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Thirty Years' Quest for Emission Reduction and Energy Efficiency Improvement of Brick Kilns in Bangladesh

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Abstract: Brick kilns have been the backbone of the construction industry in Bangladesh due to non-availability of stones in enough quantity. Brick kilns in the country use age-old technologies, which are inefficient with high emissions. In addition, the industry uses low quality of coal as fuel, with high ash and sulfur content; there by contributing to the worsening of air quality. This paper discusses the developments in brick making during the past 30 years in search of higher energy efficiency and lower pollution. It is seen that the progress in pollution abatement and energy efficiency improvement have been slow; resulting in considerable health burden for the population and other economic losses for a long time. In recent years, some affordable designs of low polluting and more energy efficient kilns have been introduced by the Department of Environment (DOE) through a number of programs; including World Bank financed Clean Air and Sustainable Environment (CASE) Project. These efforts have led to considerable pollution reduction i.e., by more than 70% for PM (Particulate Matter) and coal consumption reduction by around 30% at individual brick kiln level. Large low emission industrial kilns with imported technology are also being established. However, the rollout of these energy efficient and low emission technologies in substantial numbers is yet to be achieved. Some moves are also afoot to increase the use of non-fired bricks. In order to achieve quick all-round gains, both push as pull factors for the change in current situation need to be mobilized. What is needed is a well-articulated time bound 'Theory of Change (ToC)' for green and clean brick industry in the country. Success in this endeavor will substantially reduce the air pollution levels bringing health benefits to local population. Concurrently, it will also reduce the land-use footprint, top soil use, loss of agricultural productivity and Green House Gas (GHG) emission from the brick kilns. In addition, this will also improve employment and working conditions for labor employed in the brick sector. A simplified ToC for a cleaner and greener brick sector for a ten years' period is outlined in this work.

Keywords: Brick Kiln, Energy Efficiency, Low Emission, Air Pollution, Particulate Matter, GHG Emission, Health, Top Soil, Theory of Change

1. Introduction

Brick kilns have been the backbone of the construction industry in Bangladesh since stones are not readily available in required quantity. According to the latest survey data [1], the total number of brick kilns in the country is 7,902[1] with different technology mix discussed in section-3. The manpower employed is around one million, who are mostly seasonal workers; working for 4-5 months (December-April)

1 This 2018 inventory shows that of the 7902 kilns, 631 have been found to be inoperative.

in the year. The total bricks produced per year is estimated at about 31 billion and valued at $3.6 billion; which is about 1.3% GDP (i.e., GDP of $274 billion in 2018)[2]. Earliest brick kilns in the country were mainly Clamps and of Bull Trench Kilns (BTK)[3] type. More details on the different types of kiln technologies are given in section-3. Brick kilns in Bangladesh have been highly polluting, because of the use of inefficient technologies and low quality of coal as fuel, with high ash and sulfur content. It is about 30 years now, that Government of Bangladesh (GOB) first tried to regulate brick kilns by adopting various regulatory measures; starting with the Brick Burning Act (1989) and others measures since then. These regulatory measures had only limited success so far. The impact of the pollution from brick kilns is accentuated by the fact that the brick burning season coincides with the dry season; when ambient particulate concentrations are at their peak all over the country.

GOB has undertaken renewed initiative in recent years to reduce air pollution from the Brick kilns; including move to more energy efficient and cleaner technologies. The fixed chimney kilns (FCK) [4] have been the mainstay in the Bangladesh brick manufacturing; due to low investment cost and high profitability. As standardized designs for cleaner kilns which can replace FCKs have not been available in the market; the DOE (Department of Environment), GOB undertook the development of standard designs of similar production capacity kilns; which are more energy efficient and cleaner, while at same time reasonably priced for adoption by the existing FCK entrepreneurs. The outcomes from the initiative have resulted in substantial progress in energy efficiency improvement (i.e., around 30-40%) and emission reduction (i.e., >70%). These are improved version of a traditional Zigzag (TZigzag) kiln referred to as IZigzag (Improved Zigzag) Kilns [2]; and a miniature version of Hybrid Hoffman Kiln (MHHK) [3]. These have been piloted in a limited scale with promising results. Another two models i.e., a VSBK (Vertical Shaft Brick Kiln) [4] and a mini Tunnel Kiln (MTK) [3] have also been developed in the DOE program. Piloting of one VSBK was done, but it did not find acceptability among kiln owners and MTK is yet to be piloted. All these brick kiln models are discussed briefly in section-3.

In parallel, introduction of newer larger capacity technologies, mainly from China has been going on for about 15 years now. These are large kilns with production capacity around 100,000 bricks per day and even more, based on Hybrid Hoffman kiln (HHK) and Tunnel kiln (TK) designs [4]. However, these only accounts so far, for a small fraction of the brick produced in the country. Even with better technologies, optimal benefits can only be obtained with their proper implementation. So, strategies for deployment and other synergistic policies, which can substantially boost the energy savings and emission reduction benefits are discussed here. There are likely to be some unintended and unexpected outcomes also in the implementation of the newer technologies and policies; and these issues need to be addressed through remedial actions during implementation.

2 Available brick data have been updated using information from this 2018 inventory.

3 In a CLAMP, green bricks are stacked with fuel (wood/coal) in the traditional manner and fired from the bottom; once the fire burns out bricks are removed. Bull trench kilns (BTK) are continuous production elliptical kilns with movable chimneys (usually 30 ft high) and a moving fire zone.

4 The FCK is an improved version BTK with a 120ft chimney at the center of the kiln.

2. Developments in Brick Kilns' Regulations in Bangladesh

Traditionally commercial brick production in the country was based on Bull Trench Kilns with movable sheet-metal chimneys. Because of movability requirement, the chimneys were only 6-10 meters high. The result was extremely high local smoke pollution impacting both public health and agricultural production negatively. This gave rise to resentments among population in the vicinity of the brick kilns. The brick sector regulatory developments started with the passage of the Brick Burning Act of 1989[5]. The regulatory developments since then are summarized in table 1. Under regulatory pressure (e.g., withholding of DOE clearance), the kiln owners stared moving to Fixed Chimney kilns (FCKs) with 120 ft chimney (made compulsory in 2002); which abated the local pollution to some extent. In 2010, a further notification banning FCKs and move to cleaner technologies mandatory by 2013 was issued. As a result, the kiln owners started moving to traditional Zigzag (TZigzag) kilns; as this was the only low-cost option available at the time. The TZigzag design was imported from India and gets its name from the zigzag air flow in the kiln. These were implemented using artisans with limited skills and without standardized designs. Naturally, the sizes and production capacity varied depending on the artisans' experience used in construction. These kilns are rectangular in shape; with chimney on one side with the height of 55 feet in most cases.

