BENEFITS AND COSTS OF BRICK KILNS OPTIONS FOR AIR POLLUTION CONTROL IN GREATER DHAKA

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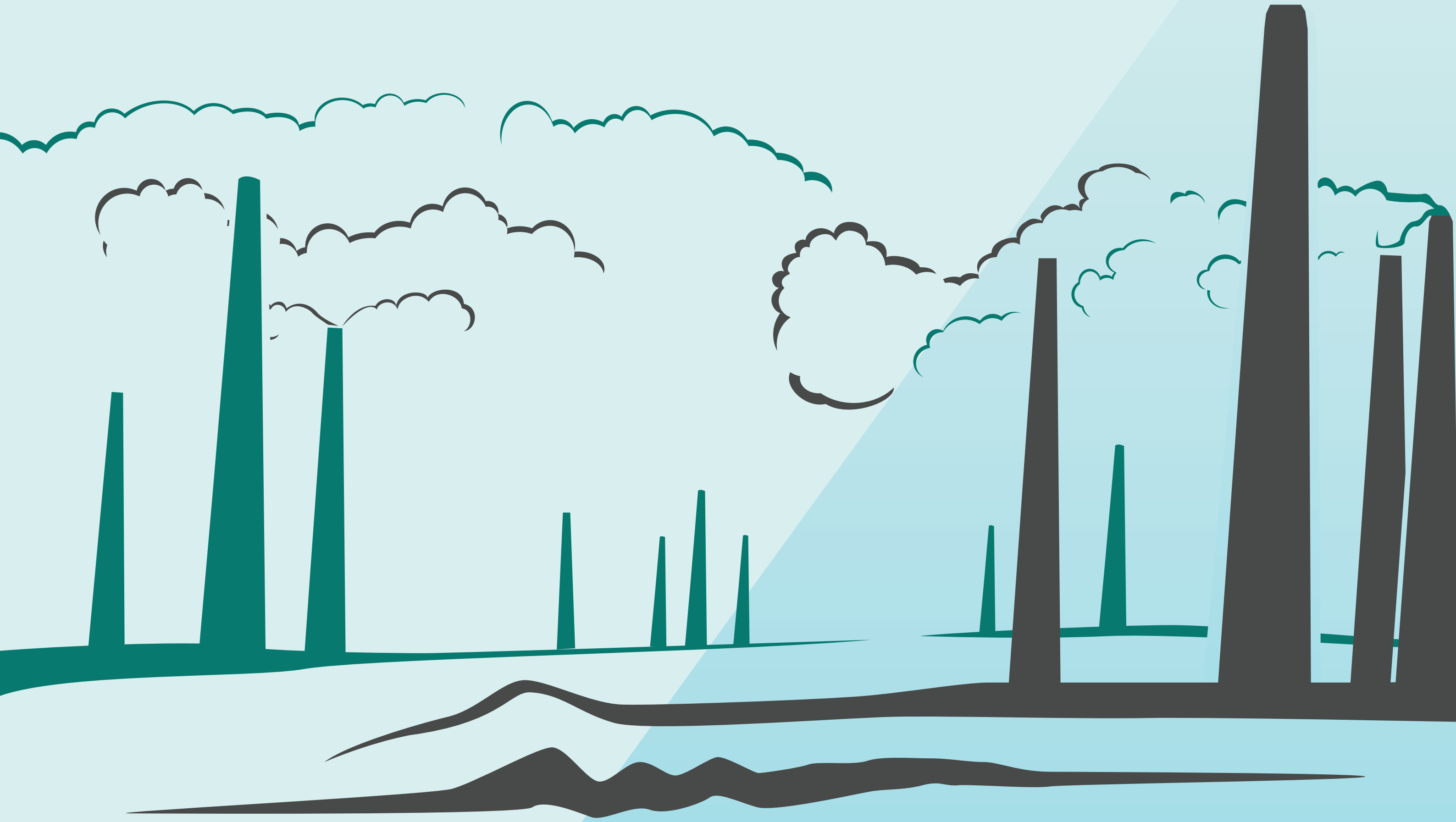

Benefits and Costs of Addressing Outdoor Air Pollution Challenges in Dhaka

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Benefits and costs of brick kiln options for air pollution control in Greater Dhaka

Bangladesh Priorities

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Acronyms

AAP	Ambient air pollution
ADB	Asian Development Bank
AF	Attributable fraction
ALRI	Acute lower respiratory infection
CB	Chronic bronchitis
CBV	Cerebrovascular disease
CCC	Copenhagen Consensus Center
CI	Confidence Interval
COPD	Chronic obstructive pulmonary disease
CP	Cardiopulmonary disease
DALY	Disability adjusted life year
FCK	Fixed Chimney Kiln
GBD	Global burden of disease
GDP	Gross domestic product
HHK	Hybrid Hoffman Kiln
IHD	Ischemic heart disease
IHME	Institute for Health Metrics & Evaluation
IZK	Improved ZigZag Kiln
LC	Lung cancer
$\mu g/m^3$	microgram per cubic meter
OR	Odds ratio
PM	Particulate matter
PPP	Purchasing power parity
RR	Relative risk
SD	Standard deviation
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change
VSBK	Vertical Shaft Brick Kiln
VSL	Value of statistical life
YLD	Year lost to disease
YLL	Year of life lost to premature death
WHO	World Health Organization

Executive summary

Greater Dhaka is one the largest metropolitan areas in the world with a population of at least 16 million, and has one of the highest annual ambient concentrations of fine particulate matter (PM2.5) of major cities in the world, causing nearly 14 thousand deaths per year.

The brick manufacturing sector is the single largest contributor to ambient PM2.5 in Greater Dhaha. The sector comprises of about 1,000 brick kilns in the area, producing 3.5-4 billion bricks per year in the dry season from October/November to March/April. Ambient PM2.5 concentrations at monitoring stations in Greater Dhaka during this six month period are on average about 130 µg/m3, or 13 times higher than WHO's annual average air quality guideline (AQG).

Most of the brick kilns in Greater Dhaka, and in Bangladesh in general, employ highly energy intensive and polluting technologies, and most kilns in Greater Dhaka consume large amounts of poor quality coal. Several technology options for cleaner brick production are available and have been initiated in the area.

The benefit-cost assessment undertaken in this study looks at four options of cleaner kiln technologies:

The first option involves an improvement or retrofitting of existing fixed chimney kilns (FCK) to so-called Improved ZigZag Kilns (IZK).

The three other options involve replacement of existing FCKs by construction of new kilns:

1.1. New IZKs.
1.2. Vertical Shaft Brick Kilns (VSBK).
1.3. Hybrid Hoffman Kilns (HHK).

Information on private benefits and costs of currently predominant and cleaner brick kiln technologies in Bangladesh, i.e., investment, production value and operating costs, applied in the benefit-cost assessment in this study is from project reports of the Asian Development Bank (ADB, 2012) as well as some more recent information in project reports of the UNDP and UNFCCC (UNDP, 2015; UNFCCC, 2014). Social benefits of cleaner technologies are estimated based on recent advances in health assessments of fine particulate matter (PM2.5) developed by the Global Burden of Disease (GBD) Project as well estimates of social benefits of carbon dioxide (CO2) emission reduction presented in Tol (2011).

Annualized benefits and costs of the four cleaner brick kiln options for Greater Dhaka are presented in table E1. The benefits includes health improvements (avoided deaths and illness), global benefits from carbon dioxide (CO2) reductions, as well as increased production value and operating cost savings from more efficient production. The cost is annualized investment cost. Benefits and cost are discounted at 5% over an assumed useful life of investment of 20 years. Annex 3 presents more details with discount rates ranging from 3% to 10%

Table E1. Annualized social benefits and costs of full conversion to cleaner brick kilns in Greater Dhaka, 2014 (BDT million)

	Benefits		Cost
	VSL	DALY	
From FCK to IZK	4,857	3,184	408
New IZK	4,857	3,184	815
New VSBK	8,606	6,097	1,605
New HHK	13,766	11,257	3,261

Note: Annualized benefits and costs are at 5% discount rate. VSL=valuation of avoided deaths using VSL. DALY=valuation of a DALY at GDP per capita. Source: Estimates by the author.

