

# Assessment of Carbon Footprint for the Bricks Manufactured in Bangladesh



Pritom Bhowmik Akash, Md. Jahedul Islam, and Md. Reaz Akter Mullick

**Abstract** To meet the ever-increasing demand for construction materials for various development projects and for the housing of growing population, the brick production trend is always upward. However, emission from brick industries is a significant concern, particularly in a developing country like Bangladesh. Carbon Footprint (CF) is an important and widely used environmental indicator defined as the equivalent carbon dioxide emitted into the environment from the direct or indirect activities linked with the manufacturing process of a product. This study reports a detailed evaluation of CF of brick technologies and compares comprehensive carbon efficiency of different types of kilns currently operating in Bangladesh from the perspective of Carbon Footprint analysis. A field survey of six different types of brick kilns was conducted to collect information regarding fuel, electricity, soil, and water used in various operations of the brick manufacturing process. The assessment was carried out by the Intergovernmental Panel on Climate Change (IPCC) guidelines. Among the four different technologies, two Zigzag kilns showed the lowest CF values, 217.561 gm CO<sub>2</sub>-eq/kg fired brick and 218.798 gm CO<sub>2</sub>-eq/kg fired brick, accordingly, for the production of 100,000 bricks. In comparison, the two Fixed-Chimney Kilns (FCK) obtained a higher value of 291.096 gm CO<sub>2</sub>-eq/kg and 265.547 gm CO<sub>2</sub>-eq/kg. Despite being the most efficient technology, Tunnel Kiln showed a higher CF value than Hybrid Hoffman Kiln (HHK). Their CF values are 284.170 gm CO<sub>2</sub>-eq/kg fired brick and 266.795 gm CO<sub>2</sub>-eq/kg fired brick, respectively. This study also identified HHK with the lowest CF value of 203.768 gm CO<sub>2</sub>-eq/kg if fired with natural gas. Being the first carbon footprint study of the brick industry of Bangladesh as per the authors' knowledge, this paper aims to help policymakers taking appropriate

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policy interventions to progress specifically in the implementation of the Sustainable Development Goal 10, i.e., take urgent action to combat climate change and its impacts.

**Keywords** Brick kiln · Carbon footprint · CO<sub>2</sub> emissions · Chattogram–Bangladesh

## 1 Introduction

Human activities are bringing on a rise of 0.2 °C of warming every ten years, thus making Global Warming one of the most globally critical issues [1, 2]. As CO<sub>2</sub> accounts for about 79% of all human-caused greenhouse gas emissions [3], measuring the gas while producing various goods and assessing different products for their contributions to climate change has now become a burning necessity. Carbon footprinting is the primary method for doing this. Carbon Footprint (CF) is a significant environmental indicator to compare the greenhouse gas emission rate from different goods or activities. Usually, it is defined as the amount of equivalent carbon dioxide emitted into the environment over a timeframe or the entire life span of the direct or indirect activities of a single person, organization, or community. Carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and various fluorinated gases are the vital greenhouse gases released into the atmosphere as a consequence of human activities, thus contributing the most to the carbon footprint [3, 4]. Even though CO<sub>2</sub> has the least capacity to absorb heat in the atmosphere, it is released in such large amounts that all greenhouse gases are converted to CO<sub>2</sub> equivalent (CO<sub>2</sub>-eq) to make the total footprint of all gases easier to quantify [5].

Bangladesh has some of the worst air quality globally, and brick kilns are a significant contributor to deteriorating air quality [6]. The brick-making industry is a critical component of Bangladesh's severe air pollution crisis [7]. Improvements in living conditions, continuous technological progress, and growing demand for new infrastructure have contributed to a globally substantial rise in construction material consumption in recent years [8]. Being a developing country, such continuous increment in Bangladesh's housing industry has forced its construction industry to depend on bricks as the primary construction material and thus making the country world's fourth largest brick manufacturer with an annual production of 23 billion bricks [6, 9]. So, the brick industry of Bangladesh is highly accountable for the country's total CO<sub>2</sub> emission.