Table 1. *Regulatory developments in the brick sector in Bangladesh.*

Year	Policies, laws, and regulations	Comments
1989	The Brick Burning (Regulation) Act of 1989[5]	Bangladesh's first brick-making law, banned the use of firewood for brick manufacturing and introduced licensing for brick kilns.
1997	Environmental Conservation Rules[6]	Sets limit for brick kiln SPM emission at 1000 mg/m^3.
2002	GOB Rule on brick kiln introduced in October, 2002	The GOB introduced this rule, making the use of 120-ft chimneys for brick kilns compulsory. This requirement was successfully enforced, especially in the vicinity of urban areas, and most Bull's Trench Kilns (BTKs) were upgraded to FCK technology.[7]
2007	GOB Notification on brick kiln	This notification stated that environmental clearance certificates would not be renewed, if the owners did not shift to alternative fuel and improved technologies by 2010.

5 Brick Burning (Regulation) Act, Act no: 8/1989.

6 Environment Conservation Rules-1997, SRO No. 47-Law/97.

7 Some BTKs continue to operate even now (anecdotal reports), albeit illegally.

Year	Policies, laws, and regulations	Comments
2010	GOB Notification on brick kiln	However, this regulation has not been implemented; as hardly any field level activity happened to facilitate the switch and no designs for improved kilns were provided. A new notification was issued in July 2010; banning FCK operations three years from this date. The kiln owners started shifting to TZigzag technology, which is somewhat cleaner and energy efficient than FCK technology; though with highly variable performance. This was also the only affordable technology available at the time; with similar production capacity as FCKs.
2013	The Brick Manufacturing and Brick Kilns Establishment (Control) Act[8]	This law was passed on November 20, 2013 and it came into force from 1st July 2014 with its publication in the Government Gazette. The FCKs were effectively banned under this law; but some kilns owners obtained court injunctions staying the ban up to March 31, 2015. However, greater number of FCK owners started moving to TZigzag kilns which was still the only low-cost option available. This law also put some locational restrictions, mandated production of 50% hollow bricks among other regulatory measures. Without the rules under the act, most of the provisions of the law could not be implemented. The rules were drafted but could not be adopted as kiln owners demanded revision of the law; which the GOB agreed.
2016	FCKs ban becomes effective (Court vacates injunctions)	The notification on FCK ban became effective after the court injunctions were vacated from July, 2016. A large number FCKs were converted to TZigzag using artisans, which did not provide the expected gains; that can be obtained from conversion to standard design with proven low emission and higher energy efficiency.
2019	Revised Brick Law passed effective from February 28, 2019[9].	This revision which addresses the concern of the entrepreneurs and provide vision for future development in the Brick Sector was passed on November 18, 2018. Rules to implement its provisions have been drafted; but not adopted yet.
2019	Notification on progressive replacement fired bricks by concrete blocks in GoB construction.	Introduced in November 2019, this notification mandates use of 10% concrete blocks instead of burnt clay bricks during 2019-20 in Government construction. The fraction is to increase progressively on yearly basis with 100% replacement in 2024-25.

Under regulatory pressure, the existing kiln owners started moving mainly to low cost TZigzag kilns; especially after the adoption of 2013 Brick Act.

3. Developments Brick Kiln Technology and Implementation

The use of fired bricks in construction in the region constituting Bangladesh, dates to time immemorial. Information on the different type of brick kilns used so far in the country are provided here in Table 2; detailing on what has been provided earlier. More details on emission data are given in the next section.

Table 2. *Brief information on the Brick Kiln technologies used so far in Bangladesh.*

Sl.	Type of Kiln	Description	Comments
1	CLAMP	The earliest kilns were CLAMPs, and dates to time immemorial. In the CLAMPS, green bricks are stacked with fuel (wood/coal) in a traditional manner, sealed with a clay layer on the surface and fired from the bottom. Once the fire is out, CLAMP is dismantled for the bricks.	These are still being used in remote areas where transportation is difficult. Bricks produced are of poor quality (i.e., a large fraction of bricks produced do not meet quality standards).
2	Bull trench kilns (BTK)	The Bull trench kilns (BTK) are continuous production elliptical kilns, with movable sheet-metal chimneys (usually 30 ft high) and a moving fire zone. The BTKs have been around for nearly a century. The average production capacity is around 20-40,000 bricks per day.	BTKs are still used occasionally in rural areas, although illegal. The emission levels are very high. The quality of bricks produced meet the Bangladesh standards except for a small fraction.[10]
3	Fixed Chimney Kiln (FCK)	FCK design is an improved version of BTK with a 120-130 ft chimney at the center of the kiln. These have been around for about half a century, since the nineteen seventies. The average production capacity is also around 40,000 bricks per day. Average SPM emission level is >1000 mg/m^3 and the average coal consumption per 100,000 standard size bricks (230x110x76 mm) is around 20 tons[11].	These kilns provide better dispersion of emitted pollutants and leading to reduced local pollution and have been the mainstay of brick production and started decreasing in number since ban in 2013. Most bricks produced in these kilns meet the national quality standard.
4	Traditional Zigzag kiln (TZigzag)	The TZigzag kilns are basically similar to FCKs; but rectangular in shape with zigzag arrangement of bricks with longer flue gas path; with forced air circulation, and chimney on one side the kiln. The Zigzag/Habla kiln design was developed in Germany and it was contemporary to BTK. The Indian version of the kiln was introduced in Bangladesh in the 2000s. The average production capacity is also around 40,000 bricks per day. The average coal consumption is around 15 tons per 100,000 standard bricks.	The SPM emission has been found to be highly variable in these kilns at 504±255 mg/m^3 (i.e., for 10 kilns). The bricks produced in these kilns (i.e., a high fraction) meet the national quality standard. TZigzags have shorter (55-60 ft) chimneys compared to 120ft for the FCKs. Under regulatory pressure about 60% of the

8 Brick Making and Kiln Construction (Control) Act of 2013; Act no. 59/2013.

9 Brick Making and Kiln Construction (Control) Revision Act; Act no. 1/2019.

10 The Bangladesh standard (BDS208: 2002) for brick quality are specified in terms of crushing strength and water absorbance (i.e., crushing strength of 175Kgf/cm^2 or 2500 PSI and 15% water absorbance).