The benefit-cost ratios (BCR) are by far the highest for the option of retrofitting existing FCKs to IZKs, with benefits being 8 to 12 times larger than cost. The three options of constructing new brick kilns have quite similar BCR (table E2).

Table E2. Benefit cost ratios (BCR) of cleaner brick kilns in Greater Dhaka, 2014

	VSL	DALY
From FCK to IZK	11.9	7.8
New IZK	6.0	3.9
VSBK	5.4	3.8
HHK	4.2	3.5

Note: BCRs are calculated with a 5% discount rate. VSL=valuation of avoided deaths using VSL. DALY=valuation of a DALY at GDP per capita. Source: Estimates by the author.

Each of these options are both financially (private costs and benefits) and economically (social costs and benefits) viable when the technologies are properly designed and adopted for Bangladeshi climatic conditions, with particularly high BCRs for conversion or retrofitting of existing FCKs to IZKs. This option is also attractive for the reason that it does not require relocation.

A key issue is to make brick kiln owners and investors aware and knowledgeable of the technology options available to improve the quality of the air, as well as the financial efficiency improvements that these technologies can provide. For the relatively large investments required in HHK, financial resources must be available at reasonable terms. And it should be emphasized that to achieve the full environmental and financial benefits, kiln conversions and retrofits to IZKs must reach good technical and operational standards. Last but not least, authorities must be committed to enforce their own regulations to the benefit of the greater public.

However, even with adoption of the cleaner kiln technologies assessed in this paper for all of brick production in Greater Dhaka, PM2.5 emissions from the sector would continue to be substantial and have severe impacts on the population in the area, if emission reduction efficiencies are not greater than the 40-60% applied in this study.

An adequate solution most therefore consider additional options, such as enhanced emission reduction technologies, fuel switching away from coal and biomass, and relocation to industrial parks located downwind from population centers.

While solving the problem of air pollution from brick kilns is a high priority, it will apparently not solve the problem of air pollution in Greater Dhaka. Other sources of air pollution must also be urgently and simultaneously addressed.

Introduction

Greater Dhaka is one the largest metropolitan areas in the world with a population of at least 16 million, and is the approximate geographic scope of this benefit-cost assessment of controlling air pollution from brick kilns in Bangladesh. Over 10% of the population of Bangladesh and nearly 1/3rd of the country's urban population live in this area. The area includes Dhaka City Corporation (DCC) and parts of several districts (zila) and sub-districts (upazila): Dhamrai in the northwest, Gazipur in the north, Savar in the west, Manikganj in the west, Keraniganj in the southwest, and Narayanganj in the south and southeast, Rupganj in the east, Kaliganj in the northeast (Motalib et al, 2015; Guttikunda et al, 2012).

Greater Dhaka has one of the highest annual ambient concentrations of fine particulate matter (PM2.5) of major cities in the world, causing nearly 14 thousand deaths per year. A major source of this pollution is about 1,000 brick kilns in the area, producing 3.5-4 billion bricks per year in the dry season from October/November to March/April. Ambient PM2.5 concentrations at monitoring stations in Greater Dhaka during this six month period are on average about 130 $\mu g/m^3$, or 13 times higher than WHO's annual average air quality guideline (AQG). For the purposes of estimating air emissions and modeling air pollution concentrations, the Greater Dhaka area comprises somewhat over 2,000 km^2 (NILU, 2014; NILU, 2015).

Most of the brick kilns in Greater Dhaka, and in Bangladesh in general, employ highly energy intensive and polluting technologies, and most kilns in Greater Dhaka consume large amounts of poor quality coal.

The benefit-cost assessment undertaken in this study looks at four options of cleaner kiln technologies. One of the options involves an improvement of existing fixed chimney kilns (FCK) to so-called Improved ZigZag Kilns (IZK). The three other options involve replacement of existing FCKs by construction of new kilns: Vertical Shaft Brick Kilns (VSBK), Hybrid Hoffman Kilns (HHK) as well as the IZK. Each of these options represents different investment requirements and provides different benefits in terms of improved energy and PM2.5 emission efficiency. Substitution away from coal to a cleaner fuel is not assessed, as this involves a major challenge at this point in time.

Information on private benefits and costs of currently predominant brick kilns and cleaner brick kiln technologies in Bangladesh - i.e., investment, production value and operating costs - applied in the benefit-cost assessment in this study is from project reports of the Asian Development Bank (ADB, 2012) as well as some more recent information in project reports of the UNDP and UNFCCC (UNDP, 2015; UNFCCC, 2014). Social benefits of cleaner technologies are estimated based on recent advances in health assessments of fine particulate matter (PM2.5) developed by the Global Burden of Disease (GBD) Project as well estimates of social benefits of carbon dioxide (CO_2) emission reduction presented in Tol (2011).

Air pollution in Dhaka

Particulate matter (PM) and especially PM2.5 is the outdoor ambient air pollutant (AAP) that globally is associated with the largest health effects (Lim et al, 2012). It is therefore the focus of this study. A decade ago the World Health Organization (WHO) reduced its guideline limits to an annual average ambient concentration of 10 micrograms per cubic meter (μg/m^3) of PM2.5 in response to increased evidence of health effects at very low concentrations of PM.[1] WHO also established three interim targets for air quality ranging from 35 μg/m^3 to 15 μg/m^3 of annual average PM2.5 (table 2.1).

Table 2.1. WHO annual PM2.5 interim targets and air quality guideline (AQG)

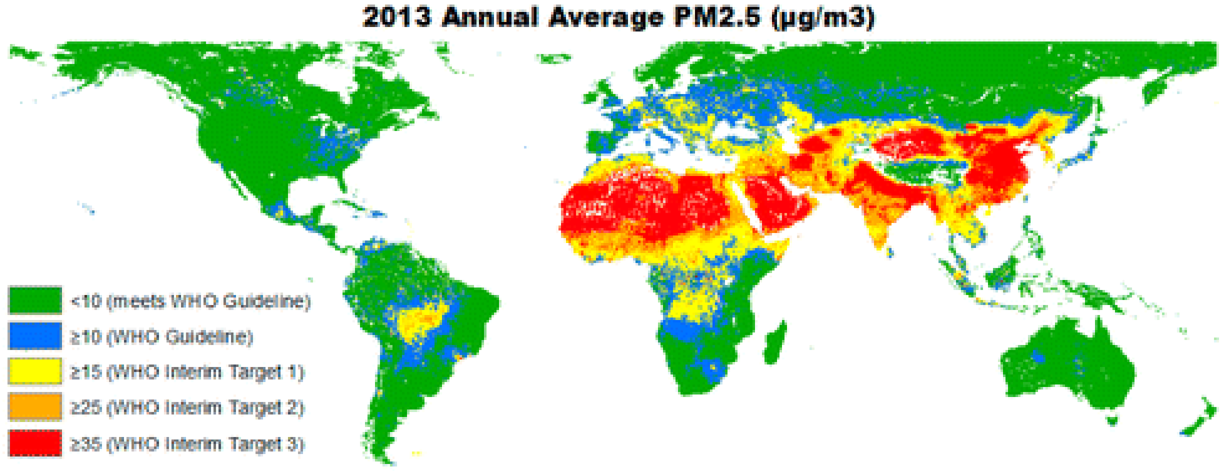
WHO PM2.5 targets	Annual PM2.5 (μg/m^3)
> WHO Interim Target 1	35
> WHO Interim Target 2	25
> WHO Interim Target 3	15
> WHO AQG	10

Source: WHO (2006).

Global estimates of annual PM2.5 concentrations at 0.1° × 0.1° spatial resolution for the Global Burden of Disease (GBD) 2013 by the Institute for Health Metrics and Evaluation (IHME) have recently been published (Brauer et al, 2015). The estimates were produced by combining satellite-based estimates, chemical transport model simulations, and ground measurements from 79 different countries. The estimates indicate that annual PM2.5 concentrations in most of Bangladesh exceed the WHO Interim Target 3 of 35 μg/m^3 (figure 2.1). Nationwide annual average PM2.5 was estimated at 48 μg/m^3.

[1] PM2.5 are particulates with a diameter smaller or equal to 2.5 micrometers (μm), respectively.