Although there are a few estimates of carbon emissions from various brick kilns used in Bangladesh, as per author's knowledge, no precise estimate of Carbon Footprint analysis from any kiln in the country is available. Imran et al. [10] estimated CO<sub>2</sub> emissions from the coal/natural gas combustion in the kilns of four different technologies (Bull's Trench Kiln, Fixed Chimney Kiln, Zigzag Kiln, and Hoffman Kiln) in Bangladesh. However, over a while, there has been a change in the existing brick technologies in the country. As of June 2017, the country has 6744 brick kilns,

where Fixed-Chimney Kiln (FCK), Zigzag Kiln, Hybrid Hoffman Kiln (HHK), and Tunnel Kiln are the leading four technologies holding the country's 99.91% of all types of brick kilns [9]. These four types of brick technologies are different from one another in terms of kiln structure, type of fuel used, production capacity, and many more. As a result, an approach has been taken to cover this gap by measuring the CF of different types of brick technologies currently operating in Bangladesh and comparing their carbon efficiency according to their type from the perspective of Carbon Footprint analysis. Moreover, the study also tries to identify and compare the major sources that have the greatest impact on the carbon footprint as a whole. For collecting data regarding all the site activities, a field survey was conducted in the six kilns of four different types of brick technologies in Chittagong. The calculations of CF due to various activities in brick kilns were done using guidelines provided by IPCC & other related resources. However, being the pioneering study on estimating carbon footprint of brick industry of Bangladesh this paper aims to help policymakers suggesting appropriate policy interventions to progress specifically in the implementation of the Sustainable Development Goal 10, i.e., take urgent action to combat climate change and its impacts.

## 2 Materials and Methods

The study region Chattogram located in southern Bangladesh, has all the main types of brick kilns currently available in the country. Hence, six brick kilns of the main four brick technologies of Bangladesh shown in Fig. 1 are designated as: Wood powered FCK (F-1), Coal powered FCK (F-2), Zigzag kiln with electric brick molding machine (Z-1), Zigzag kiln with no brick molding machine (Z-2), Tunnel kiln (T-1), Hybrid Hoffman Kiln (H-1). Before the monsoon season, a field survey was carried out between March and May of 2021. For all six kiln sites, data on the activities involved in the brick manufacturing process, different unit operations, the size and weight of bricks, and the amounts of fuel consumed in various activities are gathered during the field survey.

The "Cradle to Gate" technique estimates the current study's carbon footprint, considering all unit operations and activities until the burned clay brick is prepared for transmission to its final destination from the kiln site [11]. For this study's carbon footprint assessment, Fig. 2a depicts several activities in the brick manufacturing process inside a specific system boundary. Clay bricks are either dried under sun or dried by reusing temperature of firing chamber. So, this is not included in the system boundary. Depending on the data availability for an activity, Tier—I or Tier—II approach has been followed while selecting the emission factors and calculation formulas. For the ease of calculation and data representation, the activities are classified into four sources of CF depicted in the Fig. 2b.