11 Specific data on kilns' coal consumptions and emissions are given in table 3. Low emission kilns are defined here as kilns with emission level of SPM <250 mg/m^3. It may be noted that 250 mg/m^3 SPM standard has been adopted in India.

Sl.	Type of Kiln	Description	Comments
			FCKs have been converted to TZigzag kilns already.
5	Hybrid Hoffman Kiln (HHK)	Hybrid Hoffman kilns (HHK) are Chinese modification of Hoffman kiln designed in Germany. This technology was introduced in Bangladesh under a UNDP-GEF program in 2006. The HHKs have moving firing zone as in FCKs. It is a closed top design, with all-round high insulation and forced air circulation. It can be used round-the-year being weather proof. The average production capacity is around 100,000 bricks per day or more. The average coal consumption per 100,000 standard sized bricks is around 15 tons.	This is a low emission kiln and the bricks produced in these kilns meet the national quality standard. The low emission levels for these kilns were verified in DOE measurements (table 4).
6	Tunnel kilns (TK)	The Tunnel kilns (TK) have a fixed fire zone and the green bricks move on trolleys through the fire zone. These are also round-the-year operation kilns. Both HHK and TKs are large kilns with production capacity of 100,000 or more standard sized bricks per day. These were introduced private entrepreneurs nearly at the same time as HHKs. The average coal consumption is rather high at about 22 tons /100.000 bricks.	These are also low emission kilns. The bricks produced in these kilns meet the national quality standard.
7	Vertical Shaft Brick Kiln (VSBK)	The design is of Chinese origin. One unit was piloted in a ESMAP-WB program in 2010 [4]. A two shafts' kiln produces 8-12,000 bricks per day. The coal consumption was found to be 11-16 tons per 100,000 standard bricks.	This is also a low emission kiln. Bricks produced met the standards. However, consumer acceptability was poor; as the bricks did not look red enough. Acceptability for the kiln at entrepreneur level was also poor; because of low production capacity of the kiln.
8	Improved Zigzag Kiln (IZigzag)	The improved Zigzag (IZigzag) kilns have better insulation and flue gas treatment arrangements; leading to better energy efficiency and lower emission. The 120ft chimney is retained for the conversion of FCKs. One version for IZigzag kiln has a chimney at the kiln center; to reduce the land footprint for the kiln. This kiln has been developed in a DOE/CASE Project (2013) and 7 units have been piloted so far [2]. The average production capacity is also around 40,000 bricks per day. The average coal consumption is about 13 tons per 100,000 standard size bricks.	This is a low emission kiln. Most bricks produced met the quality standard. This technology which is modestly priced, appears to be most acceptable to the present kiln owners. TZigzag kilns can be converted to IZigzags at a modest cost.
9	Mini-Hybrid Hoffman Kiln (MHHK)	A low-cost smaller version of this HHK kiln has been developed in the DOE/CASE project (2013) and 3 units have been piloted. The average production capacity is also around 40,000 bricks per day. The average coal consumption is about 11 tons per 100,000 standard size bricks.	This is also a low emission kiln. This type of kiln is costlier than the IZigzag design. However, this can be used for round-the-year production, if constructed on land above flood level. Bricks produced meet the standards.
10	Mini-Tunnel Kiln (MTK)	MTK is a low-cost smaller version of the Tunnel kiln. This Kiln has also been developed in the DOE/CASE project (2012)[3] and this has not been piloted yet. It has a production capacity of 20,000 bricks per day and two units can provide same capacity of FCKs.	This design is yet to be piloted. It is a lower cost smaller version of the Tunnel kiln, but costlier than the IZigzags. However, this can be used for round-the-year production.

The development in the brick sector under regulatory pressure essentially moved a significant fraction of FCKs to traditional Zigzag (TZigzag) kilns; with some improvement in fuel saving and some emissions reduction which is highly variable. This happened because DOE regulation only required move to cleaner technology; without quantitative standards for fuel efficiency and emission. Standard low-cost designs for cleaner kilns with production capacity comparable with FCKs, were also not available [5]. Faced with such realities in the brick industry and unwillingness or lack of capacity of the existing kiln owners to move to larger HHK or TK technologies, the move to TZigzag became the only feasible option. The move to HHK or Tunnel kilns by the FCK owners did not happen due to high investment requirements. The owners of the HHK kilns or Tunnel kilns are mostly new entrepreneurs with large capital resources with access to bank financing. These kilns are located on lands above flood level, operated round the year with regular employees and satisfy all the requirements for small/medium industry; thus qualifying for bank financing. However, after the initial flurry, the investment in these larger kilns have slowed down.

Therefore, the DOE under its CASE Project moved to improve the traditional Zigzag kilns design incrementally. The design is such that direct conversion of FCKs to IZigzags can also be done by retaining the 120ft chimney; which is the only major investment in FCKs. The existing chimney retention saves capital loss by the existing FCK owners. In parallel, work was undertaken to develop designs for smaller HHK and TK with capacity similar to FCKs (i.e., 40,000 bricks/day) at lower costs [2, 3]. So far, seven of the designed IZigzags have been piloted in different areas in the country. Three MHK designs have also been piloted in three different areas. The piloting was done with the participation of kiln owners; who were selected through open advertisements. The DOE appointed consultants provided technical assistance for the conversion of FCKs to IZigzags and construction of the MHKs. A grant (BDT one million) was provided to each kiln owner to improve work environment for the workers in the kiln; which included provisions for drinking water, dining, childcare and education, accommodation and sanitary facilities.