Figure 2.1. Estimated annual average PM2.5 (µg/m3)



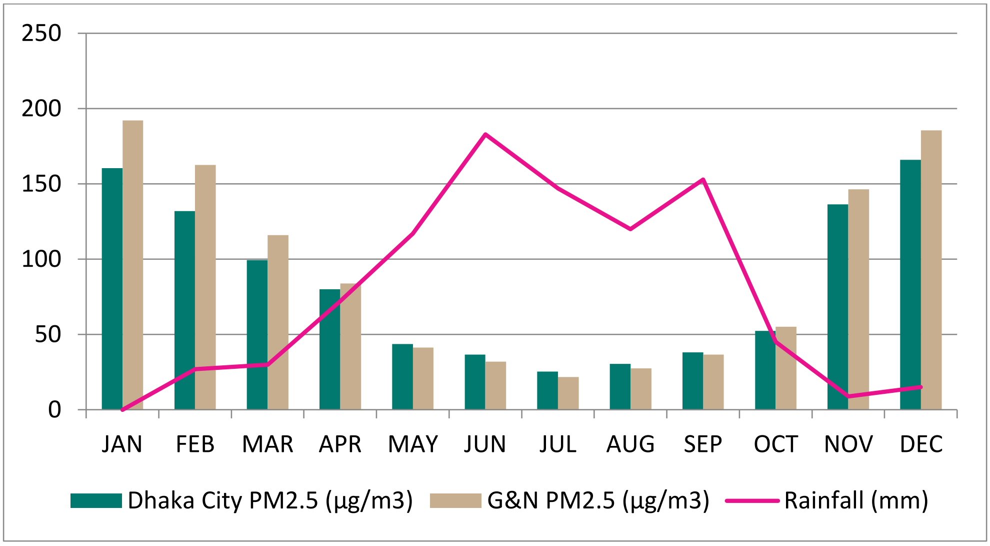
Source: Brauer et al (2015).

The advantage of nationwide estimates of PM2.5 exposure as in Brauer et al (2015) is that population wide health effects of ambient PM2.5 can be estimated, and not limited to cities with PM2.5 monitoring. These estimates can, however, have large margins of error, especially in countries in which ground level PM2.5 monitoring is scarce (van Donkelaar et al, 2015). It is therefore important to identify and utilize all available ground level monitoring data and then supplement this with data from approaches used in Brauer et al.

Monitoring of PM2.5 concentrations in Dhaka City or Metropolitan Area (DMA) is available from three sites and from one site in each of the adjacent municipalities of Gazipur (G) and Narayangonj (N) in Greater Dhaka. The two-year annual average concentration from September 2013 to August 2015 is 83 µg/m^3 in Dhaka City and 92 µg/m^3 on average at the two sites in the adjacent municipalities. This is 2.4-2.6 times higher than WHO's Interim Target 1 of 35 µ/m^3 and over 8-9 times higher than WHO's AQG of 10µg/m^3.

Monthly average PM2.5 over the two-year period is highest during the dry season and lowest during the rainy season. Average concentrations ranges from 22-31 µg/m^3 in July-August to 161-192 µg/m^3 in December-January, making Greater Dhaka one of the most polluted megacities in the world (figure 2.1). Brick kilns, numbering over 1,000 in the Greater Dhaka area, contribute greatly to the high PM2.5 concentrations during the dry season.

Figure 1.2 Monthly average PM2.5 and rainfall in Greater Dhaka



Note: G=Gazipur; N= Narayangonj. Source: PM2.5 is from Monthly Air Quality Monitoring Reports of the Ministry of Environment and Forests from Sep 2013 to Aug 2015. Rainfall is averages in 2000-2012.

The brick sector

Scale of the sector

There are thousands of brick kilns in Bangladesh. The exact size of the sector is, however, uncertain. Recent reported estimates of the number of kilns are:

- 4,500 with an annual production of 9 billion bricks per year (Gomes and Hossain, 2003)
- 5,200 with a production of 15 billion bricks (Guttikunda and Khaliquzzaman, 2014)
- over 6,000 (Hossain and Abdullah, 2012)
- nearly 7,000 as reported in New Age (2015)[2]
- 6,000-10,000 reported in UNDP (2015).

The brick kiln industry represents about 1% of GDP and employs 1-2 million people (Motalib et al, 2015; Guttikunda and Khaliquzzaman, 2014; UNDP, 2015). Brick production grew at an annual rate of 5-6% during the decade 2000-2010 and at an expected rate of 2-4% per year from 2010-2020 (Guttikunda and Khaliquzzaman, 2014).

The brick kiln sector in Greater Dhaka comprises over 1,000 brick kilns in six districts, producing over 3.5 billion bricks per year (Guttikunda et al, 2012). The sector is dominated by small individual

[2] http://newagebd.net/175292/fixed-chimney-brick-kilns-continue-to-pollute-air/

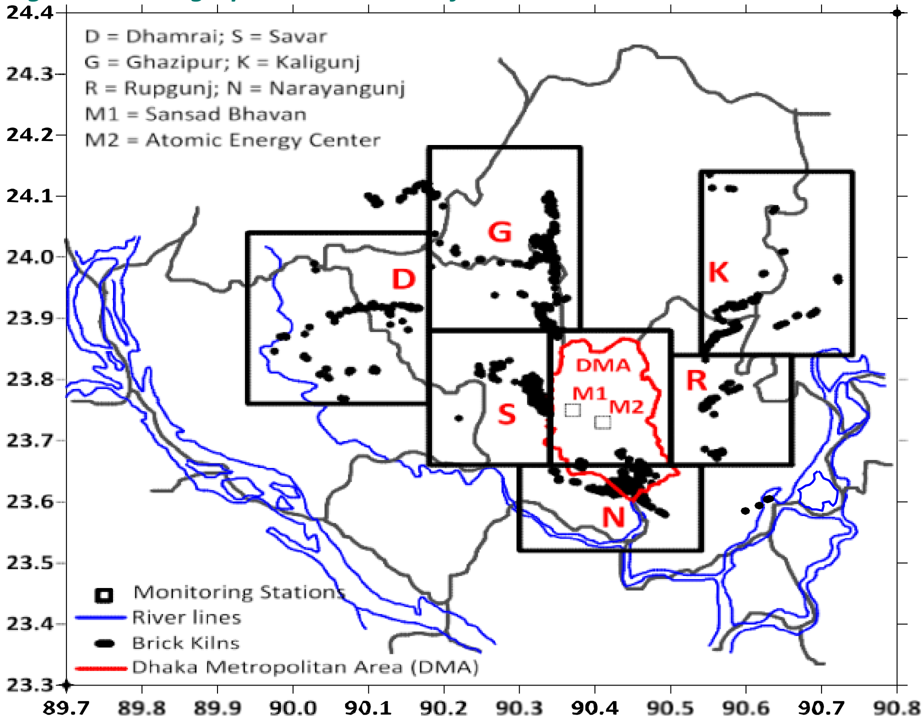
operators, each consisting of mostly 200–300 daily wage workers per kiln, employed on a seasonal basis (Guttikunda et al, 2012). The largest clusters of kilns are presented in table 3.1 and figure 3.1

Table 3.1. Major clusters of brick kilns in the Greater Dhaka area

	Number of brick kilns		Number of brick kilns
Dhaka (DMA)	-	Kaliganj (K)	90
Savar (S)	120	Ropganj (R)	50
Dhamarai (D)	80	Narayanganj (N)	270
Gazipur (G)	320	Total	930

Source: Guttikunda et al (2012).

Figure 3.1. Geographic distribution of brick kilns in the Greater Dhaka area



Source: Guttikunda et al (2012).

Brick kiln technologies

Most of the brick kilns in the Greater Dhaka area are conventional fixed chimney bull trench kilns (FCBTK) or simply fixed chimney kilns (FCK). The fuel is predominantly coal, as well as agricultural waste during the harvest season. The majority of the coal has a high ash content of 20-30% (Guttikunda et al, 2012).

Alternative technologies are being promoted and to some extent adopted. These include Improved ZigZag Kilns (IZK), Vertical Shaft Brick Kilns (VSBK) and Hybrid Hoffman Kilns (HHK). These kilns are all more energy efficient and emit less PM than the traditional FCKs (table 3.2).