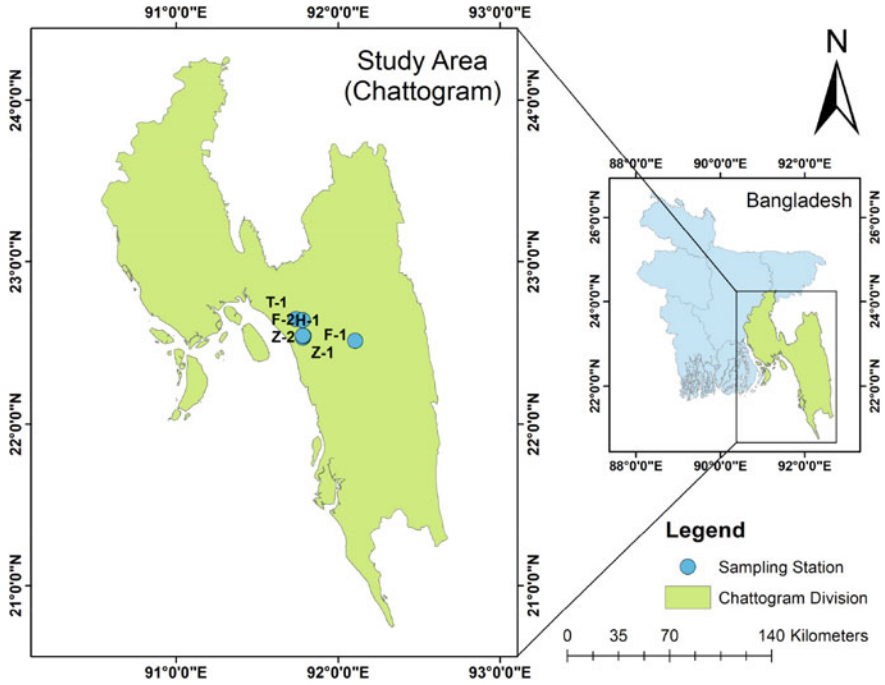


Fig. 1 Location of sampling sites (Chattogram–Bangladesh)

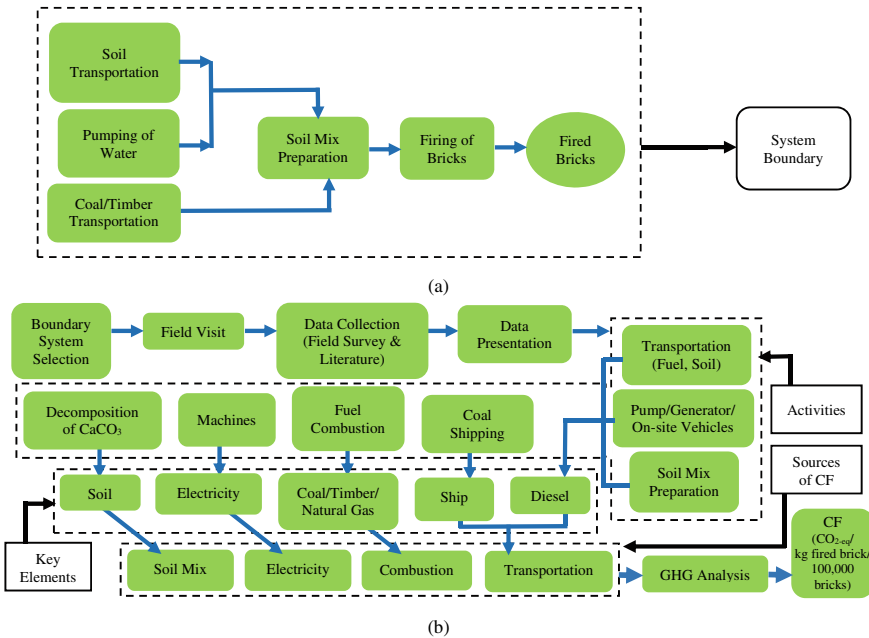
### 2.1 Emission from Coal/ Natural Gas Combustion and Transportation

This study used the following Eq. (1) given by the IPCC (1995) to determine the CO<sub>2</sub> emissions from coal/ natural gas combustion and transportation (except Shipping of Coal) depending on the parameters such as energy usage, emission factors of carbon, and the fraction of oxidized carbon in the fuel.

$$CE_i^t = \sum CE_{ij}^t = \sum E_{ij}^t \times EF_j \times (1 - CS_{jt}) \times O_j \times M \quad (1)$$

where, CE<sub>i</sub><sup>t</sup> stands for total CO<sub>2</sub> emissions in year t (in tons, t),  $\sum CE_{ij}^t$  for total CO<sub>2</sub> emissions of the I sector in year t (in tons, t),  $\sum E_{ij}^t$  for total energy consumption in year t (in tons, t), EF<sub>j</sub> for carbon emission factor of the j fuel (in tons/ton of energy consumed), CS<sub>jt</sub> for a fraction of jth fuel that is not oxidized as raw materials in year t, O<sub>j</sub> denotes the percentage of carbon according to fuel type that has been burned, and M the molecular weight ratio of carbon dioxide to carbon (44/12) [12, 13].