It is to be noted that brick quality for IZigzags and TZigzags are found to be similar to FCKs with crushing strength of 2600-3300 PSI compared to Bangladesh standard for clay bricks of 2500 PSI (175kgf/cm^2). The chemical analysis [2] showed that the major content of soils used were SiO_2 (59 - 69%), Al_2O_3 m (14 - 18%), Fe_2O_3 (5 - 6.5%) and CaO (0.4 - 2.6%). Particle size analysis showed that the dominant fraction belonged to 2-20μm size being in the 35-71% range.

The time evolution of the share of different technologies in the brick sector in Bangladesh is shown below in table 3.

Table 3. *Changes in the Kiln technology mix 2009- 2018 [1].*

Sl.	Year	Number of Brick Kiln	FCKs	No of Improved kilns					% of Improved Kilns including TZigzag
				Zigzags	HHKs	Tunnel	Other Tech.	Not in operation	
1	2009	4880	4500	150	30	0	200	-	3.69
2	2014	6,805	3498	2,983	64	40	2	-	45.39
3	2015 (Nov)	6,941	3426	3,389	71	40	2	-	50.45
4	2017 (Jan)	6,646	2541	4,108*	73	43	5	-	63.63
5	2018 (Nov)	7,902	2814	4,671*	73	43	299	631	60.57

*Includes 7 IZigzags and 3 mini MHHKs of DOE design.

The energy consumption and emission data for converted and constructed kilns were measured for the piloted kilns; by TA consultants for piloting appointed by the DOE. A set of energy and emission data were also obtained through measurements [6] by employing an independent consultant (i.e. BCSIR) for all the technologies in operation in the country. The data from these measurements are given in Table 4. It can be seen from the SPM emission data in the table 4, that in all the newer technologies (i.e., IZigzag, MHHK, HHK and, TK), the SPM emission standard of 250 mg/m^3 can be met. DOE is also mulling revision of SPM emission standard to 250 mg/m^3 in the light of the new developments. In fact, as seen from table 4, IZigzags, MHHKs, HHKs and TKs can meet 200 mg/Nm^3 emission standard for SPM at 2 standards deviations (2 sigma(2б)) level; i.e., >95% of the kilns will meet the standard. With the availability of standards designs from DOE, the FCKs and TZigzag kilns can now be retrofitted to these designs to meet the revised standard at low cost.

Table 4. *Coal Consumption (ton/100,000 standard bricks) and Emissions (mg/Nm^3) from Brick Kilns in Bangladesh.*

Coal use/ Emission	Baseline FCK (5)*	TZigzag (10)*	TZigzag (10)**	IZigzag (7)*	IZigzag (7)**	MHHK**	HHK**	TK**
Coal use (tons/ 100,000 Std. bricks)	20.1±0.6	17.9±0.9	15.3±1.8	11.2±1.7	13.3±1.3	10.5±1.1	14.8±5.3	21.5±4.9
% of Baseline	100	89±4	76±9	56±8	66±8	52±5	74±26	107±24
SPM (mg/m^3)	1103±95	243±260	504±255	71.2±35.5	124±12	131±19	54±7	123± 25
% of Baseline	100	22±24	46±23	6.5±3.2	11.2±3.4	11.9±1.7	6.9±2.9	8.6±3.6
SPM Std. at 2б level (mg/m^3)	1293	763	1014	142	148	169	68	173
SO_2 (mg/m^3)	2658±1503	2118±1668	550±318	<MDL (100)	141±121	46±5	57±61	26±16
% of Baseline	100	80±63	20.7±12	-	21±4.6	2±0.2	2.1±2.3	1.0±0.6

*Measurements in the piloting study [2]. **Measurements by independent consultant under DOE Contract [6]

The coal consumption obviously depends on coal calorific value. The average calorific values for coal used in piloting were found to be: 19.7± 0.9 MJ/kg with Range: 15.6 – 21.7 MJ/kg; and the average Sulfur content was: 2.1 ±1.4% with Range: 0.61-4.47%. The coal used came from Bangladesh, India, Indonesia, South Africa and Russia.

The improvement in energy efficiency in the IZigzag performance has been obtained by improving kiln insulation to reduce heat loss. The use of longer length water filled gravity settlement chamber and water-based scrubber, have contributed to reduced emissions. There are two designs for IZigzags; one with chimney on the side as in the TZigzags and other with chimney at the center with redesigned kiln-island and a U-shaped gravity settlement chamber. The center-chimney design reduces the land footprint of the kiln and is suited for kilns with no space for building the chimney on one side. In both the designs, the 120ft FCK chimney is retained. The dismantling and reconstruction of FCK to IZigzag with chimney on the side costs about BDT 4.6 million (i.e., about USD 55,000.); as estimated from 7 pilots implemented so far. TZigzags can be converted IZigzags at much lower cost probably at 30-50% of this amount. Average heat loss for the 7-IZigzags through different routes are shown in Table 5 along with the data for FCKs and TZigzags. It can be seen, that in the IZigzag's heat losses are reduced considerably; leading to greater energy efficiency. Both the MHK and MTK designs are closed top type; and MHK's have been found to be better in terms of fuel efficiency compared to IZigzag design; as most of the heat losses occur through the top of the kilns [2].

Table 5. *Sources of heat loss (average of 7-IZigzag Pilots) during the operation[12].*

Type of loss	FCK	TZigzag	IZigzag
Heat Loss at the top of cooling area (%)	22.1	15.7	9.8
Heat Loss at the top of firing area (%)	11.1	9.3	5.0

12 One-foot thick plastic clay is also used at the bottom of the IZigzag kilns to stop capillary water seepage; which may also improve the bottom insulation somewhat and reduce heat-loss to the ground, but this has not been measured.

Type of loss	FCK	TZigzag	IZigzag
Heat Loss at the top of drying area (%)	4.6	2.9	0.6
Heat Loss through outer wall surface %	11.7	8.4	2.8
Total Heat Loss (%)	49.5	36.3	18.2

With the availability of the standard designs from DOE, coupled with revised energy efficiency and emission standards; the Bangladesh brick sector is poised for a major improvement both emission and energy efficiency wise. However, this development by itself will not ease the air pollution situation near the major urban centers; due to clustering of large number of kilns near these centers.

