improve the environmental performance of the brick industry. For example, the Environment Protection Act 2019 and the Environment Protection Regulation 2021 require brick manufacturers to obtain environmental clearances (approval of environment assessment reports) before operating brick kilns. The legal viability of cleaner technologies has also been addressed in Nepal's Nationally Determined Contribution (NDC) under the Paris Agreement (GoN, 2016) through the commitments to reduce emissions from industrial processes and product use. The NDC includes a target to reduce GHG emissions from the brick industry by promoting the adoption of cleaner technologies. Similarly, the National Policy Framework for Brick Sector in Nepal, 2017 mandates all operating fixed chimneys with straight-line firing should be converted to zig-zag firing by 2022.

Table 5
List of national laws and policies relevant to brick industries' cleaner technologies and relevant environmental standards.

Policies and laws	Environmental standards
○ Constitution of Nepal, 2015 ○ Industrial Policy, 2067 ○ National Climate Change Policy, 2019 ○ Long-term strategy net-zero emissions, 2021 ○ Environment Protection Act, 2019 ○ Environment Protection Rules, 2020 ○ Forest Act, 2019 ○ Industrial Enterprises Act, 2016 ○ Company Act, 2006 ○ Investment Board Act, 2019 ○ Private Firm Registration Act, 1957 ○ Labour Act and Social Security Act, 2017 ○ Consumer Protection Act, 2054 ○ Foreign Investment and Technology Act, 1957 ○ Customs Act, 2007 ○ Nepal Standards (Certification Mark) Act, 1980	○ National Ambient Air Quality Standards for Nepal, 2012 ○ Standard on Emission for Dust Particles in Air ○ Standard on Emission of Smoke in Air by New Diesel Generator (Import) ○ WHO Guideline Value on Air Quality ○ Ranges of Emission Reductions Required for Various Stabilization Levels (Bali Declaration) ○ Tolerance Limits for Different Industrial Effluents Discharged into Inland Surface Water ○ Generic Standard/ Tolerance Limits for Different Industrial Effluents Discharged into Inland Surface Water ○ Nepal Water Quality Guidelines for Industries ○ Emission Standards and Chimney Height for Brick Kilns

The viability of cleaner technologies in the brick industry in Nepal has been studied extensively, and research suggests that adopting cleaner technologies such as VSBKs and HHKs can be economically viable. The IFC's study suggests that the adoption of VSBKs can result in significant cost savings for brick manufacturers. The same study found that VSBKs can reduce coal consumption by up to 50 %, resulting in an annual savings of up to US$20,000 per kiln (IFC, 2018). The adoption of cleaner technologies can also result in improved productivity and product quality, leading to increased profitability for brick manufacturers. In addition to cost savings, adopting cleaner technologies can also result in improved environmental performance. The cleaner technologies have significantly higher thermal efficiency and emit fewer GHGs and air pollutants compared to traditional brick kilns. Despite the potential economic and environmental benefits of cleaner technologies, challenges to their adoption remain. These obstacles encompass restricted access to financing, a shortage of technical expertise, and resistance to change from traditional brick manufacturers. However, various government initiatives and international organizations are working to address these challenges and promote the implementation of cleaner technologies within Nepal's brick industry.

5. Conclusion

The brick industry in Nepal is a significant contributor to the country's economy, but it is also responsible for significant environmental pollution. The adoption of cleaner technologies in the brick industry is critical to reducing the emission of harmful pollutants and improving air quality in Nepal. In this study, we assessed the current state of the brick industry, the technologies used for brick production, and the feasibility of cleaner technologies for brick kiln industry in Nepal.

Findings of this study reveal that in 2020, Nepal had a total of 1236 operational brick kilns spread across 41 districts. The majority of these brick kilns were concentrated in the Madhesh province. amongst the recorded brick kilns operating in Nepal, most were categorized as either straight-line Fixed Chimney Bull's Trench Kilns (FCBTKs) or Zig-zag FCBTKs. The study estimated a total emission of 1.30 million tons of carbon dioxide equivalent (CO_{2e}), with carbon dioxide (CO2) being the primary greenhouse gas emitted during the brick production process. The viability assessment for the adoption of cleaner technologies in Nepal's brick industry indicated a medium level of resource and financial feasibility. However, it demonstrated high environmental feasibility and very high technological and legal feasibility, collectively suggesting a high overall viability for the implementation of cleaner technologies in the Nepalese brick industry.

The brick industry is an important sector in Nepal, contributing significantly to the economy and employment. However, traditional brick kilns used in Nepal are known for their high environmental impact, including air pollution, greenhouse gas emissions, and inefficient energy consumption. Despite the availability of cleaner brick kiln technologies, their adoption in Nepal has been relatively slow due to various challenges including lack of awareness, high costs, and limited financial resources. Despite these challenges, the feasibility of cleaner technologies in the brick industry in Nepal is promising. Recent studies have shown that the implementation of cleaner technologies can significantly reduce emissions and improve air quality in the region. Furthermore, initiatives by the government and non-governmental organizations have provided support and incentives to encourage the adoption of these technologies. It is essential to continue investing in research and development to improve the feasibility and affordability of cleaner technologies in the brick industry. This can include partnerships between industry and academia to develop innovative solutions and improve the efficiency of existing technologies. Overall, the implementation of cleaner technologies in the brick industry is not only essential for environmental protection but also for the long-term sustainability of the industry. With concerted efforts and continued investments, it is possible to create a more sustainable and environmentally responsible brick industry in Nepal.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Sudeep Thakuri: Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Anup Basnet:** Writing – review & editing, Methodology, Investigation. **Khagendra Rawal:** Methodology, Data curation. **Raju Chauhan:** Writing – review & editing, Validation, Formal analysis. **Rassu Manandhar:** Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Pragyajan Yalamber Rai:** Writing – review & editing, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This study was a part of the research project undertaken by the Faculty of Science and Technology (FoST), Mid-West University, Nepal with support from the United Nations Development Programme (UNDP). The FoST closely worked with MoFE, UNDP, and relevant national stakeholders.

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