As all the kilns are using Indonesian coal, the net calorific value (NCV) of 25.75 TJ/kt was used [14]. Whilst NCV of diesel is 0.00003594 TJ/L [15]. Table 1 shows the fraction of carbon that has been burned and the carbon emission factors. Fuel was



**Fig. 2** Schematic flowchart for carbon footprint analysis **a** system boundary **b** research framework

taken out of the total amount of paper’s overall energy usage because it was a raw material for producing the end product [13]. Therefore, this analysis also accounted for the complete oxidation of fuels. Although HHK is usually powered by natural gas [9] but H-1 uses coal to fire brick due to delay in getting approval and arrangement of gas supply. Therefore, for a typical gas powered HHK H-1(G), CO<sub>2</sub> emission from gas combustion is calculated using Eq. (1). Here the energy consumption,  $\sum E_{ij}^t$  is assumed to be equivalent to the energy consumption due to coal firing in H-1.

**Table 1** Carbon emission factor and fraction of carbon oxidized<sup>a</sup>

Fuel	Carbon emission factor, EF <sub>j</sub> (tC/TJ)	Fraction of carbon oxidized, O <sub>j</sub>
Coal	25.8	0.98
Diesel	20.2	0.98
Natural gas	15.3	0.995

<sup>a</sup> [12, 13]

## 2.2 Emission from Timber Combustion

Equation [2] is used to determine the carbon emission produced by the combustion of timber in kilns [16]:

$$\text{Carbon emission} = \text{Quantity} \times \text{NCV} \times \text{CO}_2\text{emission factor} \quad (2)$$

where, NCV of wood is 0.015 TJ/ton [17].

## 2.3 Emission from Electricity

The following Eq. (3) is used to find the CO<sub>2</sub> emission from electricity consumption [16]:

$$\text{Carbon emission} = \text{Electricity consumption} \times \text{Grid emission factor} \quad (3)$$

## 2.4 Emission from Soil Mix

Kulkarni & Rao (2016) [11] assumed the clamps' firing temperature is to be over 840°C, which causes CaCO<sub>3</sub> of brick-making soil to break down into CaO and CO<sub>2</sub>. Hence, the current study estimated the emission from this sector is according to Eq. (4) [11]. Soil samples were collected in a triplicate manner from each site and percentage of CaCO<sub>3</sub> estimated via titration method [18].

$$CO_{2(\text{soil})} = \frac{M_{CO_2}}{M_{CaCO_3}} \times \%_{CaCO_3(\text{soil})} \quad (4)$$

where, CO<sub>2(Soil)</sub> stands for CO<sub>2</sub> emission from soil mix, M<sub>CO<sub>2</sub></sub> and M<sub>CaCO<sub>3</sub></sub> stands for molecular weight of CO<sub>2</sub> and CaCO<sub>3</sub>.