The growing demand of bricks in these cities due to increased urban growth, the GOB capacity to reduce or even to freeze the number of kilns may be difficult; as socio-economic issues and other practical constraints may impede move to available cleaner technologies. Moves to enforce lower emission standards and removal of kilns to reduce cluster size, are likely to face resistance from the brick kiln lobby. One way of reducing dry season emission reduction, can be the move to round the year production. This would require land above seasonal flood level which is expensive; but this will also reduce the land footprint for brick kilns, as a single kiln of same capacity will be 3 times more productive. Some form of incentives may be needed to move the present kiln owners to accept the changed needs.

4. Air Quality Scenarios and Developments

The air pollution levels in Bangladesh show strong seasonal dependence. The NAAQS (National Ambient Air Quality (daily) Standards) values are exceeded for around 100 days per year, mostly during dry months (Nov-March). From health point of view PM2.5 is the main pollutant and it is the main determinant of AQI (Air Quality Index); now published fairly regularly for 8 large cities in the country. This is illustrated in figure 1 below for PM2.5 levels in the Dhaka area with daily standard of 65 $\mu g/m^3$.

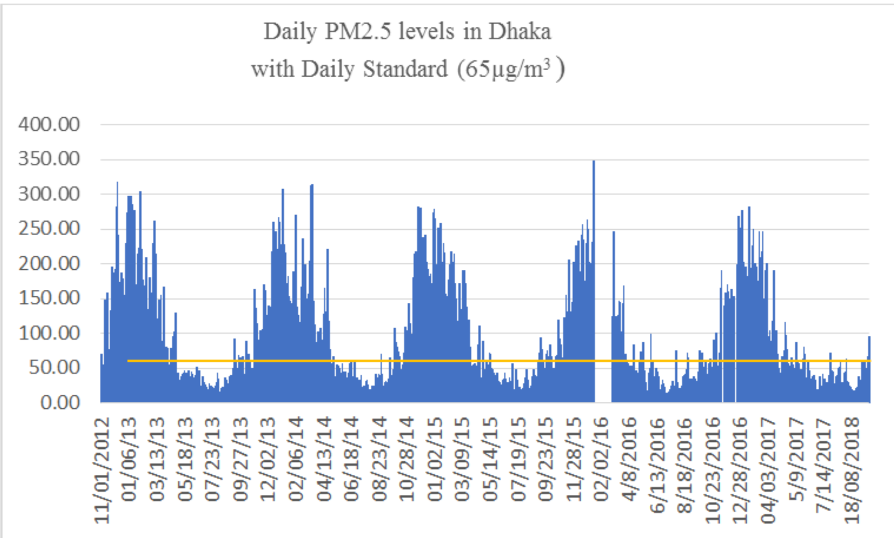

Figure 1. *Seasonal Variation in Ambient PM2.5 ($\mu g/m^3$) air pollution levels in Dhaka (Source: DOE Data Archives (2018)).*

The available source apportionment data from DOE, show that major contributors of the PM2.5 pollution in all the four major cities in the country are the brick kilns; as shown in table 6 [7]. In the Dhaka city, PM2.5 pollution level from brick kilns has now reached to 58% of the total on yearly average basis. If only the dry season is considered, the percentage is much higher. In ten years, the share of the brick kilns to air pollution in Dhaka city has increased by about 20 percentage points to 58%. In three other major cities, the contribution of brick kiln emission to PM2.5 pollution levels are found to be 36-40%. Thus, it is obvious that any plan for air quality improvement in the major urban centers must address brick kiln pollution. The industrial pollution levels are also on the rise and the perineal issue of resuspended road dust is not going to abate in the absence of measures to control it.

Table 6. *Source Apportionment (%) of PM2.5 in four largest cities in Bangladesh.*

	Dhaka		Chittagong	Khulna	Rajshahi	Comments
Source	2001-2	2010-12	2010-12	2010-12	2010-12	
Soil dust	1.0	7.6	2.59	9.0	8.39	
Road dust	-	7.70	1.54	7.7	2.91	
Brick Kilns	37.5	58.0	36.2	36.1	40.2	Largest source since 2010
Biomass Burning	2.4	7.4	19.1	23.5	35.4	
Motor vehicles	43.0	10.4	33.0	13.7	9.8	
Fugitive with Pb content	3.3	7.63	7.44	8.05	3.28	Probably industrial emission

A look at the brick kiln source factor (Figure 2-left) for PM2.5 shows that the kilns to the north and north-west of the city contribute most to the pollution. The kilns are operated during winter (December to March); when the winds are also most from the same direction; which blow the pollution into the city.

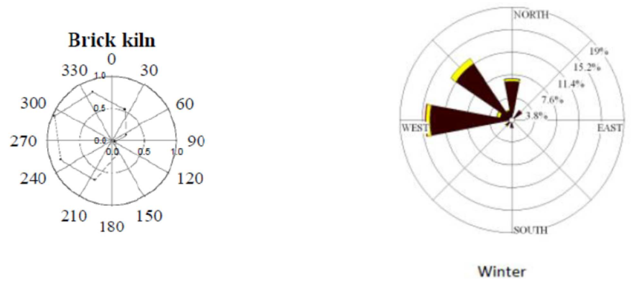

Figure 2. Dhaka Fine Particle source factor for brick kilns and Wind Rose in winter [6].