Table 3.2. Brick kiln technologies, fuel efficiencies and PM emissions

Technology	Fuel consumption (tons of coal per 100,000 bricks)[1]	Reduction in fuel consumption (% relative to FCK)[1]	Reduction in fuel consumption (% relative to FCK)[2]	PM emissions reduction (% relative to FCK)[3]
Fixed Chimney Kiln (FCK)	20-22	-	-	-
Improved ZigZag Kiln (IZK)	16-18	19%	21%	40%
Vertical Shaft Brick Kiln (VSBK)	10-12	48%	50%	60%
Hybrid Hoffman Kiln (HHK)	12-14	38%	46%	60%

Sources: [1]World Bank (2011). [2]ADB (2012). [3] Guttikunda et al (2012).

Air pollution from the brick kiln sector

Emissions of PM2.5 from brick kiln in Greater Dhaka were estimated at 17.6 thousand tons in 2013, making the sector the largest source of PM2.5 (NILU, 2014). About 80% of air pollution from brick kilns affecting the Dhaka Metropolitan Area (DMA) is from kilns in the three districts/sub-districts of Narayanganj (27%), Gazipur (30%), and Savar (23%) (Guttikunda et al, 2012).

A source apportionment study found that the PM2.5 contribution of brick kilns at the CAMS-2 Farm Gate site in Dhaka was 31 $\mu g/m^3$ of ambient 64 $\mu g/m^3$ (47%) during August 2010 to July 2012, and 31 $\mu g/m^3$ of ambient 85 $\mu g/m^3$ (37%) during 2010-2011 (Begum et al, 2014). Previous source apportionment studies from 2001-2009 indicate that brick kilns contribute 30-40% of ambient PM2.5 in Dhaka Metropolitan Area (DMA) (Guttikunda et al, 2012).

Dispersion modeling simulations indicate that on average 30 $\mu g/m^3$ of ambient PM2.5 in Dhaka Metropolitan Area (DMA) are from brick kilns in the Greater Dhaka area during the six months period from October to March. The impact is similar in Narayanganj (30 $\mu g/m^2$) and 23 $\mu g/m^3$ in Gazipur and Ropganj (table 4.1). The annual average contributions are approximately half of the seasonal contributions.

Thus these apportionment and dispersion modeling simulations indicate that the annual average PM2.5 concentrations from brick kilns affecting most of the population in Greater Dhaka are in the range of 15-30 $\mu g/m^3$. This is 17-34% of current annual ambient concentrations of 86 $\mu g/m^3$.

Table 4.1. Ambient PM2.5 contributions from brick kilns in Greater Dhaka during brick manufacturing season

	Ambient PM2.5 (μg/m³)		Ambient PM2.5 (μg/m3)
Dhaka Metropolitan Area (DMA)	30	Kaliganj (K)	15
Savar (S)	15	Ropganj (R)	23
Dhamarai (D)	6	Narayanganj (N)	30
Gazipur (G)	23		

Source: Reproduced from Guttikunda and Khaliquzzaman (2014).

Health impacts of PM2.5 emissions from the brick kiln sector

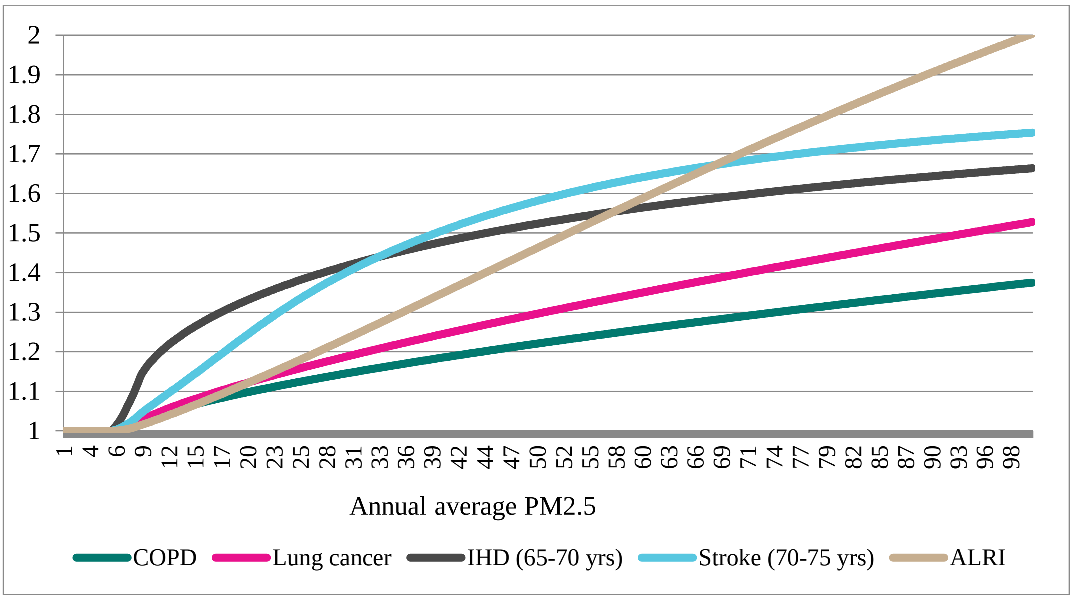
The Global Burden of Disease (GBD) Project 2010 developed an integrated exposure-response (IER) function that relates health outcomes to annual ambient PM2.5 concentrations (annex 1). Apte et al (2015) provide the relative risks of the health outcomes from PM2.5 used in the GBD Project. These relative risks are presented in figures 5.1 for PM2.5 concentrations up to 100 μg/m³. The risks of COPD, lung cancer and ALRI are age-weighted population averages. The risks of ischemic heart disease (IHD) and cerebrovascular disease (stroke) are for age groups 65-70 and 70-75 years, respectively. These are the relative risks that are approximately the same as the age-weighted population averages.[3]

The relative risks of IHD and stroke rise very quickly as PM2.5 concentrations start to exceed a lower PM2.5 threshold of about 6-7 μg/m³. The relative risk of ALRI, however, exceeds the risk of IHD and stroke for PM2.5 concentrations greater than about 58-68 μg/m³. The smallest relative risks are for lung cancer and COPD.

About 70-85% of deaths associated with AAP (PM2.5) are from ischemic heart disease (IHD) and cerebrovascular disease (stroke) and vary by country. The remaining 15-30% are from COPD, lung cancer, and ALRI. In addition, a large number of days of illness is also associated with PM2.5. These days of illness can be expressed as years lost to disease (YLD) by applying disability weights to each disease outcome.[4]

[3] Age-weighted population averages for IHD and stroke depend on the age-specific structure of IHD and stroke mortality and therefore vary somewhat by country.
[4] Several cardiovascular diseases and moderate COPD are assigned a disability weight of 0.1-0.2 in the GBD 2010 Study.

Figure 5.1 Relative risks of major disease outcomes associated PM2.5 exposure



Source: Produced from Apte et al (2015).

Applying the GBD methodology indicates that nearly 14 thousand people died in Greater Dhaka in 2014 due to ambient PM2.5 exposure. About 1,200 to 2,800 of these deaths were from brick kilns, with a central estimate of over 2,000. This represents 15% of all deaths from ambient PM2.5, although the ambient PM2.5 share from brick kilns is 26% (table 5.1).

The reason for the lower share of deaths (i.e., 15%) than the share of ambient PM2.5 from brick kilns (i.e., 26%) is the flatness of the relative risk functions for IHD and stroke at the high PM2.5 concentration levels observed in Greater Dhaka.

Table 5.1. Deaths and DALYs from ambient PM2.5 exposure in Greater Dhaka, 2014

	Total	Share for Brick kilns			% of Total
		Low	Central	High	Central
Population (million)	16	16	16	16	
Ambient annual PM2.5 (μ/m^3)	86	15	22.5	30	26%
Deaths from PM2.5	13,825	1,222	2,031	2,840	15%
Disease (YLD) from PM2.5	13,369	1,182	1,964	2,747	15%
DALY from PM2.5	386,362	34,149	56,764	79,379	15%

Source: Estimates by the author.