## 2.5 Emission from Shipping of Coal

As per field survey, all the sites use Indonesian coal. Hence shipment of coal from Indonesia to Chittagong port is calculated by Eqs. (5) and (6) [19].

$$G_w = F \times g_w \quad (5)$$

**Table 2** Emission factors of various fuels for CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O

Fuel	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O
Coal		0.001 tCH <sub>4</sub> /TJ <sup>a</sup>	0.0015 tN <sub>2</sub> O/TJ <sup>a</sup>
Timber	112 tCO <sub>2</sub> /TJ <sup>a</sup>	0.03 tCH <sub>4</sub> /TJ <sup>a</sup>	0.004 tN <sub>2</sub> O/TJ <sup>a</sup>
Diesel		0.003 tCH <sub>4</sub> /TJ <sup>a</sup>	0.0006 tN <sub>2</sub> O/TJ <sup>a</sup>
Electricity	0.67 tCO <sub>2</sub> /MWh <sup>b</sup>	0.00001095 tCH <sub>4</sub> /MWh <sup>c</sup>	0.000008283 tN <sub>2</sub> O/MWh <sup>c</sup>
Natural gas		0.001 tCH <sub>4</sub> /TJ <sup>a</sup>	0.0001 tN <sub>2</sub> O/TJ <sup>a</sup>

<sup>a</sup> [16]; <sup>b</sup> [23]; <sup>c</sup> [24]

$$F = W \times D \times E \quad (7)$$

where,  $G_W$  stands for Well-to-wheels GHG emissions CO<sub>2</sub> equivalents,  $F$  for energy consumption,  $g_w$  for emission factor,  $W$  for weight,  $D$  for distance, and  $E$  for specific energy consumption.

For bulk ships carrying coal in Asia  $E$  is 0.0014 kg/tkm [19, 20]. The shipping distance of coal from Indonesia to Bangladesh is 2306 nautical miles [21].

## 2.6 Calculation of Carbon Footprint

For the calculation of CH<sub>4</sub> and N<sub>2</sub>O emission from each sector Eq. (7) is used [16].

$$\text{Emission}_{\text{GHG, fuel}} = \text{Fuel Consumption} \times \text{Emission Factor}_{\text{GHG, fuel}} \quad (7)$$

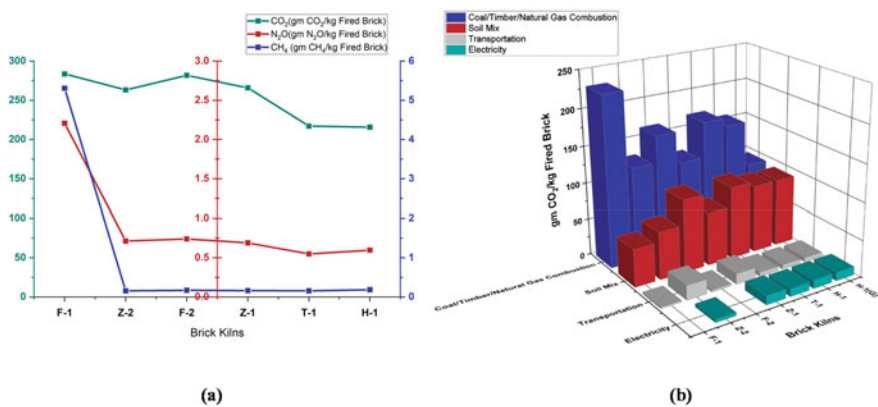
The estimated CH<sub>4</sub> and N<sub>2</sub>O emission for each kiln are taken into their CO<sub>2</sub> equivalent (CO<sub>2</sub>-eq) value applying global warming potential value of CH<sub>4</sub> as 86 and N<sub>2</sub>O as 268 [22]. Hence the Carbon footprint of a site expressed as gm CO<sub>2</sub>-eq per kg of fired brick for the production of 100,000 bricks is the summation of all CO<sub>2</sub> and its equivalent emission from each sector. Following Table 2 depicts the emission factors of different fuels for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O.