If we look at the time evolution of air pollution in Dhaka, it is seen in figure 1 that PM2.5 pollution level has stabilized and almost remained at the same level during the past five years. This has happened largely due to the decline in the vehicular pollution over the period of 15 years; as a result of various policy measures and other developments. The first of these measures was the removal of 2-stroke 3-wheelers in Dhaka in 2003. The next major step was the introduction of CNG (Compressed Natural Gas) as the transport fuel. Almost all the passenger vehicles in Dhaka are now CNG/LPG fueled. Most of the city buses (>90%) and smaller trucks have also been converted to CNG fuel. The other major development was the reduction in Sulfur level in diesel fuel; which came about as refineries in the middle east which are the source of imported diesel; switched to 500ppm Sulfur diesel production, instead of previous 2000ppm. In Chittagong; vehicular emission still remains high, due to huge port related goods traffic; using heavy duty diesel fleet. Another major source urban air pollution is the biomass burning for cooking. In cities without natural gas supply, biomass is used in cooking and even in Dhaka biomass burning has increased from around 2% to about 7%; due to restricted supply of NG during the past decade. The pollution due to this source is likely ease with the greater availability of LPG. Thus, the main pillar of air pollution control in all the major cities has to be emission reduction from the brick kilns; as stated earlier also.

5. Potential Future Trajectory for Air Pollution Reduction from Brick Kilns

It is apparent from the evidences and discussions above, that any plan for air quality improvement in Bangladesh, must address pollution from brick kilns. While tackling air pollution, other issues related to brick kilns have also to be looked at; as these issues are also of importance for public welfare. These objectives, issues and measures for emission reduction are listed below.

(i) Priority should be given for brick kiln Pollution Reduction in major urban airsheds, as the health cost is high due to large population [7, 8]. The measures may include relocation or reduction of number of kilns in near-urban clusters, move to round the year kilns from seasonal ones among others;

(ii) Reduction in brick kiln emission through replacement of current kilns by more energy efficiency kilns, leading to significant reduction in SPM and GHG emission benefits;

(iii) Reduction/elimination of top soil use through moving to non-fired bricks; which can also lead to reduction of land footprint for the same quantity of bricks produced; and

(iv) Minimization of land footprint for the production facilities by encouraging large capacity kilns with round the year production.

The various options for actions to achieve significant gains on these issues are outlined and discussed in the following. The consequential outcome of these measures will lead to reduction of unhealthy labor practices; seasonal/migrant labor; abatement of solid waste by using as filler in non-fired bricks; and upgradation of the plants to recognized SME standards with year-round production.

5.1. Improving Airsheds of Major Urban Centers Through Relocation of Brick Kilns

Relocation of polluting industries out of urban airsheds has been implemented in many countries including India and China. This measure will lead to immediate reduction of air pollution from seasonal coal fired brick kilns and can be justified on cost benefit consideration [8-12]. The costs for urban air pollution have been estimated in a recent analysis and are shown Table 7 [9]. The removal of the brick kiln from Dhaka, will save more than half the cost attributable to air pollution as brick kiln contribution is estimated as 58% on yearly basis.

Table 7. Estimated Cost of Air Pollution in Urban Areas Attributable to it ($ billions).

PM2.5 air pollution	Urban Bangladesh		Greater Dhaka	
	Welfare loss	Foregone output	Welfare loss	Foregone output
Ambient	2.42	0.49	0.53	0.11
Household	1.27	0.25	0.28	0.06
Total	3.69	0.74	0.81	0.17

If appropriate policy measures are taken, this action can be successfully implemented as elsewhere. This component will focus on reduction of air pollution from seasonal coal fired brick kilns, by closing/relocating of the polluting brick kilns from the vicinity (i.e., probably 20km from the city boundary) of the Dhaka initially and other major urban centers with large population progressively. The kilns can be closed/relocated under the provision of Brick Burning Act of 2013, which empowers DOE to take measures to improve degraded Airshed. As this is unlikely to happen only under regulatory pressure; the kiln owners may have to be offered incentives for the purpose; which may include 4 permits and compensation for capital asset loss. The owners may be issued with a permit [13], which has been successfully used elsewhere; for each of the closed kiln. For each permit, an owner will be allowed to establish a low emission kiln of approved design by DOE outside the Airshed and a compensation of for lost asset (i.e., 120 ft Chimney which is the only asset for FCKs on low land) may be provided. For every four permits (i.e., which can be purchased from owners who do not want to continue with kilns), an individual or a company will be permitted to establish one round the year kiln high capacity (i.e., at least twice the FCK production) low emission kiln with better energy efficiency on ground above flood level; or one non-fired brick plant for year-round production of similar capacity. Through this relocation, the number of kilns expected to be reduced to one-fourth of the initial number with same production, as a round the year kiln will have 3-4 times or more production than the seasonal kilns. With round the year production, the emission of pollutants will be distributed throughout year rather than in the dry season only. The problem of seasonal/ migrant labor will also be eliminated and with round the year regular employment; the kilns can be classified as regular SMEs. With substantive permanent structure, such kilns will also become bankable assets; facilitating access to finance.

5.2. Implementation of More energy Efficient and Cleaner Brick Kilns

Implementation of low emission and more energy efficient kilns will lead to significant reduction in PM level and GHG emissions. Progress in this area so far has already been discussed in section-3. This approach has been hampered by the non-availability of low-cost standardized design; but the situation has changed with the availability of the proven IZigzag and MHK and MTK designs from the DOE; although the MTK design is still to be piloted. All these designs can be adapted for round the year operation,

if built on land above flood level and with drying facility. The drying facility may simply be a shed with removable cover for sun-drying during non-rainy days. This has been found suitable in a previous pilot and widely used in Vietnam. Back process automation (i.e., mechanical green brick production) can result in better brick quality and can also be useful in the elimination of unhealthy labor practices (e.g., head loads). Production of hollow bricks with automated green brick production will lead to reduction in top soil use. These solutions can be pursued for low population density areas and for non-clustered kilns. Retrofitting of the TZigzag kilns to IZigzag standard can be a quick-win strategy for pollution reduction and fuel (i.e., also GHG) saving.

5.3. Non-fired Bricks

Increasing number of brick kilns are causing concerns apart from air pollution; these are loss of agricultural land for setting up brick kilns and the loss of top soil needed for maintaining soil fertility as brick raw material [14]. Taking note of these concerns GOB has also initiated move away from fired kilns and has issued a notification on progressive replacement fired bricks by concrete blocks in public construction in November 2019. This notification mandates use of 10% concrete blocks instead of burnt clay bricks during 2019-20 in public construction. The fraction is to increase progressively on yearly basis to 100% replacement in 2024-25. According to available information, there are about 50-60 block making plants; mostly operating in less than full capacity due to lack of demand. These plants will not be able to meet requirements if the notification is to be implemented, as all the production capacity added up may not equal even ten standard sized brick kilns. As seen from the previous experience in the brick

sector, such notifications are not easy to implement; especially in the absence of field level monitoring capacity which is currently absent.