Brick kiln interventions

The benefit-cost assessment undertaken in this study looks at four options of cleaner kiln technologies. One of the options involves an improvement of existing fixed chimney kilns (FCK) to the Improved ZigZag Kilns (IZK). The three other options involve replacement of existing FCKs by construction of new kilns: Vertical Shaft Brick Kilns (VSBK), Hybrid Hoffman Kilns (HHK) as well as the IZK.

Each of these options represents different investment requirements and provides different benefits in terms of improved energy and PM2.5 emission efficiency. Substitution away from coal to a cleaner fuel is not assessed, as this involves a major challenge at this point in time.

A key issue is to make brick kiln owners and investors aware and knowledgeable of the technology options available to improve the quality of the air, as well as the financial efficiency improvements that these technologies can provide. It is, however, important that the technologies are properly designed and adopted for Bangladeshi climatic condition, as experienced with HHKs in UNDPs project (UNDP, 2015). Also, for the relatively large investments required in HHKs, financial resources must be available at reasonable terms. And it should be emphasized that to achieve the full environmental and financial benefits, kiln conversions and retrofits to IZKs must reach good technical and operational standards. Last but not least, authorities must be committed to enforce their own regulations to the benefit of the greater public.

A World Bank project is focusing on the zigzag technology discussed below, and an ADB project provides financing for several technologies.

Improved ZigZag Kiln (IZK)

FCKs can be converted to Improved ZigZag Kilns (IZK) at low costs in the low lands at the same site as the FCK. This can be accomplished in less than 3 months. The production capacity is the same or higher compared to the FCKs. The brick quality is as good as or better than FCK, and with energy savings and PM emission reductions. Kiln owners find this technology the most attractive because they neither need to relocate nor having to look for high land (Guttikunda and Khaliquzzaman, 2014), and there is no need for large investment cost that requires commercial financing. While many FCKs have been converted to zigzag kilns in Bangladesh by now, most of them do not provide the desired environmental benefits (UNDP, 2015). To be considered IZKs, conversions must meet technological and operational standards. A World Bank project is introducing such IZKs.

Vertical Shaft Brick Kilns (VSBK)

The VSBK is suitable for small-scale brick manufacturers in developing countries. It saves 40-50% energy and needs less land compared to traditional kilns. VSBK can be used year round because it has a roof. Traditional kilns operate only 5-6 months per year (Darain et al, 2013).

The major barriers for the uptake of VSBK are product quality. Bricks are not as red as they are from FCK and HHK—a reason for common rejection among the builders. Also, the typical production capacity of the VSBK is low compared to 20,000+ from other kiln technologies. Moreover, the VSBK needs to be located on high land above flood level, which is more expensive than low land (Guttikunda and Khaliquzzaman, 2014).

Hybrid Hoffman Kilns (HHK)

HHK technology is substantially more capital intensive than the kiln technologies discussed above. It also needs high land above flood level. Thus the uptake of the HHK is slow, although production rates and brick quality are high (Guttikunda and Khaliquzzaman, 2014). However, there are over 50 HHKs in operation or in the pipeline with over 20 banks and financial institutions having provided loans. Over 40 of these kilns are in the Dhaka area (UNDP, 2015). With their high production capacity these 40+ units will contribute approximately 15% of all brick production in the Dhaka area. Nevertheless it should be emphasized that some of the units have struggled with poor technology adoption to Bangladeshi climatic conditions, resulting in too small kilns and too limited brick drying facilities, with the result that the kilns do not reach intended capacity and struggles financially. The market demand for red color of bricks also requires some modifications to kiln operations (UNDP, 2015).

Private costs and benefits of cleaner brick kilns

The benefit-cost assessment undertaken in this study makes a distinction between private and social costs and benefits of cleaner kiln investments. Private costs and benefits are those borne exclusively by the owner of the kiln, and are important in terms of the private incentive to invest in and operate a brick kiln. Social costs and benefits include those that are external to the owner, i.e., those borne by other people or the environment. They are discussed in the next section.

Information on private benefits and costs of currently predominant kilns (FCK) and cleaner brick kiln technologies in Bangladesh, i.e., investment, production value and operating costs, applied in the benefit-cost assessment in this study is from project reports of the Asian Development Bank (ADB, 2012) as well as some more recent information in project reports of the UNDP and UNFCCC (UNDP, 2015; UNFCCC, 2014).

Typical investment cost, brick production, and operating cost of brick kiln technologies in Bangladesh are presented in table 7.1. Investment cost for the IZK is only marginally higher than for the predominantly used FCK technology, but provides substantial cost savings in terms of energy efficiency improvements. The investment cost for the VSBK is 2.6-3.5 times higher than for the IZK and the FCK, but provides higher annual production and substantial energy savings. The HHK has the highest investment cost, annual production and operating cost, albeit also lower operating cost per unit of production.

Table 7.1. Private benefits and costs of FCK and cleaner brick kilns (BDT million per brick kiln)

	FCK	IZK	VSBK	HHK
Investment cost	6	8	21	160
Bricks per year (million)	3	3	4	15
Value per brick (BDT)	6.25	6.25	6.25	7.00
Production value per year	18.75	18.75	25.0	105.0
Operating cost per year	17.88	16.8	20.4	68.4
Private net benefits per year	0.87	1.95	4.6	36.6
Payback period (years)	6.9	4.1	4.6	4.4

Source: Calculations by the author based on ADB (2012); UNDP (2015); UNFCCC (2014).

Investment cost, production values, and operating cost per 1,000 bricks of production are presented in table 7.2. Unit investment cost is higher for the cleaner kilns and highest for the HHK. Unit production value is higher for the HHK because of higher brick quality and less rejects. Unit operating cost is lower for the cleaner technologies. Thus unit private net benefits per year, i.e., unit revenue less unit operating cost, increases from BDT 290 per 1,000 bricks for the FCK to BDT 2,440 per 1,000 bricks for the HHK. The investment payback period is similar for three cleaner technologies, and highest for FCK. Similar payback periods are found by Tehzeeb and Bhuiyan (2014).

Table 7.2. Private benefits and costs of FCK and cleaner brick kilns (BDT per 1,000 bricks)

	FCK	**IZK**	**VSBK**	**HHK**
Investment cost	2,000	2,667	5,250	10,667
Production value	6,250	6,250	6,250	7,000
Operating cost	5,960	5,600	5,100	4,560
Private net benefits	290	650	1,150	2,440
Payback period (years)	6.9	4.1	4.6	4.4

Source: Calculations by the author based on ADB (2012); UNDP (2015); UNFCCC (2014).

The above analysis of private benefits and costs of investment in brick kilns is relevant for an entrepreneur who considers entering the sector. For an existing brick kiln owner who considers investing in cleaner technology it is, however, the marginal change in costs and benefits that matters. This is presented in table 7.3.

The first and least expensive option is to retrofit an existing FCK to an IZK. This costs around BDT 4 million. It provides no substantial production benefits, but provides significant energy savings and thus cost reductions, with an investment payback in 3.7 years of operation.

The second option involves abandoning the existing FCK and construct a new IZK elsewhere, for instance in a designated industrial park. This involves a larger investment and thus longer payback, as the net benefits are the same as for the first option.

The third and fourth options also involve abandoning the existing FCK and construct a new brick kiln elsewhere, with reasonable payback periods of 4.5-5.6 years. These options provide production benefits due to their larger capacity, but also higher operating cost (net of energy savings) for the same reason.

In reality, the private payback periods of switching to the cleaner kilns may be less than presented in table 7.3 for two reasons. Firstly, the remaining productive life of an existing kiln may be shorter than the life of a retrofitted or new kiln, and thus would require investment or refurbishing at some point in the near future if it were continued to operate. This avoided cost by investing in a cleaner kiln is not reflected in table 7.3. Secondly, for options 2-4, the existing FCK may be sold and thus reduce the cost of investing in a new kiln. However, as a main objective of promoting investment in new kilns is to improve air quality, the selling of old, highly polluting kilns should be prevented.[5]

Table 7.3. Private benefits and costs of switching from FCK to cleaner brick kiln production

BDT million per brick kiln	**(1) From FCK to IZK**	**(2) New IZK**	**(3) New VSBK**	**(4) New HHK**
Investment cost	4	8	21	160
Incremental production value per year	0	0	6.25	86.25
Incremental cost per year	-1.08	-1.08	2.52	50.52
Incremental net private benefits per year	1.08	1.08	3.73	35.73
Payback period (years)	3.7	7.4	5.6	4.5

Source: Calculations by the author based on ADB (2012); UNDP (2015); UNFCCC (2014).