## 3 Results and Discussions

Figure 3a displays that CO<sub>2</sub> emissions are much higher than N<sub>2</sub>O and CH<sub>4</sub>. Due to the higher global warming potential value, the average N<sub>2</sub>O emission of all kilns is larger than CH<sub>4</sub>. F-1 showed a higher emission of all three gases resulting in its highest position in CF analysis depicted in Fig. 4. Although F-1 showed the highest value of CF, but coal-powered FCK (F-2) holds the fourth highest position in the CF analysis. This is because of the higher emission factor of timber than coal. The usage

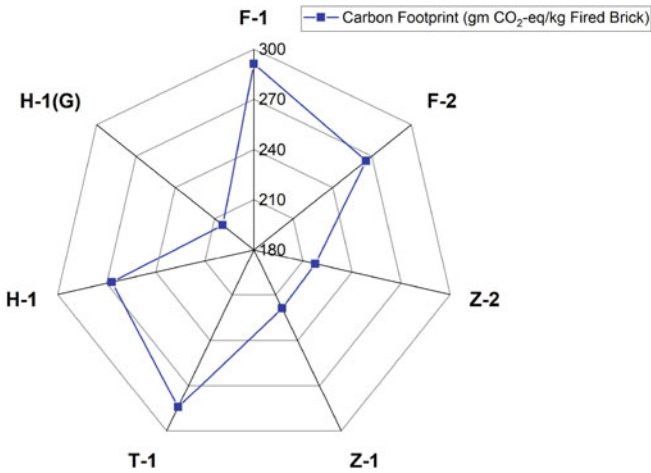
of electric machines may affect the CF values. It is observed that electric machines are used in the updated technologies like T-1 and H-1 for transporting bricks and excavated soil from one operation site to another inside the brickfield, molding of soil, and chimney fan, whereas conventional brick technologies like F-1 and F-2 use labor for these operations. Thus use of labor in different activities lessens the energy input and thus results in a lower CF value since human energy infusions into various operations are mentioned by BSI (2011) to be excluded from the boundary system [11, 25]. This is why modern technologies Tunnel kiln(T-1) and HHK (H-1) ranked second and third, respectively. Another reason for the higher value of T-1 is the lower brick production, as the kiln was not being operated at full capacity due to some maintenance works. However, the gas-powered HHK showed the lowest CF value of all. From Fig. 3b, it can be stated that firing in the kiln is the primary source of CF. As the carbon emission factor of coal is almost 1.67 times higher than natural gas, this is why H-1(G) yielded a much lower value than H-1. In the two zigzag kilns, usage of both labor and machines was seen. Also, a smaller distance of soil transport was reported during the field survey. The lower height of the chimney might be another reason why the zigzag kilns showed the lowest values than others. Z-1 having an electric brick molding machine, shows a higher CF value than Z-2 with no brick molding machine.

Combustion of Coal/Timber for firing brick is the most responsible source of CO<sub>2</sub> emission, followed by Soil Mix, Transportation, and Electricity, illustrated in Fig. 3b. The emission of CO<sub>2</sub> due to soil mix plays a significant role in the overall CF of the brick kiln. Only FCKs use local soil and bring soil from a smaller distance of 0.5 km. This lessens the diesel consumption to transport soil. Hence emission from transportation in F-1 and F-2 is much lower than in the others. The results of this study are in line with the previous worldwide studies. For example, Kulkarni & Rao (2016) [11] reported CF of a UK tunnel kiln having as 234.24 gm CO<sub>2</sub>/kg of fired brick which is a bit lower than the CF value of T-1, which is 284.17 gm CO<sub>2</sub>/kg of



**Fig. 3** Emission from brick kilns for production of 100,000 bricks **a** CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub> emission **b** CO<sub>2</sub> emission from the sources of CF





**Fig. 4** CF of brick kilns (for production of 100,000 bricks)

fired brick found in this study. Whilst, tunnel kilns of the USA and Canada have CF of 232.25 gm CO<sub>2</sub>/kg of fired brick (powered by natural gas) and 338.19 gm CO<sub>2</sub>/kg of fired brick (powered by light-fuel oil) [11]. A previous study based on the CO<sub>2</sub> emission from energy consumption in the firing chamber also designated Zigzag kilns as the best kiln in Bangladesh for its both energy and carbon efficiency [26]. The study also showed the gas-powered Hoffmann kiln as the least carbon-emitting kiln in the country. The current study also identified the HHK with the lowest CF value if fired with natural gas. The average CF of the six sites estimated in the paper is 257.33 gm CO<sub>2</sub>/kg of fired brick, slightly greater but in line with the average CF of brick in the UK is 239.4 gm CO<sub>2</sub>/kg of fired brick [27].