For substantive move to non-fired brick in the country, issues in the private sector construction have to be addressed; as bulk of the construction belongs to this sector. In the private sector the non-fired bricks are yet to gain a foothold; except for some construction companies with in-house production capacity. It will be essential to expand the use in the private sector, to reduce the demand for fired clay bricks. The concrete blocks have been commercially available for many years, but the variety of products available are limited. The main barriers for market uptake are the prevailing perceptions that the concrete blocks are heavy, difficult to plaster, have higher water seepage and it is difficult to arrange for concealed work for plumbing and wiring conduits. Additionally, most masons lack familiarity with the use of concrete blocks.

Among many advantages in using non-fired bricks, the following are commonly mentioned.

(i) Elimination of top soil use;
(ii) Minimization of land footprint for the production facilities for same production due to round the year production;
(iii) Drastic reduction in direct PM and GHG emission;
(iv) Elimination of unhealthy labor practices and seasonal labor;
(v) Use of waste material as filler; and
(vi) Recognition of the plants as SMEs due year-round production and employment.

It will be necessary to address the supply constraints by expanding non-fired brick production and the product variety at competitive price to encourage greater use. The production has to be scaled up quickly; if the time-lines envisaged in the notification are to be adhered. Going by the international experience, especially in China and India, two more technologies can be gainfully pursued in Bangladesh, in addition to the concrete blocks; for expansion of the uptake of non-fired bricks especially by the private sector. These are the Lime-Sand Bricks (LSB) and AAC (Autoclaved Aerated

Concrete) blocks technologies.

The LSBs, which are also called calcium-silicate bricks; lime is the binding material for the silicate materials. The raw materials for calcium-silicate bricks include lime mixed in an appropriate proportion with sand. Waste material can be added in the mixture which is an added advantage. The properties of these bricks are very similar to clay bricks and in addition these can be made in different colors. Large automated plants for LSB production are also available in the international market. Such plants will reduce the land footprint compared to existing kilns for same production quantity.

The AAC (Autoclaved Aerated Concrete) Block is a light and porous building material. It has light weight, high insulation, fire resistance and other advantages. It can be used in both common and industrial buildings. The main material for production will be sand; for which supply chain already exists in the country. The other ingredients are also locally available. Only one ingredient i.e., aluminum powder will need importation. Like LSB, large automated plants are also available for AAC production in the international market (e.g., from China, Germany[13] and others).

5.4. Large Scale Fired Brick Industrial Kilns

A good beginning in this sector started more than 30 years back with a number of natural gas (NG) fired Hoffman and Tunnel kilns; which were very clean in terms of emission and had many advantages. The progress was halted due to non-availability of NG. Some large coal fired HHK (Hybrid Hoffman kilns) and Tunnel kilns have been built but the progress is slow; due to high capital outlay requirements. These are anecdotal reports of high emission from these kilns; as some of these were implemented without proper technical supervision. Even, a few have been closed or abandoned. The mechanized round the year HHKs and Tunnel kilns do offer huge potential gains on pollution reduction and on other fronts. These will reduce land foot-print as one kilns can replace as many as 8-10 FCKs. Pollution during dry season will be reduced with round the year production. Hollow bricks can be produced to conserve top soil. Labor working condition will improve with the elimination of unhealthy physical work and seasonal/migrant labor problem will be eliminated. With the growth of large industrial kilns, the smaller kilns may become non-competitive and will be replaced by more economically viable and less polluting technologies as happened in China.

6. Discussions

The trends, evidences and progress in brick making in Bangladesh during the past 30 years, show rather slow progress in terms of pollution abatement and energy efficiency improvement. It is also seen that regulatory changes do not lead to desired changes; unless socio-economic conditions are right and enough incentives are available for the field level actors. There have always been demands for cleaner brick kilns from the communities directly impacted by the pollution. Once this demand was taken up by the civil society and environmental activists, the awareness on the harmful impacts of brick kiln pollution started to increase at the national level and among population at large. People started to understand the reasons for the high pollution from the brick kilns; the environmental activists started going to courts for remedy. The adversaries were the brick kiln owners; who were afraid of losing their tradition business of the brick making. The kiln owners formed associations to lobby and protect their business. Most of the kiln owners lacked capital resources to upgrade their kilns; as affordable technologies were not available. In the meanwhile, air pollution in the large cities increased to intolerable level due to urban growth. This happened due to emergence of large brick kiln clusters near the larger cities, due growth in the demand for bricks from the cities. The concomitant problems with migrant labor and occupational health started to grow also in equal pace.

While government moving ahead with regulatory measures driven by public demand, created considerable push factor for the kiln owners to move to cleaner brick making; however, the corresponding pull factors such as availability of standardized cleaner kiln designs and fiscal support for change could not be provided. The assumption that the market will provide the solutions under high regulatory pressure, also turned out to be untenable. Gradually, stakeholder started getting together, the courts started giving directives for pollution abatement and the international donors were also sensitized to help-out with the air pollution and the other associated problems. With these developments, both the push factor and pull factors for air pollution abatement have started to come together and the situation on the ground has started moving in the positive direction; albeit slowly. DOE has now developed three kilns with substantially higher energy efficiency and lower emissions; that have similar capacities to FCKs and can be implemented at affordable cost. However, the rollout is yet to happen. DOE has piloted only seven kilns so far through some incentives; it is necessary to workout the measures to make the rollout widespread.

On the larger kilns some progress has been made through import of technology for HHKs and TKs; but progress is also slow in this front. These kilns being round the year operation has many advantages as discussed in the paper. The slow down in growth needs to be studied to incentivize the larger especially TKs; as there are reportedly issues with the technical support for HHKs.