Social benefits of cleaner brick kiln options

The social benefits of cleaner brick kilns assessed in this study are health benefits of reduced PM2.5 emissions and global benefits of carbon dioxide (CO_2) emission reduction from improved energy efficiency. Other social benefits of air emissions reductions - such as reduced material damage to buildings and structures, reduced degradation of forest, soil and water, and reduced damage to agricultural crops – are not estimated as these benefits are found in most studies to be quite small compared to health benefits.

[5] In reality, it may be difficult to prevent continued operation of old kilns as long as they are profitable, unless they are forced to shut down for environmental or other reasons.

The cleaner brick kiln technologies are expected to reduce PM2.5 emissions from the kilns by 40-60%. Conversion of all kilns in Greater Dhaka to any one of these technologies will save an estimated 800-1,200 lives each year (table 8.1). This is based on the central estimate of 2,031 annual deaths from the brick kiln sector in Greater Dhaka (section 5).

Table 8.1. Avoided deaths per year from full conversion to cleaner brick kilns in Greater Dhaka

	From FCK to IZK	**New IZK**	**New VSBK**	**New HHK**
PM2.5 reductions*	40%	40%	60%	60%
Avoided deaths per year	812	812	1,219	1,219

Source: Estimates by the author. * Guttikunda et al (2012).

Avoided deaths and associated illness from cleaner brick kilns can be monetized by using various benefit valuation measures. The Copenhagen Consensus Center (CCC) has suggested to apply a value of GDP per capita per avoided “disability adjusted life year” or DALY.

A common alternative approach that attempts to reflect how much people are willing to pay to reduce the risk of death is the use of the so-called value of statistical life (VSL) for valuation of avoided deaths. A VSL of BDT 4.8 million (US$ 61,672) is estimated for Bangladesh for the year 2014 in this paper (annex 2), equivalent to 50 times GDP per capita. Along with valuation of a day of illness at 50% of wage rates in Bangladesh, this approach results in estimated health benefits that are 2 times larger than when using GDP per capita for a DALY. Health benefits using both approaches are presented in this paper.

An improvement in ambient PM2.5 air pollution is unlikely to instantaneously provide full benefits for health outcomes that develop over long periods of PM2.5 exposure, i.e., for heart disease, stroke, chronic obstructive pulmonary disease (COPD) and lung cancer. It is therefore assumed that reduced incidence of and deaths from these diseases are gradually realized over ten years. For acute lower respiratory infections (ALRI) among young children, however, full health benefits are realized in the same year as PM2.5 exposure reduction. This means that over a time horizon of 20 years annualized health benefits are 71-79% of full benefits at a discount rate of 3-10%.

The annual health benefits of cleaner brick kilns in Greater Dhaka would therefore be in the range of BDT 1.5 – 3.4 billion for IZK and BDT 2.3 – 5.2 billion for VSBK and HHK once all brick production in Greater Dhaka is converted to either of these technologies (table 8.2; and tables A3.1-2 in annex 3).[6]

[6] No attempt has been made to account for intertemporal changes in (exposed) population and PM2.5 concentrations from other sources than brick kilns.

Table 8.2. Annual value of health benefits from full conversion to cleaner brick kilns in Greater Dhaka (BDT billion per year)

Health valuation method	From FCK to IZK	New IZK	New VSBK	New HHK
DALY=GDP per capita	1.5 – 1.7	1.5 – 1.7	2.3 – 2.6	2.3 – 2.6
Averted deaths at VSL	3.1 – 3.4	3.1 – 3.4	4.6 – 5.2	4.6 – 5.2

Note: The range reflects discount rates from 3% to 10%. Source: Estimates by the author.

Estimates of global benefits of CO_2 emission reduction from improved energy efficiency of cleaner kilns are presented in table 8.3. A global social cost of US$ 19 and US$ 84 per ton of carbon at a discount rate of 5% and 3%, respectively, is applied from Tol (2011). Social cost is assumed to be zero if a discount rate as high as 10% is applied. Coal savings, compared to FCK, are 40 tons per 1 million brick for IZK and 80 tons for VSBK and HHK (World Bank, 2011). And there are approximately 1.25 tons of CO_2 emissions per ton of coal predominantly used in brick kilns in Bangladesh.[7]

Total CO_2 emission reduction benefits from full conversion of all kilns to cleaner brick kilns in Greater Dhaka are BDT 80-356 million per year for IZK and BDT 161-711 million per year for VSBK and HHK at 5% and 3% discount rates (table A3.3 in annex 3). This amounts to 3-5% of health benefits at a discount rate of 3%, and 5-25% of health benefits at a discount rate of 5%.

Table 8.3. Global benefits of CO2 reductions per 1 million bricks (BDT)

Discount rate	From FCK to IZK	New IZK	New VSBK	New HHK
3%	88,914	88,914	177,827	177,827
5%	20,111	20,111	40,223	40,223
10%	0	0	0	0

Benefit-cost ratios of interventions

The total investment cost of converting all kilns to cleaner brick kilns in Greater Dhaka range from BDT 5.3 billion (US$ 66 million) for conversion of FCKs to IZKs, to BDT 42.7 billion (US$ 533 million) for using new HHKs. This cost is for a production of 4 billion bricks per year with either of the technology options. Annual private benefits of this investment would be BDT 1.4 to 8.6 billion (table 9.1).

This means that the external health benefits estimated in the previous section are larger than the private benefits in the case of retrofitting of FCK to IZK, and new IZK, and comparable to the private

[7] Most of the coal used in kilns in Bangladesh is imported from India. Indian coal is low in caloric value and carbon (ca. 35% average carbon content) and high in ash content. Thus CO_2 emissions per ton of coal are low (Mittal et al, undated).

benefits in the case of VSBK. Even for the HHK, the external health benefits are as much as 27-60% the private benefits.

Table 9.1 Private costs and benefits of full conversion to cleaner brick kilns in Greater Dhaka, 2014 (BDT million)

	From FCK to IZK	**New IZK**	**New VSBK**	**New HHK**
Costs:				
Investment cost	5,333	10,667	21,000	42,667
Benefits:				
Increased production value per year	0	0	0	3,000
Cost savings per year	1,440	1,440	3,440	5,600
Private benefits per year	1,440	1,440	3,440	8,600

Annualized benefits and costs per kiln of the four cleaner brick kiln options for Greater Dhaka are presented in table 9.2. The benefits include health improvements, or avoided deaths and illness, as well as increased production value and operating cost savings from more efficient production. The benefits are presented with and without global benefits from CO2 emission reductions. The cost is annualized investment cost. Benefits and cost are discounted at 5% over an assumed useful life of investment of 20 years. Annex 3 presents more details with discount rates ranging from 3% to 10%.

Table 9.2. Annualized social benefits and costs of cleaner brick kilns in Greater Dhaka, 2014 (BDT million per kiln)

	Benefits (w/o CO_2)		Benefits (w/ CO_2)		Cost
	VSL	DALY	VSL	DALY	Cost
From FCK to IZK	3.58	2.33	3.64	2.39	0.31
New IZK	3.58	2.33	3.64	2.39	0.61
VSBK	8.45	5.94	8.61	6.10	1.60
HHK	51.02	41.61	51.62	42.21	12.23

Note: Annualized benefits and costs are at 5% discount rate. VSL=valuation of avoided deaths using VSL. DALY=valuation of a DALY at GDP per capita. Source: Estimates by the author.

Annualized benefits and cost of full conversion of kilns in Greater Dhaka to the four cleaner brick kiln options for Greater Dhaka are presented in table 9.3. Annualized benefits range from BDT 3.1 – 4.9 billion for IZK to BDT 11.1 – 13.8 billion for HHK. Annualized cost also increases with technological sophistication.