In an announcement in 2019, the Ministry of Environment, Forest and Climate Change took an initiative to construct all public construction projects by replacing clay bricks with concrete blocks and thus aimed for the gradual phasing out of bricks in governmental construction projects by 2025 [28]. For the production of every unit volume of concrete blocks, a CF value of 290 kg CO<sub>2</sub>-eq has been evaluated [29], which is higher than the average CF value of bricks estimated in this paper. Another study defined hollow cement block (HCV) as the most harmful building material, showing an elevated CF value of HCV than bricks [30]. However, replacing Portland cement in concrete with fly ash results in a net reduction in GHG emissions as 0.006 CO<sub>2</sub>-eq kg/ ton of fly ash is recorded only to collect the fly ash from the power plant station [31]. Although fly ash is designated as an industrial waste of thermal power plants, the production of total ash is roughly 10% of the amount of coal fired in the plant, of which 80% is estimated to be fly ash [32]. Therefore, the life cycle carbon analysis of fly ash should be studied before highlighting fly ash bricks as the best alternative to clay bricks from the carbon footprint perspective. The study relates to the fifth theme of Bangladesh Climate Change Strategy and Action Plan 2009 (BCCSAP 2009), which is “Mitigation of Low Carbon Development.” Concerning

CO<sub>2</sub> emissions, natural gas is the greenest energy source [33]. The current study also highlighted Hoffman Kilns as the least CF brick technology if fueled by gas, so using natural gas in firing bricks can be associated with the first program of the fifth theme of BCCSAP (2009). However, firing coal in the kiln accounts for higher CF values. Hence using clean coal technology in this sector can be linked with the third program of the theme. Lastly, using solar energy in the brickfield for various operations can serve both the fourth and the tenth programs of the fifth theme of BCCSAP (2009).

## 4 Conclusion

According to this baseline estimate, two Zigzag kilns showed the lowest CF values among the four different technologies. In comparison, wood-powered FCK showed the highest of all, whereas coal-powered FCK showed a lower value. Hybrid Hoffman Kiln holding a third-highest position, showed a lower CF value than Tunnel Kiln. However, Hybrid Hoffman Kiln would be the best choice in terms of CF analysis if natural gas is fired instead of coal. Additionally, it is estimated that the average carbon footprint of bricks made in Bangladeshi kilns is 257.33 g CO<sub>2</sub>-eq/kg of burnt brick, which is comparable to values for the US, Canada, and the UK, but somewhat higher than the average CF of brick in the UK. The primary source of CO<sub>2</sub> emissions has been discovered to be the burning of coal or wood, or natural gas, followed by soil composition, transportation, and power. Although from CF analysis, it can be recommended that using bricks produced from gas-powered HHK and Zigzag kilns is sustainable. Nevertheless, further studies should be carried out to compare the quality and economic analysis of the bricks of the Zigzag with the modern brick-making technologies, i.e., Tunnel and Hybrid Hoffman kilns. The study is a pioneering study of this kind in Bangladesh to analyze CF of different types of brickfields in Bangladesh. The limited sample size can hardly project the overall scenario of the country; however, the study covered all the types of kilns that are in practice in Bangladesh. Therefore, further research, primarily based on the CF from brickfields across the country, can be done focusing on implementing a larger sample size to have a more accurate outcome from statistical analysis. This study can guide decision-makers to adopt the right policies to advance specifically in the application and realization of SDG 10.

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