On the non-fired brick front, GOB has rolled out regulatory measures recently. As discussed in the paper, the problems for growth on this front appear to be perceptional on the part of the customers and lack of ready market for the manufacturers. The existing small-scale concrete block industries, have been struggling for more than 15 years and some have even closed. One remedy may be the increase in the variety of non-fired bricks suited to specific use, so that

13 https://www.wkb-systems.com/en/contact.html

customers have better choice for these bricks. As discussed in the paper largescale plants for LSB and AAC brick are available in the international market; but entrepreneurs are unwilling to invest in these for fear of being stuck with large inventory.

With all the activities during the past 30 years, air pollution due to brick kiln emission is still a continuing problem; that cause considerable health burden for the population and also substantial financial burden on the nation. Public investment for incentivizing cleaner brick making can be justified, because of public health and other benefits as discussed in this paper.

7. Conclusion

The existing situation as discussed above, calls for urgent further synergistic efforts to address the brick kiln pollution and the related issues in a comprehensive manner. In order to achieve quick all-round gains, both push as pull factors for changes have to be mobilized. What is needed, is a well-articulated 'Theory of Change [15]' (ToC) for green and clean brick industry; which will substantially reduce the health impact of the brick kilns, reduce land footprint for kilns, reduce top soil use, reduce GHG emission and improve employment and working conditions for labor employed in the brick sector.

ToC is generally understood to be the explanation of the process of change for successful outcomes. The pathways for the change need to be identified and their logical connections to all the others need to be shown. The outcomes also need to be defined with time lines. The links between outcomes are explained by statements as to why one outcome may be a prerequisite for another. Thus, the ToC can also be thought of as a strategic planning tool with monitoring, evaluation and learning; with complex interaction among all these. A primary reason why complex programs are so difficult to evaluate, is that the assumptions that inspire them are not properly understood and how the change process will unfold is uncertain. So, it is essential that attention be focused on the early and mid-term changes needed to reach the longer-term goals. A simplified ToC for a cleaner and greener brick sector is outlined in the appendix (Table 8); without interlinks among the processes and outcomes for a period of next ten years. The ToC will need to up-graded considering the feedback processes involved. Given the political will of the GOB and the goodwill of the stakeholders, there is a good possibility that most of the strategic objectives can be realized.

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Disclaimer

The findings, interpretations, and conclusions expressed in this paper are solely attributable to the authors and are not related to World Bank or the Governments of Bangladesh.

Appendix

Table 8. *A simplified Theory of Change for the transformation to cleaner and greener Brick Sector in Bangladesh.*

Sl.	Objectives	Policy Interventions	Challenges	Incentives/ supports	Expected Outcomes (3-5 Years)	Comments	Longer Term (10 years) outcomes
1.	Reduction of PM2.5 in major urban centers for maximum health benefits	Mandating Relocation/ closing of fired brick kilns within 50km from city centers. This will only partially solve the problem, especially considering the large air sheds. Hence, it has to be a carrying capacity- based approach.	(i) Lack of incentives for kiln owners; (ii) Supply constraints for skilled workers and emission control devices.	Tradable permits Conditional incentives such as land allocation or cash for capital loss.	Fired brick kilns moved from near major urban centers in 3-5 years.	Policies for replacement of brick supply to be pursued in Parallel.	1. Smaller high emission kilns will disappear near large cities. 2. Smaller low emission kilns will be limited to rural areas and near small towns. 3. Large fraction of fired brick production will shift to larger, cleaner and round the year operation kilns.
2.	Reduction of PM2.5 in smaller towns and rural areas	Phasing out high emission kilns with low emission kilns of approved designs.	Lack of awareness among kiln owners. Lack of enforcement of existing regulations.	Providing designs and technical assistance for retrofitting their current high emission kilns at low cost. Fixing SPM emission	FCKs and traditional zigzags to be replaced within 3 years	DOE has three designs available and two have already been piloted, which has validated the design performances with about 30%	4. Non-fired bricks will constitute a large fraction of bricks and wall materials

Sl.	Objectives	Policy Interventions	Challenges	Incentives/ supports	Expected Outcomes (3-5 Years)	Comments	Longer Term (10 years) outcomes
				standard at 250 mg/Nm^3. Providing cash incentives for working condition improvement.		reduction in coal consumption and more than 70% reduction in SPM emission.	produced. 5. Land foot-print for brick kilns will substantially decrease. 6. Top soil use will decrease substantially. 7. Fuel use and GHG emission will be decreased substantially. 8. PM2.5 levels will decrease by 30-40% or even more in major urban centers.
3.	Increase number of high efficiency large and round the year kilns	Incentivize move to large round the year kiln.s	Capital shortage and lack of awareness among entrepreneurs.	Encourage current owners to move to large plants by suitable measures Encourage technology import with low duties Encourage building up of supply chain for large plants. Hollow brick production to be mandated.	Number of round the year large kilns will increase at a faster rate. Round the year operation will decrease pollution levels during dry season. Hollow bricks will reduce top soil demand. Back process automation will eliminate risky work practices. The share of production for fired bricks to be 50% in next 5-7 years.	During the past 30 years about 80 such kilns have been built. The early NG fired kilns have now closed due to gas supply constraints. Restoration of gas supply for brick kilns to be considered, once LNG based supply is available. Even at full cost recovery, these kilns may be able to compete in the market place. These plants may also reduce the land use footprint by as much as 50% per million brick basis.	
4.	Increasing variety of non-fired brick products.	Piloting of one each of large AAC and LSB brick plant in the private sector or trough PPP approach.	Lack of awareness and knowhow among private entrepreneurs. No established demand for the products.	Allocation of land and capital loans for private sector entrepreneurs as a green industry. Encourage technology import with low duties Inclusion of non-fired bricks in GOB procurement. Standard specifications for non-fired bricks by BSTI.	Direct SPM emission will be largely eliminated in manufacturing. Fuel use reduced to one third or less. Use of top soil will be eliminated Plants' land footprint will be reduced considerably on per million brick basis. The market share of non-fired bricks will substantially increase.	Only Aluminum powder needs to be imported for AAC bricks. Solid wastes from industrial processes can be used as fillers in LSB bricks. It may be a good idea to mandate such inclusion for industries producing solid waste above a threshold (say 100,000 tons per year). Prices are expected to be competitive with fired bricks on volumetric basis.	

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