Table 9.3. Annualized social benefits and costs of full conversion to cleaner brick kilns in Greater Dhaka, 2014 (BDT million)

	Benefits (w/o CO_2)		Benefits (w/ CO_2)		Cost
	VSL	DALY	VSL	DALY	
From FCK to IZK	4,777	3,104	4,857	3,184	408
New IZK	4,777	3,104	4,857	3,184	815
New VSBK	8,445	5,936	8,606	6,097	1,605
New HHK	13,605	11,096	13,766	11,257	3,261

Note: Annualized benefits and costs are at 5% discount rate. VSL=valuation of avoided deaths using VSL. DALY=valuation of a DALY at GDP per capita. Source: Estimates by the author.

The benefit-cost ratios (BCR) are by far the highest for the option of retrofitting existing FCKs to IZKs, with benefits being 7.6 to 11.9 times larger than costs. The three options of constructing new brick kilns have quite similar BCR (table 9.4). More details are provided in annex 3.

Table 9.4. Benefit cost ratios (BCR) of cleaner brick kilns in Greater Dhaka, 2014

	Without CO_2		With CO_2	
	VSL	DALY	VSL	DALY
From FCK to IZK	11.7	7.6	11.9	7.8
New IZK	5.9	3.8	6.0	3.9
VSBK	5.3	3.7	5.4	3.8
HHK	4.1	3.4	4.2	3.5

Note: BCRs are calculated with a 5% discount rate. VSL=valuation of avoided deaths using VSL. DALY=valuation of a DALY at GDP per capita. Source: Estimates by the author.

Conclusions

The analysis presented in this study confirms the huge health effects of ambient PM2.5 air pollution in Greater Dhaka, using the recently available health assessment methodology developed by the GBD 2010 Project.

The brick manufacturing sector is the single largest contributor to ambient PM2.5 in Greater Dhaha. Several technology options for cleaner brick production are available and have been initiated in the area. Each of these options are both financially (private costs and benefits) and economically (social costs and benefits) viable when the technologies are properly designed and adopted for Bangladeshi climatic conditions, with particularly high BCRs for conversion or retrofitting of existing FCKs to IZKs. This option is also attractive for the reason that it does not require relocation.

A key issue is to make brick kiln owners and investors aware and knowledgeable of the technology options available to improve the quality of the air, as well as the financial efficiency improvements that these technologies can provide. For the relatively large investments required in HHK, financial resources must be available at reasonable terms. And it should be emphasized that to achieve the full environmental and financial benefits, kiln conversions and retrofits to IZKs must reach good technical and operational standards. Last but not least, authorities must be committee to enforce their own regulations to the benefit of the greater public.

However, even with adoption of the cleaner kiln technologies assessed in this paper for all of brick production in Greater Dhaka, PM2.5 emissions from the sector would continue to be substantial and have severe impacts on the population in the area, if emission reduction efficiencies are not greater than the 40-60% applied in this study.

An adequate solution most therefore consider additional options, such as enhanced emission reduction technologies, fuel switching away from coal and biomass, and relocation to industrial parks located downwind from population centers.

While solving the problem of air pollution from brick kilns is a high priority, it will alone not solve the problem of air pollution in Greater Dhaka. Other sources of air pollution must also be urgently and simultaneously addressed.

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Annex 1. An integrated exposure-response function

Health effects of PM exposure include both premature mortality and morbidity. The methodologies to estimate these health effects have evolved as the body of research evidence has increased.

Over a decade ago, Pope et al (2002) found elevated risk of cardiopulmonary (CP) and lung cancer (LC) mortality from long term exposure to outdoor PM2.5 in a study of a large population of adults 30 or more years of age in the United States. CP mortality includes mortality from respiratory infections, cardiovascular disease, and chronic respiratory disease. The World Health Organization used the study by Pope et al when estimating global mortality from outdoor air pollution (WHO 2004; 2009). Since then, recent research suggests that the *marginal increase* in relative risk of mortality from PM2.5 declines with increasing concentrations of PM2.5 (Pope et al 2009; 2011). Pope et al (2009; 2011) derive a shape of the PM2.5 exposure-response curve based on studies of mortality from active cigarette smoking, second-hand cigarette smoking (SHS), and outdoor PM2.5 air pollution.

The Global Burden of Disease 2010 Study (GBD 2010 Study) takes Pope et al (2009; 2011) some steps further by deriving an integrated exposure-response (IER) relative risk function (RR) for disease outcome, *k*, in age-group, *l,* associated with exposure to fine particulate matter pollution ($PM_{2.5}$) both in the outdoor and household environments:

$$RR(x)_{kl} = 1 \qquad \text{for } x < x_{cf}$$
(A1.1a)

$$RR(x)_{kl} = 1 + \alpha_{kl}(1 - e^{-\beta_{kl}(x - x_{cf})^{\rho_{kl}}}) \qquad \text{for } x \geq x_{cf}$$
(A1.1b)

where x is the ambient concentration of $PM_{2.5}$ in $\mu g/m^3$ and x_{cf} is a counterfactual concentration below which it is assumed that no association exists. The function allows prediction of RR over a very large range of $PM_{2.5}$ concentrations, with $RR(x_{cf}+1) \sim 1+\alpha\beta$ and $RR(\infty) = 1 + \alpha$ being the maximum risk (Burnett et al 2014; Shin et al 2013).

The parameter values of the risk function are derived based on studies of health outcomes associated with long term exposure to ambient particulate matter pollution, second hand tobacco smoking, household solid cooking fuels, and active tobacco smoking (Burnett et al, 2014). This provides a risk function that can be applied to a wide range of ambient $PM_{2.5}$ concentrations around the world as well as to high household air pollution levels of $PM_{2.5}$ from combustion of solid fuels.

The disease outcomes assessed in in the GBD 2010 Study are ischemic heart disease (IHD), cerebrovascular disease (stroke), lung cancer, chronic obstructive pulmonary disease (COPD), and acute lower respiratory infections (ALRI) (Lim et al 2012; Mehta et al 2013). The risk functions for IHD and cerebrovascular disease are age-specific with five-year age intervals from 25 years of age, while singular age-group risk functions are applied for lung cancer (≥ 25 years), COPD (≥ 25 years), and ALRI in children (< 5 years).

An x_{cf} = 7.3 $\mu g/m^3$ is applied here based on bounds of 5.8 to 8.8 $\mu g/m^3$ used in the GBD 2010 Study (Lim et al, 2012).

The population attributable fraction of disease from PM2.5 exposure is calculated by the following expression:

$$PAF = \sum_{i=1}^{n} P_i [RR\left(\frac{x_i + x_{i-1}}{2}\right) - 1]/(\sum_{i=1}^{n} P_i [RR(\frac{x_i + x_{i-1}}{2}) - 1] + 1)$$
(A1.2)

where P_i is the share of the population exposed to PM2.5 concentrations in the range x_{i-1} to x_i. This attributable fraction is calculated for each disease outcome, *k*, and age group, *l*. The disease burden (B) in terms of annual cases of disease outcomes due to PM2.5 exposure is then estimated by:

$$B = \sum_{k=1}^{t} \sum_{l=1}^{s} D_{kl} PAF_{kl}$$
(A1.3)

where D_{kl} is the total annual number of cases of disease, *k*, in age group, *l*, and PAF_{kl} is the population attributable fraction of these cases of disease, *k*, in age group, *l*, due to PM2.5 exposure.

The potential impact fraction is applied to estimate the reduction in disease burden from a change in the population exposure distribution that can result from an intervention to control PM2.5 exposure levels among the population

$$PIF = [\sum_{i=1}^{n} P_i RR\left(\frac{x_i + x_{i-1}}{2}\right) - \sum_{i=1}^{n} P_i' \, RR\left(\frac{x_i + x_{i-1}}{2}\right)]/(\sum_{i=1}^{n} P_i RR(\frac{x_i + x_{i-1}}{2})$$
(A1.4)

where P'_i is the population exposure distribution after the intervention. The reduction in annual cases of disease outcomes is then estimated by:

$$\Delta B = \sum_{k=1}^{t} \sum_{l=1}^{s} D_{kl} PIF_{kl}$$
(A1.5)

This approach is applied to the five disease outcomes discussed above using the RRs from the IER function reported by Apte et al (2015).

Annex 2. Valuation of health benefits

Two valuation measures are considered for estimating the benefit of avoided illness is in this paper: i) a day of disease is valued as 50% of average labor income per day; or ii) a year lost to disease (YLD) is valued at GDP per capita as suggested by the Copenhagen Consensus Center (CCC).

Two valuation measures are considered for estimating the benefit of an avoided death in this paper: i) the value of statistical life (VSL); or ii) a year of life lost (YLL) to premature mortality is valued at GDP per capita as suggested by CCC.

A VSL for Bangladesh is estimated based on Navrud and Lindhjem (2010). Navrud and Lindhjem conducted a meta-analysis of VSL studies for OECD based exclusively on stated preference studies which arguably are of greater relevance for valuation of mortality risk from environmental factors than hedonic wage studies. These stated preference studies are from a database of more than 1,000 VSL estimates from multiple studies in over 30 countries, including in developing countries. Navrud and Lindhjem provide an empirically estimated benefit-transfer (BT) function from these stated preference studies that can be applied to estimate VSL in any country or region. A modified BT function with income elasticity of one is applied here:[8]

$$\ln VSL = 0.22 + 1.0 \ln(gdp) - 0.445 \ln(r) \quad \text{(A2.1)}$$

where *VSL* is expressed in purchasing power parity (PPP) adjusted dollars; *gdp* is GDP per capita in PPP adjusted dollars; and *r* is the change in risk of mortality.[9] The VSL is then converted to a country's currency by multiplying by the PPP rate as reported in World Bank (2015b), which is the ratio "GDP in local currency / PPP adjusted GDP in dollars".

Applying the BT function also involves specifying change in mortality risk (r). The mortality risk from environmental factors depends on the environmental factor at hand. Most stated preference studies of VSL use a mortality risk in the range of 1/10,000 to 5/10,000 per year. A mid-point risk of 2.5/10,000 per year is applied in this paper.

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[8] A later version of their paper (Lindhjem et al, 2011) reports income elasticities in the range of 0.77 – 0.88 for a screened sample of VSL studies.

[9] This BT function implies that the income elasticity is 1.0, meaning that VSL varies across countries in proportion to their PPP adjusted GDP per capita level.

The VSL estimated for Bangladesh for the year 2014 by this methodology is BDT 4.79 million, or about 50 times GDP per capita that year (table A2.1).

Table A2.1 Economic data and VSL for Bangladesh, 2014

GDP per capita	BDT 95,864	Bangladesh Bureau of Statistics
Average monthly wage	BDT 7,307	International Labour Organization
Value of statistical life (VSL)	BDT 4,787,591	Calculated from equation A2.1

Annex 3. Benefits and costs

Table A3.1. Annual value of health benefits (DALY=GDP per capita) from full conversion to cleaner brick kilns in Greater Dhaka (BDT million per year)

Discount rate	**From FCK to IZK**	**New IZK**	**New VSBK**	**New HHK**
3%	1,716	1,716	2,574	2,574
5%	1,664	1,664	2,496	2,496
10%	1,536	1,536	2,304	2,304

Source: Estimates by the author.

Table A3.2. Annual value of health benefits (VSL) from full conversion to cleaner brick kilns in Greater Dhaka (BDT million per year)

Discount rate	**From FCK to IZK**	**New IZK**	**New VSBK**	**New HHK**
3%	3,442	3,442	5,163	5,163
5%	3,337	3,337	5,005	5,005
10%	3,081	3,081	4,622	4,622

Source: Estimates by the author.

Table A3.3. Global benefits of CO2 reductions from full conversion to cleaner brick kilns in Greater Dhaka (BDT million per year)

Discount rate	**From FCK to IZK**	**New IZK**	**New VSBK**	**New HHK**
3%	356	356	711	711
5%	80	80	161	161
10%	0	0	0	0

Source: Estimates by the author.

Table A3.4. Annualized benefits and costs (VSL and CO2 benefits) of full conversion to cleaner brick kiln options in Greater Dhaka, 2014 (BDT million)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	5,238	348	15.0	4,857	408	11.9	4,521	570	7.9
New IZK	5,238	696	7.5	4,857	815	6.0	4,521	1,139	4.0
New VSBK	9,314	1,370	6.8	8,606	1,605	5.4	8,062	2,242	3.6
New HHK	14,474	2,784	5.2	13,766	3,261	4.2	13,222	4,556	2.9

Source: Estimates by the author.

Table A3.5. Annualized benefits and costs (DALY=GDP per capita, and CO2 benefits) of full conversion to cleaner brick kiln options in Greater Dhaka, 2014 (BDT million)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	3,512	348	10.1	3,184	408	7.8	2,976	570	5.2
New IZK	3,512	696	5.0	3,184	815	3.9	2,976	1,139	2.6
New VSBK	6,726	1,370	4.9	6,097	1,605	3.8	5,744	2,242	2.6
New HHK	11,886	2,784	4.3	11,257	3,261	3.5	10,904	4,556	2.4

Source: Estimates by the author.

Table A3.6. Annualized benefits and costs per kiln (VSL and without CO2 benefits) of cleaner brick kiln options in Greater Dhaka, 2014 (BDT million per kiln)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	3.7	0.3	14.0	3.6	0.3	11.7	3.4	0.4	7.9
New IZK	3.7	0.5	7.0	3.6	0.6	5.9	3.4	0.9	4.0
New VSBK	8.6	1.4	6.3	8.4	1.6	5.3	8.1	2.2	3.6
New HHK	51.6	10.4	4.9	51.0	12.2	4.2	49.6	17.1	2.9

Source: Estimates by the author.

Table A3.7. Annualized benefits and costs per kiln (DALY=GDP per capita and without CO2 benefits) of cleaner brick kiln options in Greater Dhaka, 2014 (BDT million per kiln)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	2.4	0.3	9.1	2.3	0.3	7.6	2.2	0.4	5.2
New IZK	2.4	0.5	4.5	2.3	0.6	3.8	2.2	0.9	2.6
New VSBK	6.0	1.4	4.4	5.9	1.6	3.7	5.7	2.2	2.6
New HHK	41.9	10.4	4.0	41.6	12.2	3.4	40.9	17.1	2.4

Source: Estimates by the author.

Table A3.8. Annualized benefits and costs per kiln (VSL and with CO2 benefits) of cleaner brick kiln options in Greater Dhaka, 2014 (BDT million per kiln)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	3.9	0.3	15.0	3.6	0.3	11.9	3.4	0.4	7.9
New IZK	3.9	0.5	7.5	3.6	0.6	6.0	3.4	0.9	4.0
New VSBK	9.3	1.4	6.8	8.6	1.6	5.4	8.1	2.2	3.6
New HHK	54.3	10.4	5.2	51.6	12.2	4.2	49.6	17.1	2.9

Source: Estimates by the author.

Table A3.9. Annualized benefits and costs per kiln (DALY=GDP per capita and with CO2 benefits) of cleaner brick kiln options in Greater Dhaka, 2014 (BDT million per kiln)

	3% discount rate			5% discount rate			10% discount rate		
	Benefit	Cost	BCR	Benefit	Cost	BCR	Benefit	Cost	BCR
From FCK to IZK	2.6	0.3	10.1	2.4	0.3	7.8	2.2	0.4	5.2
New IZK	2.6	0.5	5.0	2.4	0.6	3.9	2.2	0.9	2.6
New VSBK	6.7	1.4	4.9	6.1	1.6	3.8	5.7	2.2	2.6
New HHK	44.6	10.4	4.3	42.2	12.2	3.5	40.9	17.1	2.4

Source: Estimates by the author.

Bangladesh, like most nations, faces a large number of challenges. What should be the top priorities for policy makers, international donors, NGOs and businesses? With limited resources and time, it is crucial that focus is informed by what will do the most good for each taka spent. The Bangladesh Priorities project, a collaboration between Copenhagen Consensus and BRAC, works with stakeholders across Bangladesh to find, analyze, rank and disseminate the best solutions for the country. We engage Bangladeshis from all parts of society, through readers of newspapers, along with NGOs, decision makers, sector experts and businesses to propose the best solutions. We have commissioned some of the best economists from Bangladesh and the world to calculate the social, environmental and economic costs and benefits of these proposals. This research will help set priorities for the country through a nationwide conversation about what the smart - and not-so-smart - solutions are for Bangladesh's future.

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